Complete Manual
Embedded Rail Systems on Bridges

Design and integration directives and realisation methods of edilon)(sedra Corkelast® ERS (Embedded Rail Systems)
Acknowledgements

No book can ever be written without the help of others and it is no different with this manual. We want to thank the railway bridge experts who were willing to critically read the text contained in this book and to provide valuable information. Thank you Graham Reeves of AGA Rail Consultancy Limited for your editing expertise. We would also like to thank the readers for their input and constructive criticism.

Edited by Frans Klösters | Amy de Man | Rik Monteban | Gertjan Laan

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Introduction

When edilon|sedra builds a bridge we start with the track! When designing bridges that facilitate railway systems, a wide variety of technical, social and financial considerations must be taken into account. Often a suitable railway system is only decided upon after the bridge has been designed. This could be an opportunity missed, especially when you consider the benefits offered by the edilon|sedra Corkelast® ERS (Embedded Rail System) - hereinafter only ERS. This also serves as a vital requirement when designing a light rail or heavy rail bridge to first determine the optimum track structure, with a holistic view of the project requirements.

The integrated design of the bridge and track must comply with requirements with regard to sustainability, safety, vibrations and noise disturbances and aesthetic requirements. It must for example be easy to integrate a railway system into different types of bridges and bridge decks. The system must also be maintenance friendly and cater for future developments. It must also be possible to quickly install a system and to perform maintenance within a limited period of time to maximise availability. Furthermore, it is important to take the architectural suitability of bridges and accompanying railway system with the environment into consideration.

This manual will attempt to build a bridge between the diversity of challenges faced when designing railway bridges and the solutions that ERS Embedded Rail System provides in practice. Considerations that must be addressed when using embedded rails on bridges are considered from a technical/ practical point of view. The result of the considerations must be addressed as a whole and it must result in the integral realisation of a railway bridge design.
Reading guide

Chapter 1 of the manual provides a description of the Corkelast® ERS Embedded Rail System.

Chapter 2 contains a discussion of the features of the ERS system. A description is also provided of where these features have been derived from and what benefits they hold with regard to railway bridges. Aspects such as technical implementation, operation, finances and lifespan are also discussed in more detail.

Chapter 3 looks in detail into the design technical application of embedded rail systems with bridges. Different types of bridges and bridge covers are discussed, based on the compatibility of ERS, as well as solutions for transition zones, integration of compensation welds or devices, as well as glue seals, ATB (Automatische Trein Beïnvloeding - a Dutch train protection system), signal and detection currents and draining.

Chapter 4 discusses new construction and reconstruction methods of the embedded rail system on bridges.

Chapter 5 discusses maintenance, repairs and renovation of the embedded rail system on bridges.

For consistent coordination of topics, the standard as used by the Dutch rail structure operator ProRail forms an important part of Chapter 3. Another principle that concerns all chapters is design experience gained through international light rail

In case of questions and/or remarks related to this manual: T +31 (0)23 5319519 | E info@edilonsedra.com
Chapter 1
What is the Corkelast® ERS Embedded Rail System?

1.1 History
Due to the typical geographic aspects of the Netherlands - a landscape with numerous channels and rivers that mostly lies below sea level - the country has many large and small bridges in the railway network. Typically old steel bridges often required excessive maintenance, while they also impact on the surrounding environment generating high noise and vibration levels. In order to combat these problems, Dutch Railways (currently ProRail) and edilon(sedra) started to look for sustainable solutions to these longstanding impacts. One of the solutions was the edilon(sedra Corkelast® ERS (Embedded Rail System), which was already in extensive use at level crossings.

The first application of ERS on bridges soon followed, which was on a 250 metre long concrete bridge ‘Roode Vaart’, which is a part of a goods line in the city of Rotterdam. This bridge was originally installed in 1972 and did not require any substantial maintenance until the rail replacement in 2012.

Since then ERS has been used all over the world in a variety of rail applications. The most common use of ERS is with level crossings and bridges, but it can also be found in railway tunnels, stations, depots, tram lanes and crane way.

1.2 The embedded rail system
The most important feature of the ERS Embedded Rail System is that the rail is attached without the use of traditional rail fastenings. The rail is instead anchored in a concrete or steel channel by “embedding” it or by bonding the rail with a two-component polyurethane plastic: edilon(sedra Corkelast®. The rail is thereby continuously supported by the elastic Trackelast® Rail Strip. After hardening it remains slightly elastic, but very tough, thereby creating a very stable and very durable rail bond. Below is an image of the embedded edilon(sedra Corkelast®.

The system technical properties of ERS provide a very stable, durable and continuous support of the rails and a uniform transfer of forces from the rail to the supporting environment. This addresses forces and tension caused by passing rail and road traffic and physical influences such as temperature changes.

Since the plastic used is in liquid form initially, any rail profile can be bonded with the same method, without having to use special components. Naturally a suitable channel design is required.
Example of an application of an embedded rail system: Danube bridge in Tulln, Austria (ballast serves to reduce noise)
Application of the embedded rail fastening method delivers a number of benefits, as summarised below:

- Very limited construction height
- Sharp reduction in construction weight
- Reduction in noise pollution
- Effective elimination of residual currents
- Maintenance friendly
- Deferred wave and side wear compared to discrete rail bearing points
- Operation continues following rail damage
- Replacement of a single defective rail is possible
- Does not attract dirt and is easier to clean
- Facilitates fast and safe emergency evacuation
- Provides a running surface accessible to road/traffic
- Aesthetically compatible with numerous environments
- Easily compatible in alignment
- Enables rail adjustment to be undertaken in the channel
- Quick installation

Chapter 2 explains where these features originate from and what they could mean.
Example of an application of the embedded rail system: Erasmus bridge in Rotterdam, the Netherlands.
Chapter 2
ERS features explained

2.1 Application and features of the embedded rail system

This chapter discusses the most important features of the embedded rail system, where these features were derived from and which benefits these features offer to railway bridges. As previously stated, it was attempted to achieve a comprehensive approach. Technical, financial, social, and aesthetic aspects were therefore taken into consideration.

