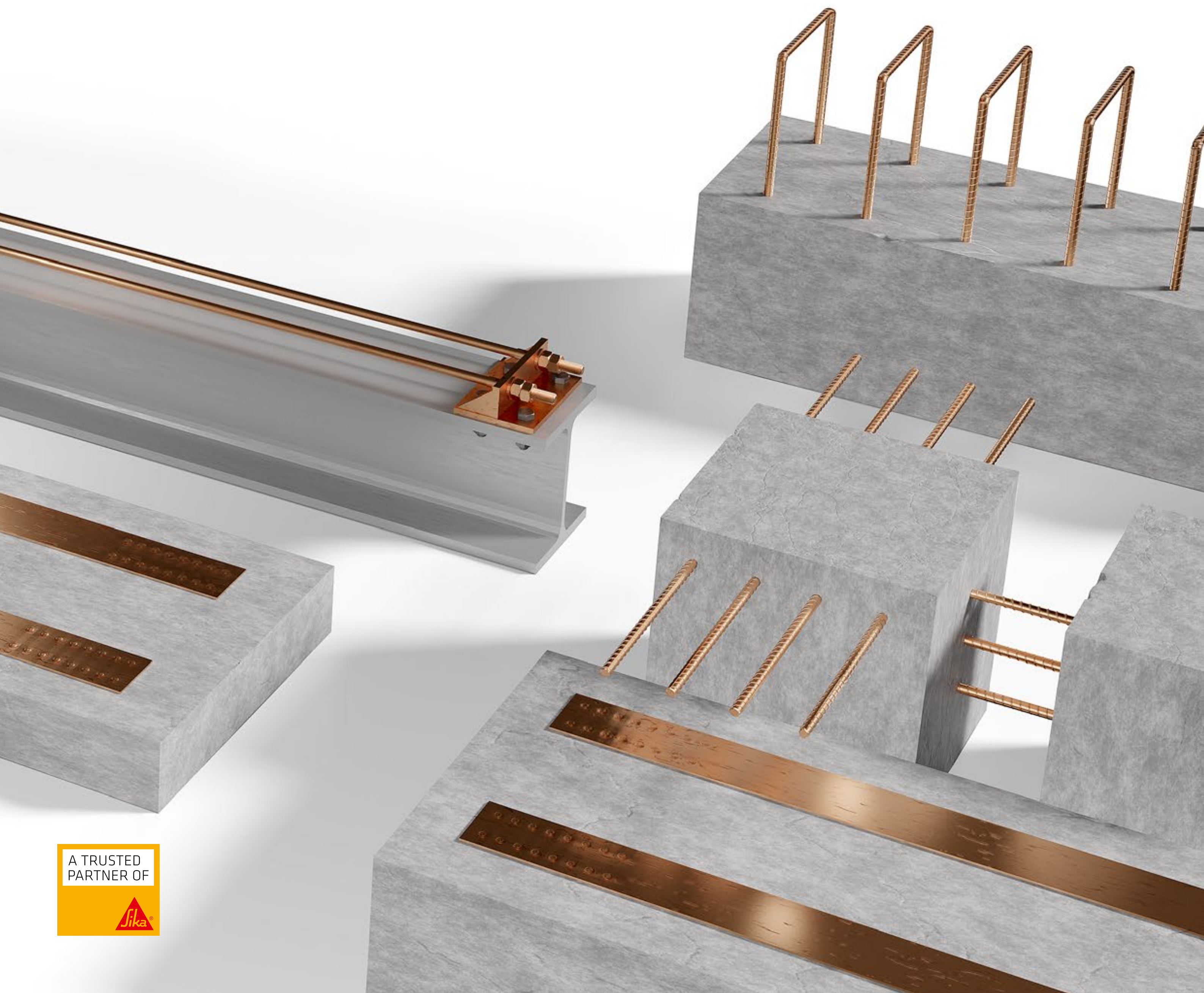
re-fer.eu
strengthening solutions

memory®-steel prestressing techniques

for strengthening and new construction

under «static and dynamic loading»



A TRUSTED PARTNER OF Sika

Our vision

We are aiming for global market leadership in memory®-steel prestressing techniques. Our proximity to the customer worldwide, plus our technical expertise and practical experience, enable us to combine research and development with best practice on-site. memory®-steel is 100% recyclable and contributes positively to sustainability. Through continuous development and patents, we intend to secure the long-term competitiveness of re-fer.

Our mission

By increasing the service life and strengthening of existing built infrastructure, we are adding value for our customers. Upgrading and repurposing of existing structures also helps to protect the environment more than with new constructions. Prestressing new concrete floor/deck slabs can also eliminate the need for downstand beams. We provide designers with better reinforcing solutions for the producing filigree concrete elements.

Casting of memory®-steel

Contents

Click on the page numbers to return to the table of contents.

Innovation: memory®-steel prestressing techniques

Conventional strengthening

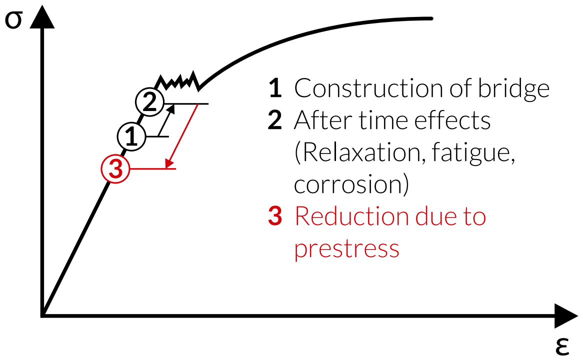
Currently, externally bonded reinforcements made of steel or CFRP lamellas are often used as strengthening systems for building components in flexure. However, the force transfer from adhesive reinforcements into the concrete substrate is often insufficient. The main reason is that loads are introduced via an adhesive layer into the structural substrate only through the concrete cover, which often exhibits cracks. Additionally, concrete in outdoor applications can be heavily influenced by frost, de-icing salt, carbonation, etc. before the repair. CFRP lamellas with a low ultimate strain of 1.5-2.0% are very brittle and fail prematurely. Load redistribution of forces in the event of settlement or in the event of an earthquake is not possible with these reinforcements. CFRP lamellas are approved by the building authorities for components subjected to static loads, and only in exceptional cases for elements subjected to dynamic loads.

Innovation: Robust strengthening with memory®-steel

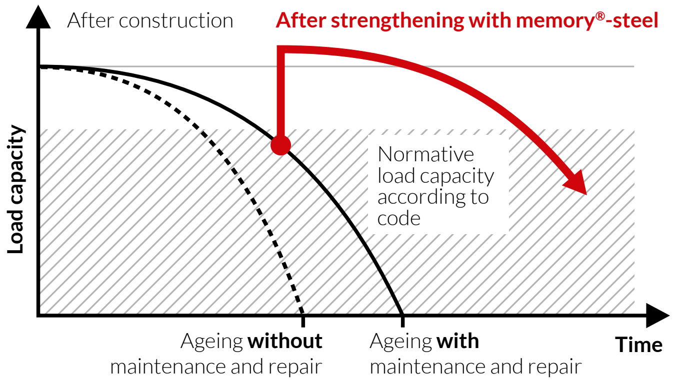
In strengthening with memory®-steel **«re-plate»,** the prestressing force is introduced into the core concrete through a mechanical end anchorage. This strengthening measure is very simple to install and can be applied without great preparation to the load-bearing concrete substrate and prestressed in a few minutes.

In strengthening with the **«re-bar»** ribbed steels, the force is introduced into the concrete core through a new mortar layer which replaces the damaged concrete layer. Existing cracks in the bearing substrate are significantly reduced by prestressing with the memory®-steel. Owing to the high ductility and ultimate strain of >20%, concrete compressive failure in the compression zone constitutes the prevalent failure mode under flexure. While enabling force redistribution, memory®-steel is also eligible for seismic retrofitting.

Stress in existing reinforcement:



Service life:



Dynamic and continuous loading as well as relaxation of the internal reinforcement occurs on a lower stress level after the strengthening.

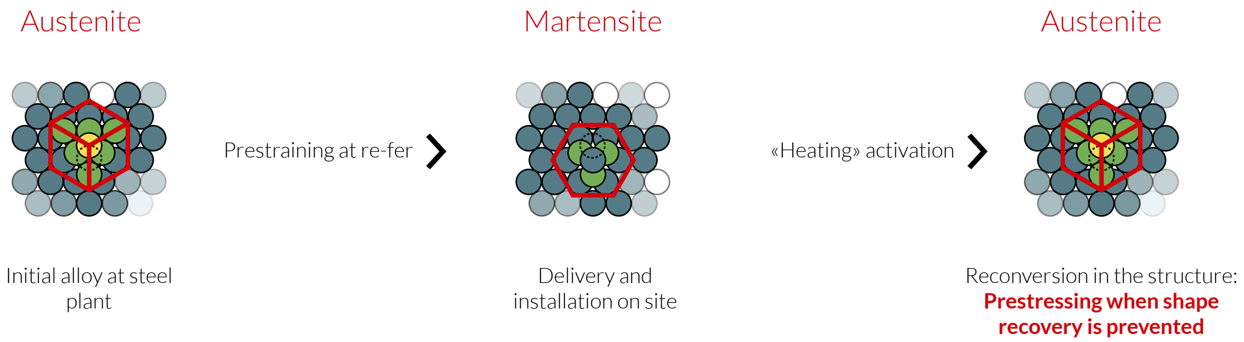
Sika repair mortars protect re-bar, as well as the internal reinforcement against corrosion in the long term.

Iron-based shape-memory alloy

Shape memory alloys (SMA) return to their original shape after a pre-elongation upon heat supply. memory®-steel remembers its original shape due to the «martensite to austenite» crystal structure transformation.

memory®-steel is iron-based and is suitable for use in construction.

Atomic structure



Uniform prestressing without friction loss.

The existing internal reinforcement is relieved due to prestressing and hence the service-life of the structure is extended.

Three memory®-steel techniques are offered

re-plate method for concrete structures	re-bar technique for concrete structures	re-bar R18 technique for steel structures
Steel plate mechanically end anchored in the concrete	Ribbed steel for embedding in mortar or concrete	Round steel fixed through end anchorage to the steel beam
External unbonded tensile strip	Internal bonded reinforcement	External unbonded tension bar
For statically loaded elements	**For statically and dynamically loaded elements**	

re-plate method for concrete structures

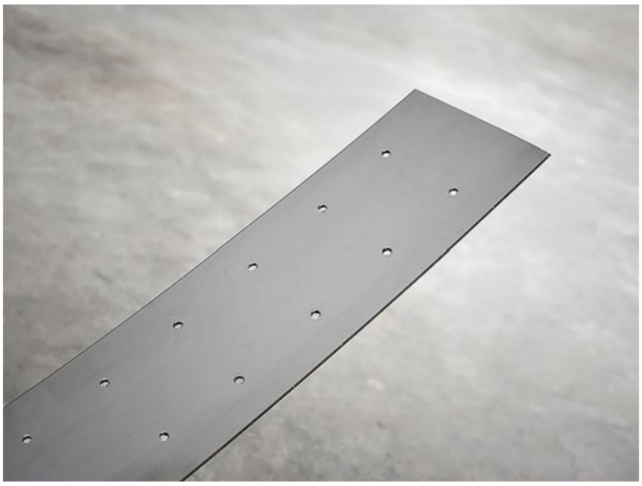
«for statically loaded elements»

re-plate «memory®-steel plate» is used for retrofitting of structures «for statically and in exceptional cases non statically loaded elements». re-plate is anchored on both sides and functions as an external, unbonded tension strip. re-plate is elongated in the factory and supplied pre-punched at the ends ready to use on-site. The mechanical end anchorage is composed of a Hilti direct fastening system. For activation of the «pre-stressing«, the plate is heated using a gas burner or infrared heater.

Product	Cross-section	Max. tensile stress*	Max. tensile force*	Elongation at break
re-plate 120/1.5 mm	180 mm²	460 N/mm²	**83.1 kN**	25 %

* Design value for 12 nails and a concrete strength (cube) >20 N/mm² (with safety factor 1.3)

Product	Heat temperature	Prestress	Prestressing force	Relaxation
re-plate – standard solution	Gas 300 – 350°C	380 N/mm²	**68.4 kN**	15 % t_∞
Corrosion coating or fire risk	Infrared 165°C	300 N/mm²	**54.0 kN**	15 % t_∞



Steel plate similar to a material 1.4003 according to DIN EN 10088 (corrosion resistance class I)

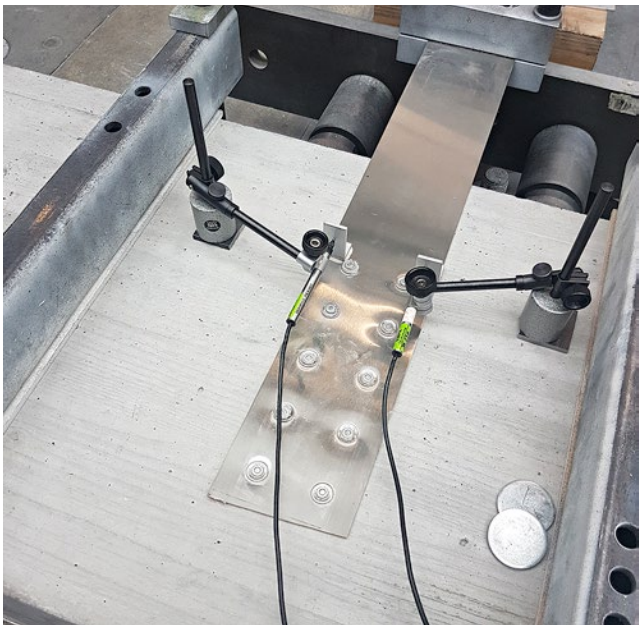
Basic tests with re-plate

Mechanical end anchorage

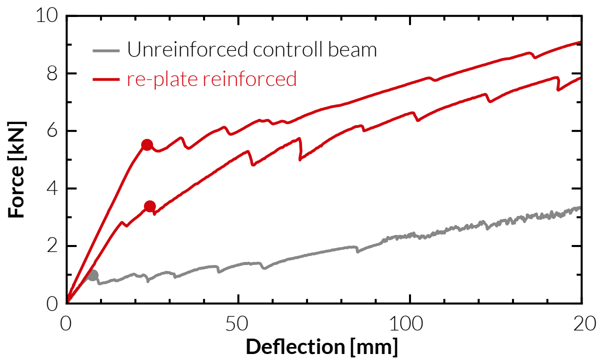
Pull-out tests were performed to check the mechanical end anchorage resistance of the Hilti direct fastening in combination with re-plate.

The full end anchorage resistance requires a concrete compressive strength (cube) of >20 N/mm². For lower concrete qualities, the anchorage and resistance should be discussed with the re-fer engineer.

Failure of re-plate at the reduced cross-section at the front row of holes.



Structural behaviour



The structural behaviour of the strengthening was tested on slabs with dimensions of l = 4 m, h = 150 mm, and b = 500 mm. A control slab was compared with two strengthened slabs.

At serviceability a 3-5 times higher cracking load was observed.

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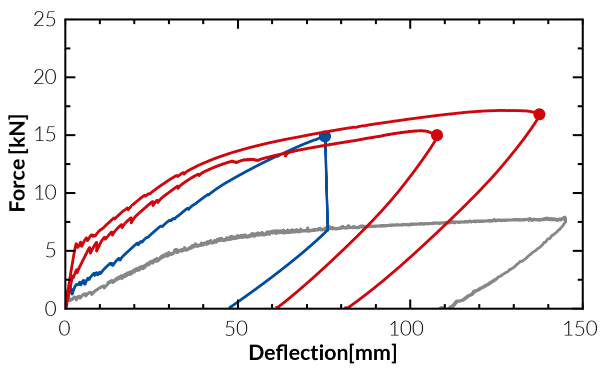
Materials Science and Technology

Large-scale test: re-plate comparison with CFRP laminates

Flexural tests at Empa show re-plate and CFRP laminates at similar axial stiffness EA. The strengthened concrete slabs (depth 150 mm, width 500 mm, span 4 m) were also compared with a control beam with no strengthening and showed much higher failure loads. For the ductile re-plate strengthening system, failure occured due to concrete crushing in the compression zone at high deflection levels. The CFRP strengthening system with low elongation at break failed prematurely due to strip debonding. By prestressing with the ductile re-plate strengthening system, a much higher cracking load was also achieved.