The edilon)(sedra Corkelas® ERS (Embedded Rail System) - or ERS - has been in use for decades already throughout the world and it has been proven extensively in practice. ERS is suitable for all forms of rail transport, i.e. train, tram, metro, crane runway, and for newer rail concepts such as light rail and high speed lines (HSL).

Some uses of ERS in practice

More technical information about ERS can be found in edilon)(sedra system information sheets and accompanying drawings.
2.2 Limited construction height

The embedded rail system differs from the traditional (ballasted) rail systems due to its limited construction height. The rail system is completely incorporated in the bridge superstructure. The system thereby saves space and promotes cost effective designs. Therefore the structural clearance is optimised and the bridge deck construction depth is as shallow as possible; an optimum compatible design can therefore be realised.

Bridges with an earthworks slope extending from the abutments must be considered for the purposes of integration of the bridge into the environment. Due to the smaller construction height of the embedded rail system, the embankment would extend from lower top of bank position reducing the overall footprint of the structure making a significant reduction to the earthworks required.

The images below show the differences between edilon)(sedra ERS, edilon)(sedra EBS (Embedded Block System) and traditional ballast rails. ERS does not only have a beneficial construction height at bridges, this height-saving measure can also have major (cost) benefits for tunnels.

![Difference in height compatibility of ERS versus ballasted rails (side-view of the bridge)](image)

![Compare construction heights from left to right: 2 variants ERS, EBS (Embedded Block System) and traditional ballast rail with blue Sub Ballast Mat (SBM)](image)
2.3 Considerable reduction in construction weight

A potential benefit of the application of the embedded rail system ERS in comparison with ballast rail, is that the rail bridge superstructure or deck dead load is reduced and can therefore be built more cost effectively. When implemented in steel bridge construction the optimum benefits of an embedded rail system are realised. The increased dead load of the ballasted track does not need to be catered for, so the bridge deck can be made lighter.

2.4 Reduction in noise pollution

The embedded rail system ERS significantly reduces the noise generated from the track. The Corkelast® casting compound encapsulates the rail for the most part (with the exception of the rail head). Vibrations generated through rail-wheel contact and re-radiated from the web of the rail are absorbed by encapsulating Corkelast® compound. The radiating surface of the rail is therefore limited to the rail head and greatly limits the noise generated by the track structure within the bridge. The “Calculation and measurement prescriptions of Noise 2012” (RMG2012) attributes the lowest noise to ERS if it is used in steel bridges in comparison with other rail systems.

It is possible to tune the embedded rail system with the characteristic noise properties of the bridge. The elasticity of the Corkelast® casting compound is adjustable, even if it is within the client's framework. Trackelast® Rail Strip selected (to support the rail) determines the transfer of vibrations into the bridge structure. Structural noise and vibration levels can be effectively reduced as a result.

In combination with a mass spring system incorporated into the bridge deck design the embedded rail system offers an even higher reduction of noise and vibration emanating from the track structure.
2.5 Effective elimination of residual currents

Since with the embedded rail system the rail is not fastened to the bearing structure, there is a complete separation between the rail and the rest of the bridge structure. Due to the strong electric insulating properties of the Corkelast® casting compound and the Trackelast® Rail Strip, ERS provides the highest possible stray current insulation of the rail system.

2.6 Maintenance friendly

ERS is maintenance friendly. In fact the system will have a long ‘rail life’ without requiring any maintenance. The embedded rail system has been used for more than 40 years on some routes without any maintenance being required. This is attributed to the absence of traditional rail fastenings and their component parts. Furthermore, tamping and refreshing the ballast (position maintenance) is not required: A bearing construction for a superstructure will normally be designed for a minimum lifespan of 50 years. The moisture-blocking and stray current limiting features of ERS ensures that there is a strong reduction in corrosion of the rail. Well documented repair and replacement instructions in the event of damage to the system caused by external forces is available from edilon)(sedra, however.

2.7 Deferred wave and side wear compared to discrete rail bearing points

The embedded rail system provides continuous support to the rail, which establishes a beneficial interaction between the wheel and the rail. A continuous support delays the creation and the growth of wave wear and other forms of rail wear in comparison to systems with a discrete support, such as systems with sleepers. The images below illustrate the principle of this difference, which is also known as secondary deflection. The illustrated effect also works side-ways.

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Secondary deflection with discrete rail support

No secondary deflection with continuous rail support (ERS)
2.8 Operation continues following track damage

If a rail breaks within the embedded rail system, the route almost always remains open for rail traffic. The reason for this is that the rail maintains its alignment within the Corkelast® bonding compound. This positional stability of the rail is due its encapsulation within the casting compound rather than with other rail systems providing discreet support allowing either side of the break to move independently. The image below shows such a situation where the broken rail required connecting electrically and enabling rail replacement to be undertaken months later. Allowing operations to continue uninterrupted until a convenient window within which replacement can be undertaken.

2.9 Replacement of damaged or defective rail is possible

It is relatively easy to replace the embedded rail system. After cutting the hardened Corkelast® casting compound along the channel walls with a so-called ‘pizza knife’, removal of the rail and the preparation of the channel can be carried out and the embedment of new rail undertaken. All other parts of the superstructure, such as the steel channel or the concrete slab remain in situ during this operation.

This information is particularly relevant in comparison to systems that utilise gauge ties to maintain gauge. In case of the latter the superstructure would be demolished completely and will need to be rebuilt completely.

2.10 Does not attract dirt and is easier to clean

Due to the smooth surface of the superstructure of ERS it is easy to clean the rail. It is also less likely that debris and rubbish can build up against the rail, as is the case with ballasted track. This is a maintenance implication and aesthetic factor within station platform confines.

2.11 Fast and safe emergency evacuation

In the scenario of emergency de-training the embedded rail system provides significant benefits over a ballasted track system as it provides a relatively unobstructed walking surface. Since the rail is embedded it creates a near flat surface with only two relatively small channels for the passage of wheels. Therefore passengers progress along the track with a significantly reduced risk of slips, trips or falls.

Permanent availability of the ERS rail in case of a rail break.

ERS provides a good walking surface (Stary Most bridge in Bratislava, Slovakia)
2.12 Accessible to road traffic

The flat surface of the embedded rail system makes it possible to drive on it with road vehicles (for maintenance and emergency services). There are even situations where the rail reserve (bridge or tunnel) is shared with road traffic.