Concrete slab, test at Empa Switzerland

70 - 170 % increase in cracking load compared with CFRP laminates.



	re-plate	CFR strip
Axial stiffness EA [kN]	~10*10³	~11*10³
Cracking load [kN]	3.4 – 5.4	2.0

— Control beam, no strengthening
● Concrete compression
● Strip debonding

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Often appropriate: Combination of re-plate and Sika®CarboDur®.

re-plate

– Against deflection and cracks in the slab and the wall element above
– To relieve load on the existing internal reinforcement
– To cover loads at serviceability state and under fire «Example photo 3: Load and behaviour under fire is covered by re-plate – additional fire protection is only necessary for the re-plate»

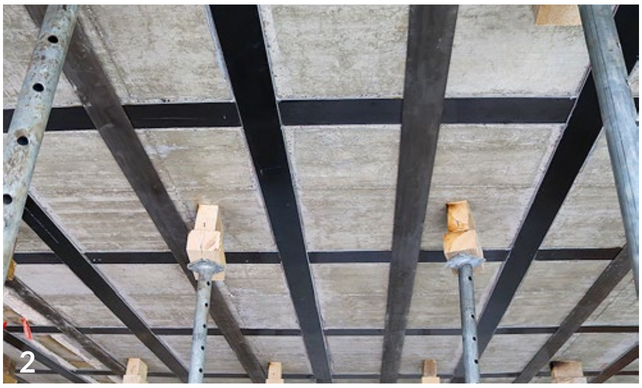
Sika®CarboDur® CFRP strips

– To cover the remaining failure load requirement

Video of strengthening after a fire:
www.re-fer.eu/fire

After a fire, the service and the fire load are covered with re-plate. Sika® CarboDur® is used for the remaining gap to cover the ultimate load. The strengthening is protected with the fire protective sprayed mortar SikaCem® Pyrocoat (see p. 12)

Typical strengthening of the positive bending moment with re-plate



Combination of re-plate with CFR strip

Fire protection for re-plate in combination with CFRP strip

If re-plate and CFRP strips are load bearing in the same direction, the slack CFRP laminates are always applied after the prestressed re-plate. If re-plate is applied longitudinally over pre-installed CFRP strips (transversely), aluminium foil must be inserted as an isolation layer at the re-plate/CFRP intersections, to prevent an adhesive bond between the re-plate and CFRP strips.

Installation of re-plate

Flexural strengthening «Increasing the service and failure load»


1


2

Preparation

1 Remove any coatings and/or insulation from the area before strengthening

2 Temporarily fix re-plate with T-supports


3


4

Bilateral (both ends) anchorage

3 Drill the substrate through the pre-punched re-plate ends

4 End anchor mechanically using the Hilti bolt direct fastening system with tested stainless steel bolts (X-CR 48 P8 S15)


5A


5B

Activation of prestressing

5A/B Segment-wise heating with gas or re-IR 3000 infrared heater/ temperatures controlled by sensors


6

Completion

6 re-plate shows its load-bearing effect immediately after activation and cooling (photo: shows subsequent removal of the structural wall)

Applications with re-plate

Removal of existing supports or bearings

The structural system of a deck slab is changed by prestressing of re-plate. Existing supports or bearings can be removed. This creates new opportunities for space utilization in residential or industrial buildings.

Positive moment strengthening

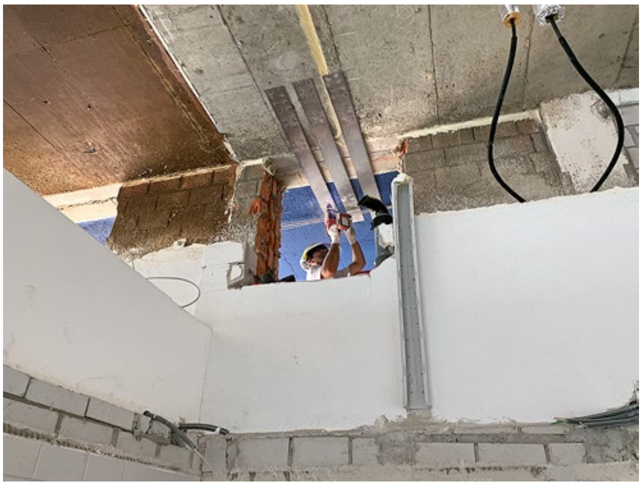
The span in the main tensile direction was extended by prestressing an expansion joint and removal of the support below. The higher positive bending moment and prestressing over the joint were both covered by re-plate.

Negative moment strengthening

The negative moment was strengthened on the top of a balcony in order to remove the external support below.

Local strengthening next to a cut-out in a slab

re-plate was installed where tensile reinforcement was missing due to a cut-out in the slab. The prestressing forces were rerouted to the load-bearing system of the existing slab. re-plate was installed directly on the concrete and was applied and prestressed in a few minutes. Strengthening works are completed prior to the cut-outs.

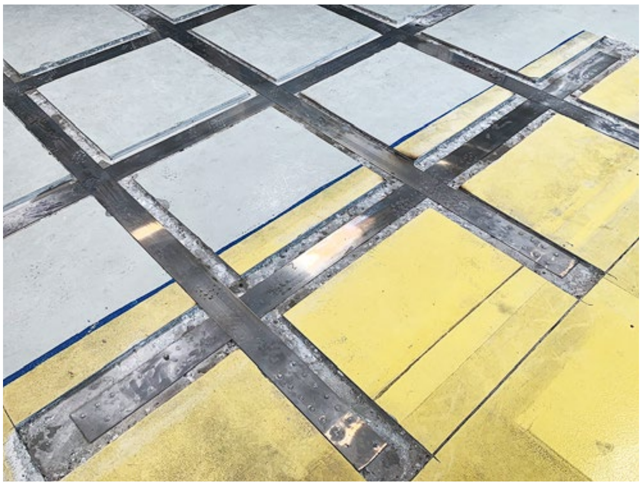


Prestressing of coupling joints

Expansion/coupling joints can be prestressed with short re-plate to create rigid connections between the two sides. This application is of interest for seismic mitigation in buildings and can also be useful for strengthening works on bridges.

Local strengthening of a bridge girder

In this example, a bridge beam suffered localized impact damage from road vehicles to the extent that internal prestressing strands were partly damaged. Strengthening with re-plate was completed within just two hours, whilst the traffic underneath the bridge was temporarily diverted to one lane. This was possible with the re-plate system because it can be applied very quickly and efficiently. Additionally, because de-icing salts are used on this motorway in winter and of the increased chloride exposure, additional corrosion protection was applied on the re-plate. Prestressing activation was performed by using an infrared heater with the activation temperature limited to 165°C.



Strengthening against punching shear

By applying the prestressed re-plate system on top of this deck slab, resistance in negative bending and against punching could be increased. Areas of voids were present under the re-plate due to the unevenness of the concrete surface. These voids were filled laterally with a grouting mortar to prevent vibration/movement of the re-plate. Afterwards, re-plate is also covered with the grouting mortar or coating. a selected deck coating/flooring system was finally applied on top of the strengthening system.

Reducing deflection and closing cracks

Following a building conversion and higher loads being imposed, it was clear that the existing concrete deck slab was under-reinforced. The excessive deflection (blue) led to cracks in the masonry on top (red). Eight re-plate strengthening plates were applied and activated to increase the behavior under service loads as well as the load carrying capacity. The visible cracks could also be closed.

Visible crack before strengthening

Crack is closed after strengthening

Film Activation of re-plate:
www.re-fer.eu/mov01

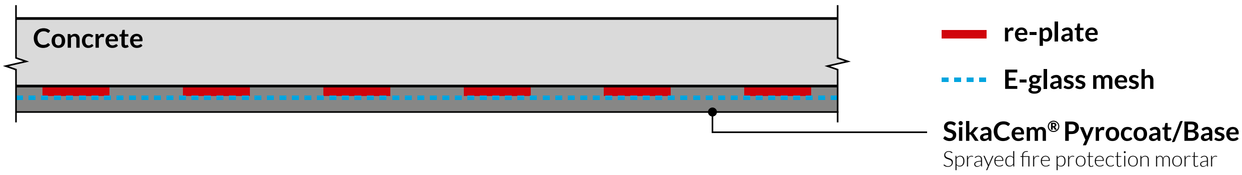
Fire protection for re-plate

re-plate reaction to fire

re-plate has a similar reaction to fire to that of conventional steel, losing strength significantly from about 400°C on, and reducing its prestressing to zero at about 350°C. The same applies to the anchorage with Hilti direct fasters; separate results are available for these. Fire protection of the strengthening measures is always required if the specific fire load for the relevant standard and country is not covered without the strengthening. The design tool (p. 43) shows an example of this for comparison.

Fire protection

The concrete substrate and strengthening plates are cleaned and fully covered with the base coat SikaCem® Pyrocoat Base. A fine layer of SikaCem® Pyrocoat sprayed mortar is then applied over the full strengthening system. This mortar also levels any uneven areas. An E-glass mesh fabric (alkali-resistant) is fully embedded into the mortar over the re-plate. To prevent voids due to re-plate movement, the sprayed mortar is applied laterally into these gaps.



SikaCem® Pyrocoat «sprayed mortar» applied by machine	
layer thickness 25 mm	**R120**
Results not finalised yet. Current values can be found on the re-fer website	**R90**
	R60
	R30

The fire protection system was tested at MFPA Leipzig, Germany. The test reports are available in the download section on the website or on demand.

Additional fire tested mortars in the Sika MonoTop® range are available for outdoor applications and in tunnelling. The fire protection measures and stated layer thicknesses are guide values and must also conform and be compatible with all relevant local regulations and standards.

Corrosion protection of re-plate

Corrosion behaviour of memory®-steel

The memory®-steel alloy contains about 10% chromium and behaves similarly to a 1.4003 alloy according to DIN EN 10088 (corrosion resistance class I). A known risk associated with prestressing steels is stress corrosion cracking. In the adapted fib test for stress corrosion cracking, memory®-steel achieves stand durations of over 250 hours. For severely exposed structures in environments with a high chloride concentration – such as indoor swimming pools and highways splash zones – an additional corrosion protection should always be considered and applied. SikaCor® EG-1 is a suitable corrosion protection product for exposed re-plate.

Note: re-bar is embedded in a cementitious matrix which functions as an alkaline deposit for the internal reinforcement and a protective barrier layer against the penetration of chloride ions.

Corrosion protection is recommended for elements with high chloride exposure.

re-plate pre-punched

Factory sandblasting with corundum

Corrosion protection with SikaCor® EG-1 applied in factory

Application of memory®-steel corrosion protection

The re-plate surface is roughened lightly by corundum sandblasting and is then coated with SikaCor® EG-1. Any transport damage to this coating is also to be repaired on site with a thin layer of SikaCor® EG-1. Due to this protective coating with «temporary thermal resistance of ca. 180°C», the heat temperature of the prestressing process is limited to 165°C. Correspondingly, a maximum prestressing force of 54 kN/re-plate is applicable. After application and activation, the re-plate is additionally sealed in position with Sikaflex® PRO-3 on both sides to prevent water ingress between the concrete substrate and the re-plate.

SikaCor® EG-1 «coating» applied in factory
The epoxy resin based protective coating is applied on both sides of re-plate in the factory. On site, the nails and possible imperfections are coated. The edges of re-plate are sealed on site with Sikaflex® PRO-3, PU based sealant after the activation.

*Attention: reduced heat temperature 165°C «prestressing force 54 kN/re-plate»

re-bar method for concrete structures

«for statically and dynamically loaded elements»

Post-strengthening of structures

The Ø10 or Ø16 mm ribbed re-bar is end anchored in Sika repair mortar. After sufficient cure of the end anchorage, re-bar is activated by a gas burner. Finally, the remaining free length is also embedded in mortar. The installed re-bar acts as an internal prestressing. re-bar 10 U-profiles (stirrups) are embedded in Sika repair mortar and activated by using an electric current.

Product	Cross-section	Max. tensile stress*	Max. tensile force*	Elongation at break
re-bar 10	89.9 mm^2	520 N/mm^2	**46.7 kN**	30 %
re-bar 16	211.2 mm^2	520 N/mm^2	**109.8 kN**	30 %

*Design value reduced by safety factor

Product	Heat temperature	Prestress	Prestressing force	Relaxation
re-bar 10 – bars	Gas 300 – 350°C	400 N/mm^2	**36.0 kN**	15 % t_∞
re-bar 10 – U-profiles	Electricity 200°C	350 N/mm^2	**2 x 31.5 kN = 63 kN**	15 % t_∞
re-bar 16 – bars	Gas 300 – 350°C	320 N/mm^2	**67.6 kN**	15 % t_∞

In concrete for new construction (internal downstand beam)

In new concrete structures, re-bar 16 is used similarly to traditional reinforcement. Activation is performed by resistive heating with electric current applied before the concrete formwork is removed.

Product	Heat temperature	Prestress	Prestressing force	Relaxation
re-bar 16 – with end hooks for electrical connection	Electricity 200°C	250 N/mm^2	**52.8 kN**	15 % t_∞

Ribbed bar similar to a 1.4003 alloy according to DIN EN 10088 (corrosion resistance class I)

Basic tests on re-bar

Bond tests

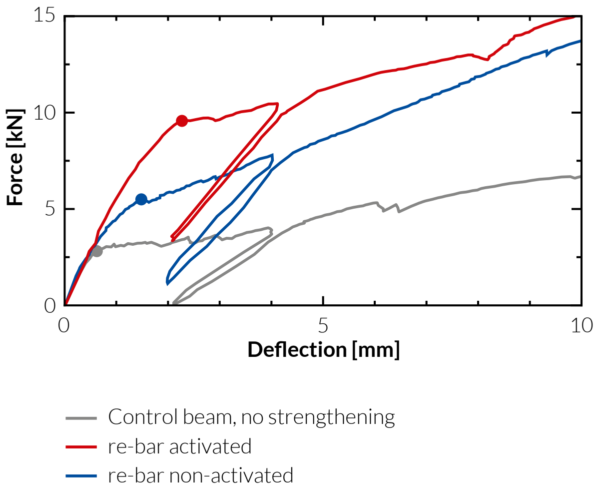
Pull-out tests were run to investigate the bond behavior of the end anchorage with different mortars from Sika. The anchorage length with the mortars tested was determined and is used as follows on a concrete with compressive strength >25 N/mm^2:

In Sika repair and sprayed mortars
Anchorage length: >500 mm
(depending on situation)

In cut grooves with Sika grouting mortar
Anchorage length
re-bar 10: ≥400 mm
re-bar 16: ≥600 mm
Clearance between grooves: ≥100 mm

The anchorage length can be reduced for higher concrete qualities. Alternative anchorage types are shown on page 27.

Structural behaviour



The structural behaviour of the strengthening method was tested on a beam with dimensions of depth 160 mm, width 250 mm, span 2 m. The activated and non-activated re-bars were compared.

Cracking load was doubled due to the activation.

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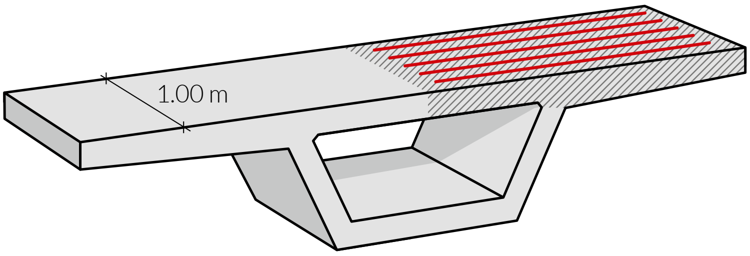
Large-scale test: Bridge deck negative moment strengthening

A research project at Empa Switzerland investigated the flexural load carrying capacity of bridge decks strengthened with re-bar. The bars were installed in grooves cut in the top of the concrete deck and grouted with SikaGrout®-314 N. In a second series, the re-bar was installed on the roughened concrete surface, embedded in Sika MonoTop®-452 N repair mortar over the full width of the deck. This large-scale test simulated a bridge deck transversely strengthened with 5 prestressed re-bars.