ERS can be used in situations with mixed traffic (Stary Most bridge in Bratislava, Slovakia)

2.13 Aesthetically perfectly compatible

Design aesthetics play an increasing role in the future with the design of rail bridges within the urban environment. From an aesthetic point of view the embedded rail system is visually unobtrusive and from a technical perspective it is flexible and compatible within the strict design guidelines imposed on designers and urban landscapers. Incorporating the integral design approach, the embedded rail system can be used effectively on existing bridges or new bridges that must fit into their surrounding environment. The options of surface finishes are very diverse.

Djurgårdsbron bridge in Stockholm, Sweden - ERS for trams

2.14 Easily compatible in alignment

ERS is suitable for use with a vast range of rail profiles currently in use with rail systems around the world, with alignment limitations being related generally to the ability of the rail to accommodate the geometric constraints imposed. The system can also be used at exchanges (light rail) and other rail facilities, and customised according to the local requirements and wishes with regard to alignment.

2.15 Forgiving with rail adjustment in the channel

Since the embedded rail system does not depend on the exact placement of the fastening system components (baseplates, etc), the system is flexible with respect to the adjustment of the location rail in the channel prior the Corkelast® casting compound’s application. This offers the designer the opportunity to undertake minor adjustment to the alignment until the last moment.

2.16 Quick installation possible

ERS offers a relatively quick installation process especially when using prefabricated channel elements (concrete or steel) the superstructure can be built quickly and effectively on the bridge in preparation of the installation of the embedded rail system.

The rapid curing properties of the Corkelast® casting compound enables the track to be brought back into use relatively quickly after works have been completed.

edilon)(sedra offers engineering options for the staging of works in the limited time available. A concrete building method and schedule can also be prepared in combination with the edilon)(sedra execution company.

Interest in references of ERS bridge projects?
T +31 (0)23 5319519
E info@edilonsedra.com
Chapter 3
Design and compatibility

In general it can be stated that there are two types of bridges:
- **Static bridges**
- **Opening bridges**

Any type of superstructure can be used on permanent bridges. For opening bridges a ballasted track structure is not suitable due to the weight and the risk that ballast particles may end up between opening bridge sections. Naturally ballasted track on bridges with vertically rotating deck is unsuitable.

The edilon®sedra Corkelast® ERS (Embedded Rail System) superstructure system, or ERS, can be used on any type of bridge. This chapter deals with design and compatibility aspects of ERS, and is divided into 4 parts:

3.1 Bridge structure
3.2 Bridge implementation
3.3 Integration of the embedded rail system on or in the bridge structure
3.4 Other characteristics and specifications

Numerous aspects of the embedded rail system are discussed in these 4 parts, from general and abstract to specific and detailed. The most important source of information is the experience gained at ProRail with ERS and the regulations prepared by ProRail involving ERS. As already stated in Chapter 2, ProRail has been using ERS for more than 40 years already. During this time regulations have been developed for the embedded rail system on bridges that - supplemented with experience and best practice examples - could be useful for many designers of rail infrastructure on bridges elsewhere, regardless whether it concerns light rail or heavy rail.

3.1 Bridge structure
3.1.1 Type of bridges, materials and suitability for the embedded rail system

As stated in the introduction of this chapter, there are two types of bridges: static bridges and opening bridges. Steel is usually used as material for the bridge structure for long, static bridges and for opening bridges.

Concrete and steel-concrete can only be used for static bridges. Since 1984, ERS has been a full superstructure system that is suitable for steel, concrete and steel-concrete bridges.

3.1.2 Bridge length and use of embedded rail system

The purpose of a bridge is to span a certain distance. The maximum allowable length that can be spanned depends to quite a significant extent on the selection for the application of seamless rail or of couplers on the bridge.

Furthermore, this maximum allowable length, which is related to the ‘dilating length’ \( L_T \) of the bridge or of the separate bridge parts, depends on the type of superstructure system on the bridge.

Dilating length refers to the length of the bridge (or of one or two bridge sections), which increase or decrease in length with the temperature changes and of which the change in length concentrates in one point (dilation). In order to determine the dilating length, it needs to be checked how the bridge was set up and what type of bearings are used.

In the past a bridge was secured on one side on a permanent bearing and on the other side with a roller bearing. This way the bridge can dilate in one direction. The movement of the bridge at the fixed bearing is then 0 mm and \( L \) at the roller bearing, or \( D_T \).
Later the permanent and roller bearings at concrete bridges are replaced by elastic blocks. These blocks give elasticity and allows a limited amount of deflection and is in the longitudinal direction of the bridge. The level of deflection and the capacity depend on the manufacturer of the blocks. A bridge that is secured on both sides on elastic blocks can move in both directions so that the dilating length can more or less be halved.

With the embedded rail system ERS the dilating length may not be longer than 30 m with a steel bridge. The maximum of 35 m is applicable to a concrete and steel-concrete bridge. As long as one stays below these lengths, the embedded rail system can be secured seamless under the bridge.

If the dilating length is longer than 30 m or 35 m, expansion joints or expansion equipment must be applied between the rail on the bridge and the rail on the embankment. This is also applicable if a bridge consists of multiple bridge parts with a dilating length of more than 30 m and 35 m. The expansion joints that Prorail uses have a capacity up to 110 mm. Calculations must indicate whether this capacity is sufficient. However, if the dilating length is so long that expansion joints have insufficient capacity, expansion equipment must be used. At ProRail, this standard has a capacity of up to 220 mm, but there are special types with higher capacity. There is also an European Standard for the design and manufacturing of expansion joints and equipment.

The fact that the ballasted track on the embankment can expand a maximum of 12 mm when heated and can shrink a maximum of 27 mm when cooled must also be taken into account with the calculation of the required capacity of expansion joints and equipment. These values are applicable to the situation in the Netherlands.

3.1.3 International accounting rules for bridge cover length and ERS

In the European Standard EN 1991-2:2003 and the UIC cards 774-3:2001 and 776-2:2009 the accounting method is described that indicate the need for using expansion joints or equipment or the absence thereof. In contrast to ballasted track and rail with direct fastening, ERS is discussed very little in the standard. This is mainly due to the international unawareness and lack of experience with the embedded rail system. ERS has been used in numerous rail bridges in the Netherlands. In retrospect it appears that said EN 1991-2:2003 and UIC fiches 774-3:2001 and 776-2:2009 could often not be used. For this reason, ProRail specified adjusted accounting rules and additional requirements in OVS00030 and RLN00283.

For example, in RLN00283 it states that an expansion joint must be used for bridges with the embedded rail system with a dilating length of 30 m to 150 m, and expansion equipment at a dilating length of 120 m to 240 m. ProRail has a special type of embedded expansion joint and expansion equipment, as described in section 3.3.1, which links well with the channel structure of standard ERS.

3.1.4 Additional effects when supporting bridge covers

With the bearings of the bridge decks, such as at the pillars and in particular with piers, multiple effects could play a role in creating tension in the rails:

- Deflection and end rotation, and
- Uplift and the piers

Both are caused by deflection of the bridge deck under vertical load.

The rules that apply in section 3.1.2 for ProRail implicitly takes these effects into account. As far as is known, the elasticity of the embedded rail system is sufficient to sustainably absorb the shear stresses and longitudinal movements that occur.
a) Deflection and end rotation

The bigger the distance of the rails with regard to the neutral line of the bridge deck is, the bigger the shear stresses and longitudinal movements will be that are created with the deflection and end rotation of the bridge deck. The direction of the stresses and movements depends on the fact whether the bridge deck is positive, flat or negative deflected when not in use. The size of the stress and movements depend on the maximum deflection of the bridge\textsuperscript{x}. More important than the maximum deflection, is the maximum end rotation, for which ProRail has double strict requirements for non-ballasted rail as for ballasted rail\textsuperscript{xii}.

b) Uplift and the piers

If the rail moves over to the embankment on the bridge, the connecting rail on the embankment will be tilted due to the aforementioned end rotation. The bigger the rotation, the bigger the uplift. The rail of the embankment will thus be higher and be tilted along a longer length. Trains that pass this point will press the track down with more force. This causes, for example, extra setting in the subsoil, which increases the stroke effect even more.

There are various measures and design modifications to the piers to restrict the uplift, which is generally used and that are not specific to the embedded rail system. One of this is not fastening the rail on the first support point on the piers, also called support beam.

A loose rail attachment on the support beam to restrict the uplift forces

Further, extra reinforced ground layers or concrete sheets / concrete trays are often used under the rail, sometimes tens of meters before the bridge cover. These measures serve to keep the geometrics of the rail as low as possible. Gluing of the ballast and installing extra rails also have a favourable effect. Further, every attempt is made to minimise the differences in rail stiffness on the embankment and on the bridge deck, so that the springs are similar and can continue to limit dynamic impact forces, to relieve the load on the superstructure and to delay settlement. If the embedded rail system is also used on the piers, a type that can absorb more upward movement, than other non-ballasted superstructure systems will be chosen.

3.1.5 Differences between single-rail and multi-rail bridge covers

Multi-rail bridge decks are subjected to the same influences as single-rail bridge decks, but by using welding combinations, certain effects can be customised with multi-rail bridge decks that cannot be used with single-rail bridge decks.

This will be discussed in more detail below.

a) Thermal load

With regard to the thermal forces in the rails there is in principle no difference between single-rail and multi-rail bridge decks. But due to the design (slanted, bent) of the bridge deck and placement of permanent and roller bearings there could be higher and more concentrated forces that influence the piers, pillars and the rails.
b) Vertical load
With multi rail bridge decks, simultaneous load by two trains are possible\(^{x\text{i}}\). This way the deflection of the bridge will be bigger than with a similar single-rail bridge. The effect of the load combinations thus also influences the end rotation and uplift as discussed in the previous section.

c) Braking and acceleration forces
The braking or acceleration forces that can be exercised on the rails of a multi-rail bridge, could: face in the same direction, or the opposite direction.

In both situations the forces that are exercised on the bridge do not influence the superstructure system on the bridge. European Standard EN 1991-2:2003 describes the accounting method used for brake- and acceleration forces\(^{x\text{iii}}\).

In the past ProRail applied the braking- and acceleration Directive 1009 of March 1997. The size of the braking- and accelerator forces depends on the type of superstructure system. However, the way in which the superstructure system transfers braking and acceleration forces, but also thermal forces to the bridge deck, is different (see the difference in maximum dilating length for seamless rail).

The force that can be transferred by ERS per meter rail to the bridge is determined in a shear test. The value for the regular ERS designs is circa 120 kN per meter rail when it moves at least 10 mm\(^{x\text{iv}}\).

In comparison, the force that direct fastenings can transfer is circa 30 kN per meter rail. This occurs from circa 0.5 mm slip of the rail by the fastening clamps on\(^{x\text{v}}\). At the ballast rail, the distribution is different. The most important conclusion is that braking and acceleration forces in ERS become more concentrated transmitted to the bridge deck compared to other rail fastening systems and that the movement of the rail will be less relative to the bridge deck.

3.2 Bridge implementation
3.2.1 Steel and concrete bridge constructions

a) Shape of the channels
The channels of the embedded rail system have walls that are straight (vertical) or that slightly incline outwards. Adherence of the Corkelast\(^{®}\) casting compound to the walls of the channels is so strong that impacts and elastic deformations are transferred without any detachment taking place.

In the Seventies, some of the first applications of ERS in concrete that were carried out were on a bridge over the Roode Vaart near Moerdijk, with a length of 240 m, (787 ft) and on an unballasted track in Deurne (NL). In both cases channels with walls inclining inwards were applied. This shape (trapezium) was selected to limit the risk of lifting of the rails. It has been observed in practice that this is not a real risk, however.