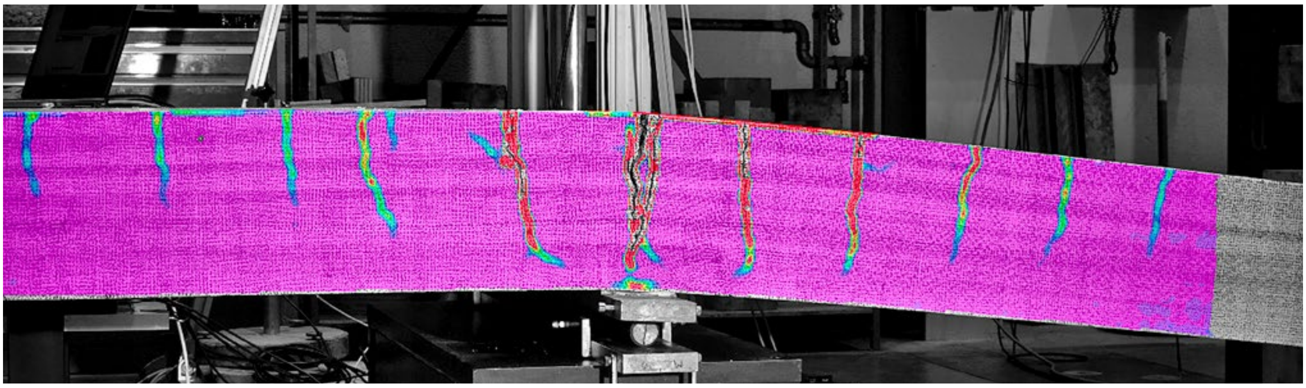

Strengthening in cut grooves


Strengthening embedded in repair mortar over the full surface

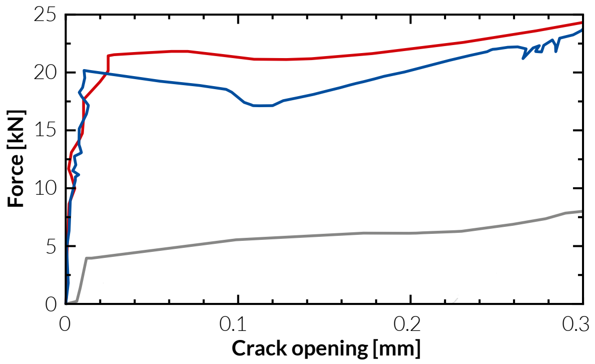

Test on concrete deck at Empa

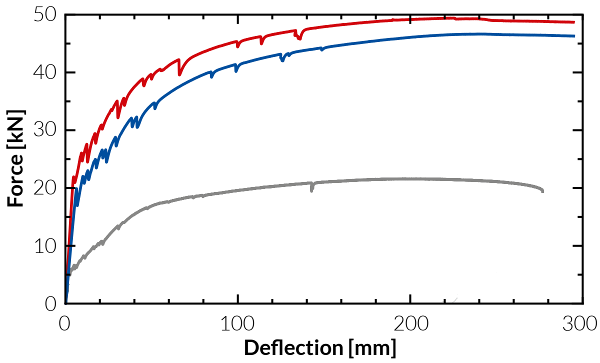


Test results: Negative moment strengthening



	Control beam	re-bar in concrete groove	re-bar in repair mortar
Cracking load [kN]	5.9	20.0	21.9
Failure load [kN]	21.6	46.6	49.4





— Ref. beam, no strengthening
— re-bar in repair mortar
— re-bar in cut groove

Internal reinforcement is relieved from load.

Longer lifetime.

The crack widths measured were significantly reduced for the same loading. The structure remained in the uncracked state for longer. The fact that load is removed from the inner tensile reinforcement by an additional prestressing also benefits the fatigue behaviour and therefore the lifetime of the structure.

Cracking load was tripled.
Failure load was doubled.

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Materials Science and Technology

Application of re-bar for strengthening

Positive/negative moment strengthening

Preparation

1 Roughen the concrete load-bearing substrate until the required profile is obtained

2 Fix re-bar with **re-clip** electrical insulators to the internal reinforcement or **re-bolt** to the substrate

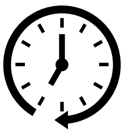
Bilateral end anchorage

On the deck

3 Bilateral (both ends) embedment in **Sika MonoTop®-452 N** «repair mortar» as end anchorage

Overhead

4 Bilateral (both ends) embedment in **Sika MonoTop®-412 Eco/-4012** «sprayed mortar» as end anchorage



Activation of re-bar as soon as compressive strength >35 N/mm² is reached in the mortar

Activation of prestressing

5 Heat re-bar with gas burner and record activation temperature

Completion

On the deck

6 Apply **Sika MonoTop®-452 N** «repair mortar» between the end anchorages

Overhead

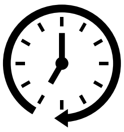
7 Apply **Sika MonoTop®-412 Eco/ -4012** «sprayed mortar» between the end anchorages

Strengthening negative bending moment in cut grooves

Preparation

1 Cut the groove in the load bearing concrete substrate
re-bar 10: width 25 mm/depth 25 mm
re-bar 16: width 30 mm/depth 30 mm

2 Fix re-bar centrally in the groove



Activation of re-bar as soon as compressive strength >35 N/mm^2 is reached in the mortar

Bilateral end anchorage

3 Bilateral (both ends) embedment in- **SikaGrout®-314 N** «grouting mortar»

Activation of prestressing

4 Activate/heat re-bar with gas burner

5 Record activation temperature

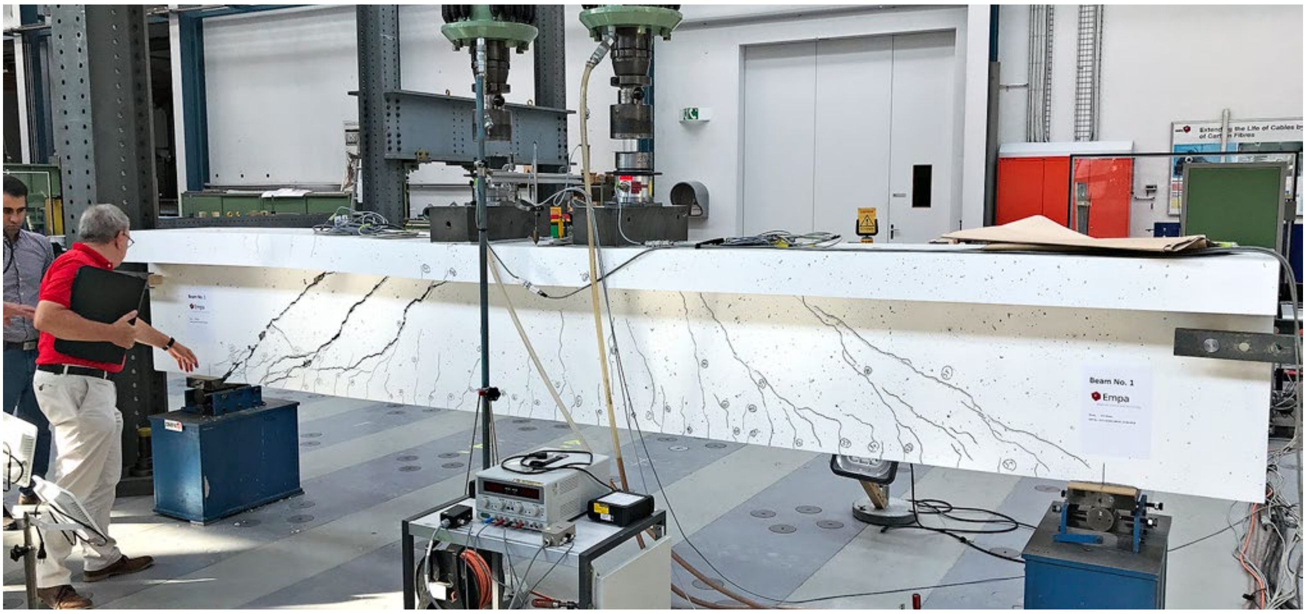
Completion

6 Grout re-bar with **SikaGrout®-314 N** between the bilateral end anchorages

7 Install the deck waterproofing and asphalt pavement topping

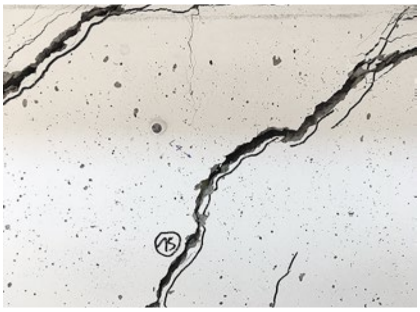
Failure load test: shear strengthening on T-beam

Failure load tests were carried out at Empa in Switzerland designed to obtain shear failure. An initial control test beam, without additional re-bar shear stirrup strengthening, was loaded to failure. This severely damaged control beam with broken shear reinforcement and gaping cracks was repaired by injection and post-strengthened with Sika products and re-bar stirrups. Four additional undamaged T-beams were strengthened with re-bar shear stirrups and tested in the same procedure.