Starting in the Eighties channels on concrete bridges were designed with walls that are straight or that are slightly inclining outwards. On steel bridges, and to a lesser extent also on concrete and steel-concrete bridges, rectangular channels were initially applied using two steel angle bars. Later on welded steel channels were also introduced. Back in the Nineties, when the aspect of noise pollution gradually became more important, the so-called ‘Silent Bridge’ construction was introduced on steel bridges, which - again - comprises trapezium shaped channels that are completely integrated in the covering panels or in the bridge deck.

b) Dimensions of the channels
The optimal channel width and channel depth for ProRail has been determined through experimentation. If channels with other dimensions are used, the (rail) rigidity of the embedded rail system is basically altered. Besides the dimensions of the channels, the moment of inertia of the rails, the type of Corkelast\(^{®}\) casting compound and the type of Trackelast\(^{®}\) Rail Strip are determining factors for the flexure of the rails under an axle load or a wheel load (rail rigidity). In the past it was shown through practical measurements that the vertical flexure of ballasted tracks put under an axle load of 22.5 ton lies
between 0.4 and 1.5 mm with ProRail. This flexure is determined through factors such as the elasticity of the subsoil, the thickness of the ballast bed and the rigidity of the components of the rails. ProRail has opted for a rail rigidity of the embedded rails which results in a greater flexure than that of ballasted rails. With the standard ERS, under an axle load of 22.5 ton, a vertical flexure of the rail relative to the channel of 1.5 to 2.0 mm is achieved. This applies to ERS both on steel bridges and on concrete bridges.

c) Temperature influences
It is common knowledge that a steel bridge will assume the ambient temperature more rapidly than a concrete bridge. In OVS00030-6:2003 ProRail established the following calculation values:

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<th>Minimum °C</th>
<th>Reference °C</th>
<th>Maximum °C</th>
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<tbody>
<tr>
<td>Rails</td>
<td>-23</td>
<td>25</td>
<td>55</td>
</tr>
<tr>
<td>Construction without covering</td>
<td>-25</td>
<td>10</td>
<td>45</td>
</tr>
<tr>
<td>Construction with covering by way of ballast</td>
<td>-20</td>
<td>10</td>
<td>40</td>
</tr>
</tbody>
</table>

Table containing calculation values for temperatures for steel and steel-concrete bridges

<table>
<thead>
<tr>
<th></th>
<th>Minimum °C</th>
<th>Reference °C</th>
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<td>-20</td>
<td>10</td>
<td>40</td>
</tr>
<tr>
<td>Construction with covering by way of ballast</td>
<td>-15</td>
<td>10</td>
<td>35</td>
</tr>
</tbody>
</table>

Table containing calculation values for temperatures for concrete bridges

Using these temperatures design calculations can be applied for determining rail loads, whereby the need for application of expansion joints or expansion devices can be determined.
3.2.2 Channels on steel or concrete bridges

a) Steels bridges with embedded rail system
On the first steel bridges with an embedded rail system, the channels were constructed using steel angle profiles. As a result, the channels had a rectangular cross-section. Four bridges fitted with this type of channel were constructed in Roermond. Afterwards, the large bridges over the Amsterdam-Rhine Canal near Weesp, the Singelgracht Bridge in Amsterdam and the Bridge over the Old Meuse near Dordrecht were also fitted with this type of channels. In the Nineties, the so-called ‘Silent Bridge’ construction concept was designed and introduced. In these structures the channels were integrated in the bridge deck or in the deck panels. This type of construction is applied to both new and renovated bridges.

b) Concrete bridges
On concrete bridges, the channels for an embedded rail system can be installed in two manners:
- The channels are created on the bridge deck by installing separate concrete elements on the deck (gluing). In the past, this was applied e.g. in the renovation process of a few railway bridges in Amsterdam.
- The channels are integrated in the bridge deck. Currently this is also the most common construction method.
3.2.3 Conversion of steel or concrete bridges

Before 1950, steel bridges were equipped with rails with timber sleepers. In 1955, the first steel bridge was constructed that was equipped with direct fixation system. Conversion of existing bridges equipped with timber sleepers to the embedded rail system requires a constructive solution that differs from that of conversion from direct mounting to the embedded rail system. Both procedures are elaborated below.

a) Conversion of bridges with timber sleepers to embedded rail system

Moerdijk Bridge in the Netherlands was the first large bridge where timber sleepers were converted to ERS in 2003. After dismantling of the old rails, ‘Silent Bridge’ deck panels with integrated channels were installed on the main spars. In the channels, the Trackelast® Rail Strip was glued, and the height and lateral adjustment of the rails set up. Also, the expansion joints were adjusted. Finally, the Corkelast® casting compound was applied.
b) Conversion of track with direct mounting to an embedded rail system

After direct attachment of the longitudinal girders (side supports) has been removed, new deck panels are adjusted. The galvanised prefabricated deck panels are equipped with supports on which steel plates are welded at the bottom. The entire section is then installed on the longitudinal girders by way of clamping bolts and synthetic resin. Subsequently, the Trackelast® Rail Strip is glued to the bottom of the channel, the rails are installed in the channels and the height and lateral adjustment are set, and finally, the rail is embedded using Corkelast® casting compound.
3.3 Integration of the embedded rail system on or in the bridge construction

3.3.1 Integration of expansion joints or expansion devices

It is possible to integrate expansion joints and expansion devices in the embedded rail system, but that has to be taken into account during the design stage of the bridge. After all, an expansion joint or expansion device is better installed on a civil engineering structure than on the embankment. The centre of the expansion joint should be situated at least 3 m - and by preference 6 m - from the end of the bridge deck. The location of the expansion joint or expansion device should be indicated on the design drawing of the bridge. The rails may be embedded before and after the expansion joint or device as standard ERS. However, at the location of the expansion joint or device, the channels should be interrupted for or widened over an identified section. At this location, the pins (the processed rails) will be supported laterally and vertically, while movement in longitudinal direction remains possible. With ProRail, there is a special type of embedded expansion joint or device, which connects very well with the channel construction of standard ERS. Yet, also the classic expansion joint or device of the direct installation on base panels is often used in combination with ERS situations.

Regardless of whether or not it concerns the embedded rail system or another superstructure system for ballastless track, according to ProRail, the following restrictions for the application of expansion joints or devices should be followed and maintained:

• Expansion joints should not be used in a horizontal curve of $R_h < 1000$ m
• Expansion devices should not be used in a horizontal curve of $R_h < 2500$ m
• Not to be applied in a track transition curve
• Expansion devices should not be used in a vertical curve with $R_v < 8000$ m

3.3.2 Integration of derailment containment (guards rails) in embedded rail system

On steel bridges, as on concrete bridges and composite steel and concrete bridges, various constructions have been created for the integration of derailment containment (guard rails) in the embedded rail system.

The first guard rails for a steel bridge with ERS were installed on the Ruhr bridge in Roermond. Such guard rails are also applied on bridges with sleeper track, and it consists of a side mounted rail profile that forms a guiding channel for a derailed wheel; the rail fastened to the deck at regular intervals. In addition, an integrated guard rail can also be used with a Silent Bridge construction or with Silent Bridge deck panels. In both cases, the guard rail is located on the inside of the running rails.
In some cases, the derailment containment on concrete bridges is located on the outside of the track, as can be seen on the bridge over the Roode Vaart near Moerdijk, but it is usually located on the inside.

It is often placed in the same concrete that is used for the construction of the channels. In rare cases a guard rail consisting of a rotated rail profile on supports is installed on a concrete bridge deck, but that is one of the options available.

### 3.3.3 Application of other mounting systems

Alongside the embedded rail system, also other mounting systems may be used on a bridge. In that case, around the expansion joints, expansion devices and bridge crossings, no ERS will be installed in the channels, for another superstructure system will be installed, generally by way of direct fastening on baseplates.
3.3.4 Longitudinal rigidity and dilating section

Jointless track can be applied on a bridge, provided that the maximum allowable tensile force or tensile stress in the rails originating from the bridge itself is not exceeded. For that purpose the value as shown in EN 1991-2:2003 of 92 N/mm² is maintained. This limit value is also applicable to ERS, and just like for other types of unballasted railway - it also applies to compression forces or compressive stress.

As indicated above, in section 3.1.2, the calculations that were carried out by ProRail demonstrated that the maximum allowable tensile stress in rails on steel and steel-concrete composite bridges equipped with ERS is reached if the dilating section has a length of 30 m, and on concrete bridges equipped with ERS, a length of 35 m. These limit values apply to ERS with a longitudinal rigidity of approx. 12 kN/mm per metre of track, just like ProRail does it by standard. In case ERS with a lower longitudinal rigidity is used, the maximum allowable tensile stress in the rails will be reached with dilating sections with a greater length. That implies that jointless track on a longer bridge becomes an option.

The longitudinal rigidity of ERS is determined with the test method that is described in EN 13146-1:2012. The rigidity is specified as a defined displacement $D_R$. As a general rule displacement is defined as 7 mm. By widening the channel or by using other types of Corkelas® casting compound, the longitudinal rigidity is decreased. As a general rule, ERS with a low longitudinal rigidity should only be applied over a section with a limited length on the very end of the movable bridge deck to be effective.

However, another option is to apply it over a section with a limited length of a sliding channel construction, into which the embedded rail system is installed as standard.

3.3.5 Lateral stability of the embedded rail system in curves

Because bridges may also be placed in horizontal curves, lateral wheel forces may work on the rails, which should not lead to lateral displacement of the rail heads that are excessively large. As this could lead to a discrepancy of the track gauge that could result in an unwanted wheel-rail interaction. In order to have as little lateral wheel forces as possible on the rails, the track in horizontal curves is installed as canted track. ERS may be applied on bridges with a maximum cant of 150 mm, with a track gauge of 1435 mm.

Often, the requirement is taken into account that the maximum allowable lateral displacement of the railhead equals 2 mm, under a defined force that is working on the rails. For this purpose, results from endurance testing of rail fastening systems according to European Standard EN 13146-4:2012 are often used.

To guarantee sufficient stability, ProRail applies the rule that the extent of canting discrepancy determines whether high casting beside the railhead is necessary. The two images below for concrete bridges are a result of the principle.

ERS in an upright position and in curves with a cant deficiency up to $i = 40$ mm

ERS in curves with a cant deficiency of $i = 40$ mm up to $i = 80$ mm
Great lateral forces cause lateral wear of the railhead. Therefore, at ProRail, the allowable cant deficiency for ERS is limited by maintaining $i \leq 80$ mm. This is not a safety standard, but is rather determined based on economic grounds.

### 3.4 Other characteristics and specifications

#### 3.4.1 Signalling and detection currents, adhesive joints and embedded rail system

Many railway companies use safety systems involving signalling- and detection systems running through the tracks. As such, the signals are ‘operated’ by the train itself. For that purpose, the track is divided into sections (blocks). For signalling currents (alternating current) these sections are separated electrically from each other by way of insulated rail joints (IRJ), also referred to as block joints.

In some cases, it is necessary to insert an IRJ in a section of the track in which the embedded rail system is applied. For this, the embedded rail system must be mounted around the IRJ in a specific manner. It has to be taken into account that IRJ’s may have a shorter life than normal rails, and they may, depending on performance, be replaced after a shorter period of time in comparison to the adjacent running rail. Moreover, certain devices (namely relay coils) have to be installed, by which the return currents are diverted around the IRJ by way of cables. Both the IRJ’s and the cables must remain visible to allow rapid detection of defects and for repairs and renewal work to be carried out quickly. It is therefore recommended to interrupt the embedded rail system and to apply IRJ’s with direct fastening.

In the past, however, IRJ’s have been embedded, albeit in a wider channel and not embedded over the entire height in Corkelast® casting compound.

An IRJ should be supported in a more rigid manner than for standard ERS, because an interrupted rail and the two joint panels together are less rigid than an uninterrupted rail. Excessive flexure should be avoided to limit vertical deflection from the wheels on the joint as much as possible. The wheel set length of most trains is approx. 3 m. The support for the IRJ’s must therefore be more rigid over a length of 6 m. To achieve that, the Trackelast® Rail Strip under the rails is left out over this section and the resulting space is filled with Corkelast® casting compound.

Because IRJ’s may be replaced more frequently than running rails, pockets must be provided in the channel for thermit welding, 3 m before and 3 m after the joint. Both in steel channels and in concrete channels, it has to be taken into account that on both sides of the IRJ, it should be possible to bond cables to the rails. At these locations, the channels should be interrupted by way of small pockets. In addition, it has to be taken into account that it should be possible to install the ATB (Automatische Trein Beïnvloeding - a Dutch train protection system) cables along the IRJ.