Test beam at Empa

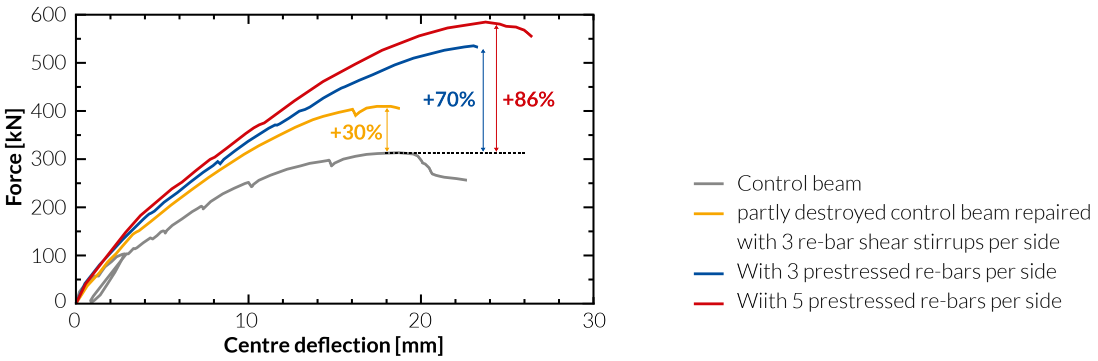
Fixing the strain gauge on internal stirrup reinforcement



Open cracks in the destroyed control beam

Thermal image recording of the activated/heated re-bar stirrups

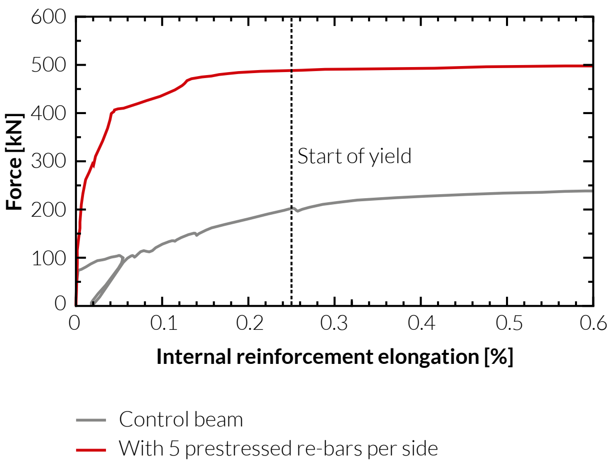
The tests on the re-bar strengthened beams showed considerable gains in their shear failure load. The prestressing also kept the crack opening widths smaller at equal loadings than without prestressing.



Strengthening of partly destroyed structures after earthquakes is possible.

Due to the prestressed re-bar shear stirrups, a 30% increase in the failure load of the partly destroyed control beam was obtained.

Due to activation/prestressing of the re-bar shear stirrups, crack opening only occurred with a 50% higher load capacity.



Due to the prestressing, the tensile stress in the internal shear reinforcement was relieved. Strain gauges on the internal reinforcement showed that it began to yield in the control beam at ~200 kN. Due to the prestressing with 5 prestressed re-bars, reinforcement yield only began at ~500 kN.

Load removal from internal shear stirrups.

Improved fatigue behaviour.

Empa
Materials Science and Technology

Application of re-bar U-stirrups

Crack injection if necessary

1 Surface sealing of the cracks with **Sika® FastFix-121** and injection with **Sika® InjectoCem-190**

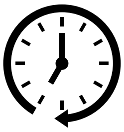
Preparation

2 Hydromechanical or mechanical preparation to required roughness (sandblast first if mechanically pre-pared)

3 Fix re-bar shear stirrups with re-bolt plastic dowels (for electrical insulation of the internal reinforcement)

Concrete repair/replacement

4 Apply **Sika MonoTop®-412 Eco/-4012** by the wet spray process, pre-grout holes with **SikaGrout®-314 N**. Alternatively: Use formwork, fill with **SikaGrout®-314 N** mortar



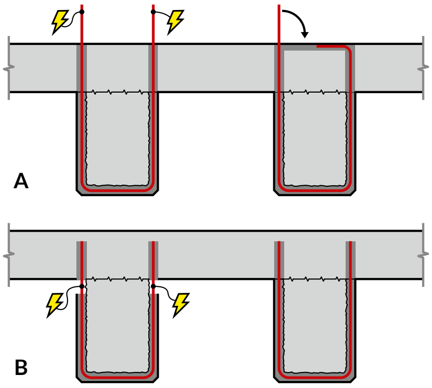
Activation of re-bar as soon as com-pressive strength >35 N/mm²
is reached in the mortar.

Activation of prestressing

5 Activatie with electrical resistive heat-ing, then bend and grout the stirrups on the top side.

Prestressing force: 2 x 31.5 kN = 63 kN per double shear U-profile

Site electricity connection:400 V, 2 x 56 A (63 A CEE connector) in a radius of 20 m



Completion

6 View of strengthened element after mortar repair/replacement

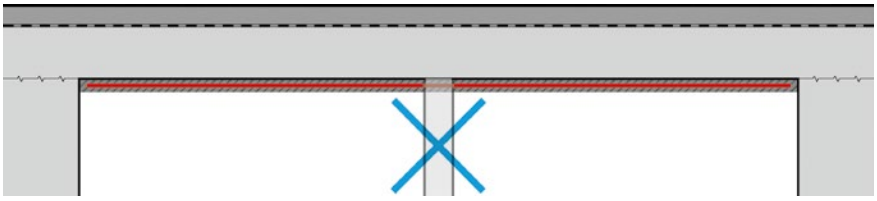
Anchorage in compression zone

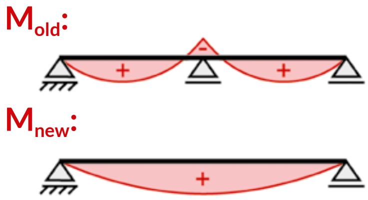
A U-profile sealed
B U-profile anchored in the concrete

Applications of re-bar for post-strengthening

Flexural strengthening of bridge slab

To improve the water flow profile under a culvert bridge, the central pier (marked in blue on the longitudinal sketch) was to be removed. The culvert had to be drained for the construction works and temporary supports were provided under the bridge to remove the central pier. The new positive moment **M_{new}** also had to be reinforced due to the new wider span and was taken over by the prestressed re-bar positioned across the centre and installed in Sika MonoTop® sprayed mortar. To ensure a good bond with the existing load-bearing deck, the concrete substrate was prepared and roughened by high-pressure water jetting.





Bending moment line
before/after strengthening

After removal of the dividing wall, temporary support and high-pressure water jetting to roughen the surface

Fixing the re-bar to internal reinforcement (with re-clip) and to the concrete substrate (with re-bolt)

Bilateral 600 mm end anchorage of the re-bars with Sika MonoTop® wet sprayed mortar

Activation of re-bar with gas torch and temperature monitoring

The end anchorage bond in the cementitious Sika MonoTop® was checked at Empa by pull-out tests. The bilateral anchorage length is based on compressive strength of the old concrete >25 N/mm^2. Compressive strength of the existing structural concrete must always be checked in advance with a test hammer, or by taking a small cylinder sample.

Film Activation of re-bar:
www.re-fer.eu/mov02

Application of Sika MonoTop® in the central region

Improved flow in the culvert under the bridge after strengthening

Flexural strengthening of a bridge girder

Besides the load carrying capacity, the stress level of the internal reinforcement and amplitude under dynamic continuous loading is also decisive for the sustainability of a bridge. Depending on the condition, different constructional measures may be required to ensure the durability. The near-surface concrete layers of the bridge slab and girder are heavily carbonated, and the internal reinforcement shows corrosion damage. Concrete of poor quality is removed hydromechanically and the areas for the strengthening are roughened.