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[L] Adhesive joint before it is partially embedded in a steel bridge

[R] Relay coil and cables to divert the returning current around the adhesive joint
3.4.2 Operation of ATB in combination with embedded rail system

The signal for ATB (Automatische Trein Beïnvloeding - a Dutch train protection system) that transmits the ‘mode’ of the signals also runs in the embedded rail system, through the rails, and it is modulated on top of an alternating current. The ATB signal indicates the maximum driving speed. This signal creates a magnetic field around the rails. By way of an antenna, which is installed in the front of the train, this signal is picked up and transmitted to the train driver.

If the ATB signal runs through the tracks, the magnetic field needs to extend sufficiently high above the railhead to be able to be picked up. In steel bridges equipped with the embedded rail system in channels this is often not possible because the magnetic field will start to run through the steel channels, and will partially be diverted to into the bridge structure. However, to create a magnetic field of sufficient strength above the railhead, one or more ATB cables are installed through PVC pipes on the bottom of the rails, and the current of the ATB signal is increased.

![ATB cables in ERS in rectangular channels](image1.jpg)

![ATB cables in ERS in 'Silent Bridge' construction](image2.jpg)

3.4.3 Specific facilities for maintenance or replacements

Maintenance on the embedded rail system mainly consists of fitting one or more replacement part(s) whenever rail breakage or another type of defect on the track occurs. Rail breakage mainly occurs near an IRJ, a thermit weld or a butt weld. Also, a failed IRJ may cause an interruption to service provision. Therefore, it may be necessary to replace an IRJ in good time under planned maintenance, just like for expansion joints or expansion devices and for instance bridge crossings (i.e. the well-known components that are subject to wear). During the design of the bridge provision should be made for undertaking these procedures e.g. by installing pockets (channel interruptions). In locations of channel interruptions, the rails may be cut. After the defective section of rail is removed, a thermit weld can be made to joint the replacement rail into the surrounding plain line and a reinstatement of the embedded railway system can be undertaken. If a replacement length of rail is installed, special attention to weld straightness should be exercised to ensure that the closure welds have the right geometry after they cool.
3.4.4 Drainage on bridges

In the design of bridges, provision for the collection and discharge of rainwater, meltwater (from snow and ice) and other liquids has to be an integral part of the design. On (open) steel construction bridges historically it was taken for granted that water would find its way through the construction itself.

Steel cover panels and also concrete and steel-concrete bridges have made it possible to include drainage provision within the design. Hence, they have also become an integral part of the periodic maintenance of the bridge.

In the embedded rail system on bridges, the flangeways along the rails, the locations in which the rail may be partially or totally not embedded are locations where water and liquids will accumulate – in addition dust and dirt may accumulate. In many cases, channels or tubes are installed for the discharge of water and the cleaning of the track (by jetting). From a constructability and maintainability perspective, the choice of the discharge (pipe or channel) and the routing are important.
The spot where the water is discharged is carefully selected to avoid damage to other parts of the construction and for it not to cause any interruption to the operation of the railway. With ERS, there are more options to collect and discharge all drainage run-off compared to many other railway systems.

3.4.5 Location of bridge and selection of superstructure

The location of a bridge leads to a number of key points, for ballasted track, as well as for unballasted track with ERS of with direct fastening. Preferably, the track before a bridge should be level. If the track leading up to the bridge were located on a significant length of climbing gradient, heavy trains could get into trouble. On a limited number of bridges in The Netherlands this problem occurs, e.g. on the railway that runs from Watergraafsmeer in the direction of Hilversum, with the bridge passes over the Amsterdam-Rhine Canal near Weesp, and the railway that runs from Dordrecht Station to Zwijndrecht, with the bridge carries it over the Old Meuse.

When the locomotive that is pulling the train passes over the highest point of one of these bridges, it continues to pull the trailing wagons up the slope. In such a case, it may be possible the tractive power become excessive and for wheel slippage to occur, this may lead to wheel burns on the running surface of the rail. Depending on the severity of the wheel burn cracks may extend into the head of the rail, which would lead to premature replacement of the rails on the bridge. This is undesirable, especially in bridges with an embedded rail system. One option is to review to tractive effort required and put an extra locomotive behind the train on the approaches to the bridge to provide assistance.

Another option is to ensure that the train is provided with a clear path on approaching the bridge and is able to maintain sufficient forward inertia to negotiate the slope. Unfortunately, both options are not necessarily that easy to implement and the situation should therefore be accepted as it is and the likelihood of premature rail replacement built into the maintenance regime of the bridge and surrounding track.
Chapter 4
New constructions and conversions

4.1 New constructions

Projects involving new constructions with an embedded rail system on bridges can be divided into two main groups, namely those with an integrated design (embedded railway as a part of the supporting structure) and those with a partition between the supporting structure and the railway structure.

The ‘Silent Bridge’ constructions in steel and the SLEP (Standard Low Emission Prefabricated) bridges in concrete belong to the first category. As a general rule, these are single track bridges of no more than 25 metres in length.

Many other railway bridges fall under the second category, on which e.g. a plinth construction made of concrete or a channel construction made of steel may be installed on the supporting construction of the bridge. Steel, concrete, as well as steel-concrete composite bridges fall under this category. The examples sequentially concern the steel bridges for the design of which the Old Meuse Bridge in Dordrecht is a prime example, and the steel-concrete composite bridges of which the Danube bridge in Tullin and the ‘Demka bridge’ in Utrecht represent.

4.2 Conversions

In conversion projects, there is often the prerequisite that the Top of Rail (TOR) must be maintained, which implies that it has to be carefully checked which part of the construction should be and can be replaced.