Poor quality concrete before retrofitting


Corroded internal reinforcement

re-bar can be applied specifically as a flexural strengthening on the bridge girders. The stress in the existing internal tensile reinforcement is reduced due to prestressing. The anchoring zones are supplemented with U-stirrups (conventional reinforcing steel). One stirrup Ø12 mm can redirect the prestressing force of one re-bar 16 into the compression zone. Sometimes the shear reinforcement is insufficient. In such cases re-bar U-profiles can be applied and prestressed.


Temporary scaffolding for the retrofitting


Anchoring zone of three re-bar 16 (prestressed) with three U-stirrups Ø12 mm (conventional reinforcing steel) in Sika sprayed mortar

Embedding re-bar in Sika sprayed mortar

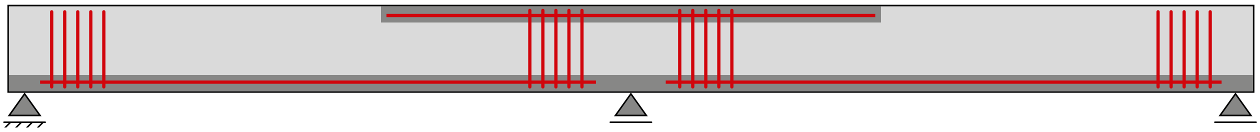
By embedding re-bar with Sika MonoTop® sprayed mortar a new alkali deposit is created protecting the internal reinforcement against corrosion. The robust and durable strengthening solution increases the structure's lifespan.

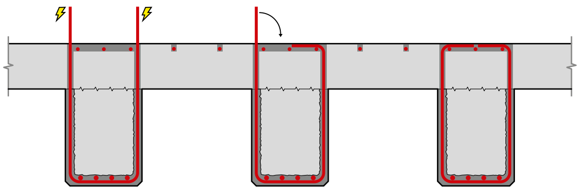
Before strengthening:
Carbonated concrete and corroded internal reinforcement

After strengthening:
Finishing Sika mortar on the complete surface

Combined flexural/shear applications on bridge structures

re-bar is suitable for partial and complete rehabilitation of a bridge beam or solid deck downstand. For conversions or repairs of old, carbonated concrete sections, memory®-steel re-bar is installed in new mortar layers for flexural or shear strengthening. The cementitious mortar layer functions as a protective alkaline environment for the embedded steel reinforcement. These strengthening works create a durable load-bearing system with integral corrosion protection for memory®-steel and the existing internal reinforcement.





memory®-steel is protected from corrosion.

Robust anchorage due to vertical pressure over the cross-section.

Resistant to fatigue.

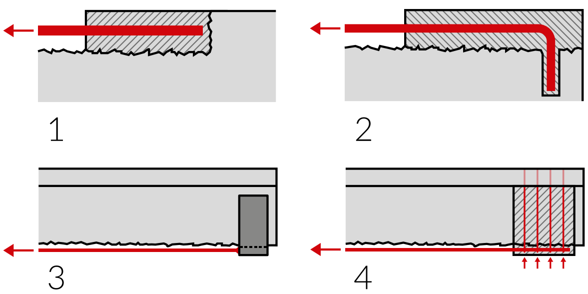
Internal reinforcement load relief.

Higher load capacity/ lower deflection.

Flexible anchorage options

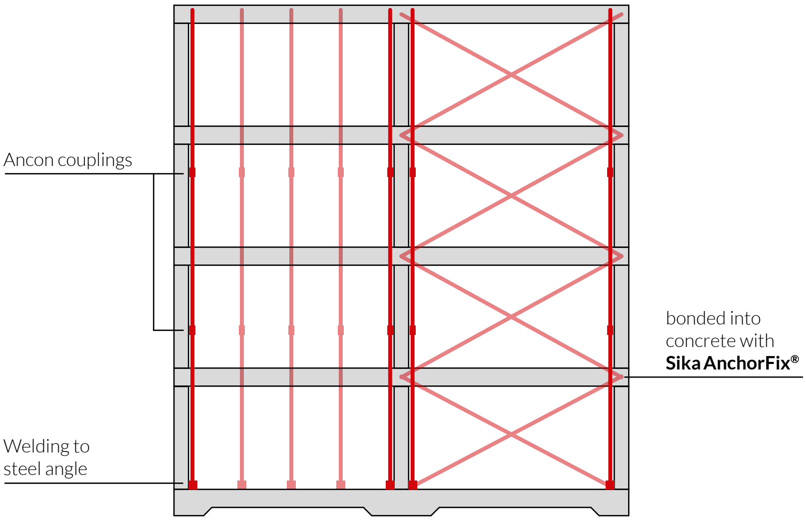
For flexural strengthening, re-bar is anchored behind or on the zero-moment position, and for shear strengthening, re-bar is anchored in the compression zone. Transmission of the prestressing force is normally achieved through the bonded mortar (1), alternatively end hooks can also be used, in which case the anchorage generates a better resistance due to the deeper penetration into the core concrete (2). Additional special solutions such as bonded or externally bolted steel angles with welded re-bars are also possible options (3).

Prestressed re-bar shear stirrups are particularly suitable for applying pressure over the shear bond between the new mortar and the bearing concrete substrate (4).



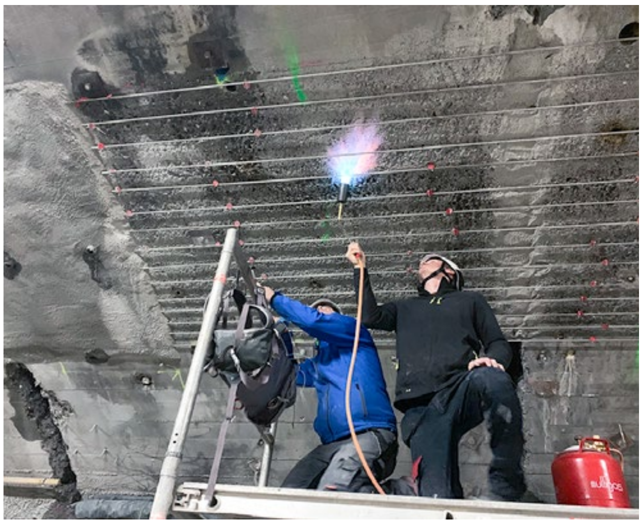
Seismic strengthening

Thanks to the weldability of memory®-steel, simple anchorages of re-bar are possible. For example, re-bar can be welded to a steel L-profile and anchored in the concrete slab of fondation. Additionally, re-bar can be embedded in Sika MonoTop®-412 Eco/-4012 sprayed mortar. Welding must be carried out by a qualified stainless steel welder (tungsten tip, inert gas, weld metal «Böhler A7 CN-IG» 1.6 mm wire).



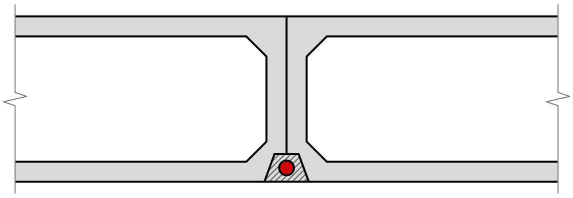
Strengthening in tunnelling

For arch strengthening in tunnelling or for increased pressure over coupling joints, e.g. in water treatment, re-bar is embedded in the dry sprayed mortar Sika® Rock Gunite BE-8.



Strengthening of a hollow floor

re-bar was placed in a groove cut in the concrete area between the hollow blocks, then end anchored and activated. The activation temperature was adjusted to provide the prestressing force required.

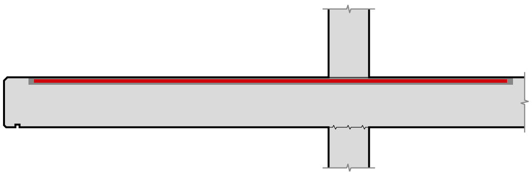


Strengthening against uplift

This inadequately reinforced floor slab bulged and cracks had developed on the top surface. Strengthening against the groundwater uplift pressure was carried out in both load-bearing directions. A combination of «cut groove» re-bar was inserted in one direction, and re-bar embedded «in repair mortar» in the other direction.

Strengthening of balcony connection

On the structure, the top surface of the deck and balcony slab was strengthened with re-bar inserted in «cut grooves». This reduced the slab deflection and higher live loads could be applied on the balcony.