An example of the conversion of a concrete bridge is the Slotherrensvej bridge in Copenhagen (Denmark). The old system (direct fastening) resulted in poor discharge of water, which partially led to excessive maintenance requirements. Also, the old system generated excessive noise pollution. While preserving the bridge construction a conversion was carried out from a track system comprised of direct fastening to an ERS in steel channels. The existing anchors were used for the conversion. The photos below show in the key steps for this conversion.
The Slotsherrensvej bridge in Kopenhagen [M] and [R] Old and poorly functioning system with direct fastening

Removal of the old system [M] Conditioning of concrete channel [R] Adjusting of steel channel

Preparation of concrete channel [M] Installation of steel channel [R] Fastening of steel channel

Preparation of steel channel [M] Installation and adjusting of rails [R] Casting of Corkelast®

The result
Examples of the conversion of bridges made of steel are the bridge over the Dinkel near Oldenzaal and the Moerdijk bridge near Dordrecht (from timber sleepers to ‘Silent Bridge’ deck panels with ERS in was installed in channels.

edilon)sedra has detailed and standardised work instructions available for the installation process of ERS. When necessary and if agreed, these can be adjusted according to a site specific conditions.

Conversion of the Bridge over the Dinkel

Conversion of steel bridge deck to prefab concrete bridge deck (SLEP design) - Winterhausen, Germany

In case of questions and/or remarks related to this manual: T +31 (0)23 5319519 | E info@edilonsedra.com
Chapter 5
Maintenance, repairs and renovation

In this chapter, a number of key aspects with reference to maintenance, repairs and renovation of the embedded rail system are briefly explained. Also here it is important that work procedures related to maintenance, repairs and renovation are taken into account during the design stage of the bridge and the track already. edilon)(sedra has detailed and standardised work instructions available for all maintenance, repairs and renovation procedures of ERS, which can be adapted according to the specific conditions.

5.1 Maintenance and repairs

5.1.1 Replacement of rails in the embedded rail system

A maintenance aspect that may occur is the replacement of rails in the embedded railway system. Although the system enjoys a longer life span due to the continuous support, this lifespan is naturally not endless. A rail section may also become damaged or broken.

In the case of rail replacement, the method to select depends strongly on the extent of the work and the time available to undertake the work. It may also occur that the time required to carry out the rail replacement may exceed the possession time available. Therefore the rail replacement may require to be undertaken in several stages, during which it would be possible to release the track back into service.

To carry out rail replacement within the embedded rail system, the following steps should apply:

- Joint gaps (if relevant) should be made on both sides of the rail that is to be replaced
- Replacement of the rail is undertaken
- Thermit welding is undertaken (2 joints)
- Embedding of rail is undertaken

Please refer to the edilon)(sedra work instructions for more detailed information.

5.1.3 Adjusting the Corkelast®-level

It may occur that the Corkelast®-level needs to be adjusted because it has been installed incorrectly or because the Corkelast®-surface is showing anomalies that need to be remedied (mechanical damage, pollution during application). If only the Corkelast®-level needs to be lowered, a method by which an acceptable Corkelast®-surface is achieved is feasible. As a result, the procedure will be limited to only removing the excess Corkelast® casting compound with a cutter wagon or a router.

If the Corkelast®-level would be too low, or if the Corkelast®-surface is showing anomalies, Corkelast® compound should be cast. An adequate adhesive surface and sufficient volume should be created. This is done by first removing the top layer of the Corkelast® casting compound with e.g. a milling machine, brushing machine or pump-jet. After the Corkelast® casting compound has been removed, the surface on to which the casting will occur has to be cleaned, dried and primed.

Finally, the Corkelast® compound can be cast according to the processing instructions. Please refer to the edilon)(sedra work instructions for more detailed information. In this chapter, a number of key aspects with reference to maintenance, repairs and renovation of the embedded rail system are described in a nutshell. For any maintenance, repairs and renovation procedures on this system, edilon)(sedra has (detailed) work instructions available, which can be adapted according to the specific conditions.
5.2 Renovation

In the case of renovation of ERS, the essential steps are cutting the rails, cutting the cured Corkelast® casting compound, cleaning the channels, adjusting the new rails and embedding, followed by welding. Please refer to the edilon sedra work instructions for more detailed information on this subject.

One of the essential steps, the cutting of the cured Corkelast® casting compound, is elaborated below.

5.2.1 Cutting the Corkelast® casting compound

The cutting of the cured Corkelast® casting compound can be undertaken with various machines. In the images below, two examples can be seen of machines that are used for this procedure on bridges. In each situation, it should be assessed, with regard to the site constraints, which machine is most suitable to use. The following are factors for consideration are:

- The extent of the work
- Required speed of execution
- Availability of machine
- Craftsmanship of the personnel carrying out the work
- Logistics

[L] Cutting of Corkelast® casting compound with a so-called ‘pizza cutter’ attached to a crane on wheels
[R] Cutting of Corkelast® casting compound with a brushing machine
Final Notes

i. For method of analysis, ref. to e.g. EN 1991-2:2003 paragraph 6.5.4.2

ii. Ref. to EN 1991-2:2003, Fig. 6.17

iii. Ref. to ProRail OVS00030-6:2012

iv. Ref. to ProRail RLN00283:2010

v. For method of analysis, ref. to e.g. EN 1991-2:2003 paragraph 6.5.4.2

vi. ProRail RLN00283:2010

vii. Ref. to EN 13232-8:2007

viii. Ref. to ProRail RLN00283:2010 and OVS00030-6:2012

ix. Ref. to ProRail OVS00030-6:2012 and RLN00283:2010

x. Ref. to EN 1991-2:2003, paragraph 6.3, combined with national additions

xi. Ref. to ProRail OVS00030-6:2012, page 17, Table A2.7.1.

xii. For load combinations, ref. to e.g. EN 1991-2:2003, Table 6.10

xiii. Ref. to EN 1991-2:2003, paragraph 6.5.3, combined with national additions

xiv. Ref. to ProRail PVE00121:2006, chapters 3.3 and 4.3

xv. Ref. to EN 1991-2:2003 Fig. 6.20 and UIC 774-3:2001 paragraph 1.2.2

xvi. Ref. to ProRail OVS00030-6:2003, chapter 4.2

xvii. Ref. to ProRail RLN000283:2010, chapter 2.3

xviii. Ref. to EN 1991-2:2003 paragraph 6.5.4.5.1. Note: The limit value applies to 60E1 rails

xix. Figures adopted from ProRail RLN00112:2010, chapter 5

xx. Ref. to ProRail RLN00112:2010, chapter 5

xii. Also ref. to ProRail reporting on ‘Betonplaat Best’

xii. Ref. to ProRail OHD00017:2001