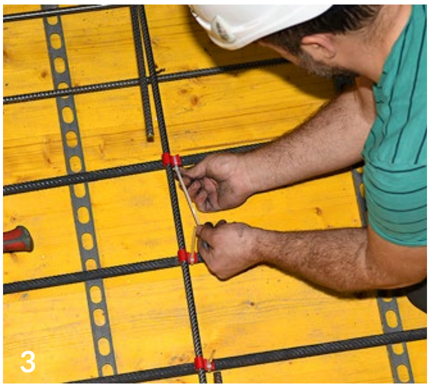
Use of re-bar in new construction

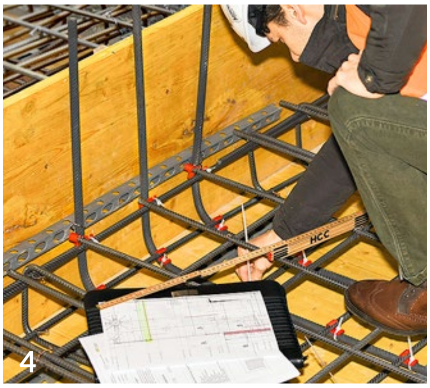
Creation of internal, prestressed downstand beams

Installing the reinforcement

1 Build the formwork, install spacers and the 1st layer of conventional internal reinforcement

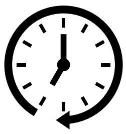
2 Install re-bar in the concealed downstand region between the internal reinforcement





3 Fix the transverse reinforcement (2nd layer)/contact with the re-bar is separated by re-clip electrical insulators

4 Check on the re-bar by the responsible engineer (including electrical contact, position, electrical connection points etc.)



Activation of re-bar as soon as compressive strength >25 N/mm^2 is reached in the concrete.

Concreting

5 Concrete works after approval by the responsible engineer.

Activation of prestressing

6 Activation/electric heating (before striking formwork). Measurement of the prestressing force with a load cell is possible.

Site power connection: 400 V, 2 x 56 A (63 A CEE connector) in a radius of 20 m

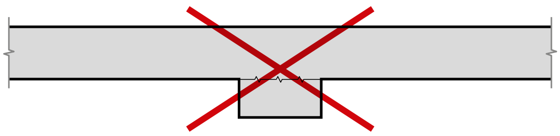
7 Detachment of re-bar connections and completion of the deck

Application of re-bar in new construction

Concealed, prestressed downstand beams in a building

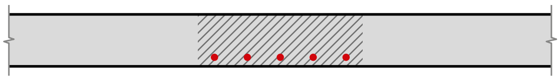
The targeted use of memory®-steel in new build structures can reduce concrete slab/deck thickness and therefore is an alternative to conventional load-bearing systems such as downstand beams, overlays, or additional support elements. re-bar is specifically used for concrete lintels or filigree concrete slabs with a span of up to approx. 15 m and thicknesses up to approx. 30 cm. Its ease of handling and optimum internal lever arm utilisation provides several advantages over conventional post-tensioning systems.

original design:

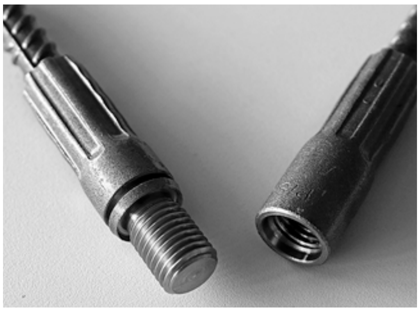


Not desired by architect/owner.

re-bar solution:



To avoid restricting the internal room height, the client and their architect wanted to use a concealed downstand beam. To enable the slab deflection to remain compliant in that area, re-bars were laid between the bottom reinforcement layer. The re-bar was electrically activated after hardening but before removal of the deck formwork. The strengthening reinforcement formed in the filigree concrete slab covered the same structural requirements as the downstand beam originally proposed.



re-bar 16 is delivered in standard lengths that are suitable for transportation. The re-bars can be joined/extended on site with a special coupling system.

re-bar R18 method for steel structures

«for statically and dynamically loaded elements»

The Ø18 mm re-bar R18 round bar is end anchored on the existing steel element by bolts. In exceptional cases, local welding of the end anchorage is possible. Activation/prestressing is done with a gas burner according to the re-fer product data sheet. During heating, a heat shield is placed between re-bar R18 and the existing steel structure.

Product	Cross-section	Max. tensile stress	Max. tensile force	Elongation at break
re-bar R18	254.5 mm²	750 N/mm²	**190.8 kN**	15 %

Product	Heat temperature	Prestress	Prestressing force	Relaxation
re-bar R18	Gas 300 – 350°C	380 N/mm²	**96.7 kN**	15 % t_∞

The re-bar R18 is delivered on site in a maximum bar length of 5.2 m. A special M19.5 thread is rolled onto the bars at both ends. The R18 C coupling is used to join the bars on site.

Corrosion protection to the structural steel and the re-bar prestressing steel is done according to the technical bulletin from re-fer.

Round steel similar to a 1.4003 alloy according to DIN EN 10088 (corrosion resistance class I)

R18 C Couplings with M19.5 internal thread

Additional products for re-bar R18

Strengthening with re-bar R18 can be done with one, two or four bars. They can be applied parallel to the steel beam or with a central devication.

Strengthening type	«Single»	«Double»	«Quadruple»
Number of re-bar R18	1	2	4
Prestressing force	**96.7 kN**	**193.4 kN**	**386.8 kN**
Tensile force	190.8 kN	381.6 kN	763.2 kN

R18 end anchorage

The end anchorage base plate is adapted to the structure and bolted to the existing steel profile. Special applications or structures with extra profiles are possible. R18 nuts with washers are supplied to fix re-bar R18. The washers (spherical disc + conical seat) allow misalignment angle of up to 3°.

R18 «Single, Double and Quadruple» end anchorages (bolted)

R18 Nuts and washers with misalignment angle of up to 3°

The standard end anchorages are designed for the following steel profiles:

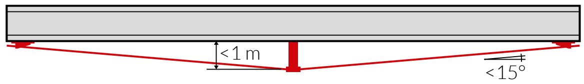
steel profiles	IPE	PEA	INP	HEA	HEB	HEM
«Single»	270 – 750	270 – 600	300 – 550	140 – 1000	140 – 1000	140 – 1000
«Double»	350 – 750	300 – 600	360 – 550	140 – 1000	140 – 1000	140 – 1000
«Quadruple»	750			260 – 1000	260 – 1000	260 – 1000

R18 deflection support

To increase the prestressing moment, a deflection support can be installed in the centre of the beam. To prevent cross-sectional weakening of the steel beam at that point, the R18 deflection supports are clamped. The supports are designed for a maximum cant of 1 m. With the washers and the base incline of the bracket, misalignment of 15° is possible.

R18 Deflection support «Double and Quadruple» clamped

Strengthening with deviation to the steel beam:



Deflection support clamped

Strengthening parallel to the steel beam:

End anchorage bolted to the steel beam flange

Installation instructions can be found in the product data sheet. The re-fer team provides support for special applications (e.g. installing re-bar R18 in the web region etc.). If strengthening ribs are mounted at the force transmission points, checking by the engineer is required. Application and prestressing must be done on the structure after load removal.

Tests on dynamic continuous loading

Prestressed re-bar R18 bars have passed dynamic continuous loading tests of 2 million load cycles with a butt weld and a stress amplitude of 60 N/mm², and with an M19.5 coupler and a stress amplitude of 50 N/mm².

Suitable for applications with dynamic loading.

Empa
Materials Science and Technology

Applications of re-bar R18

Flexural strengthening of a composite steel/concrete bridge

Adjustments in construction standards can result in higher load requirements. The composite steel/concrete bridge shows a structural deficit. To increase the resistance against flexion and fatigue loadings, the main steel girders are strengthened with the re-bar R18 method.

Composite steel and concrete bridge before strengthening

The existing steel parts are sandblasted and coated with the Sika corrosion protection system on site. The re-bar R18 are fixed on both sides to the end anchorages, which are screwed onto the steel beam. After that, the whole length of re-bar R18 is heated/activated by a gas torch.

Existing steel beams with corrosion protection

Installed re-bar R18 with end anchorage

re-bar R18 is mounted parallel to the main span direction of the steel beams. Intermediate supports in the centre of the span are used because the bridge shows high deflections. At these positions, deviation forces are introduced precisely. A corrosion protection is applied for the strengthening measure as a consequence of the humid environment and harmful chlorides (de-icing salts).

Existing steel beams with corrosion protection

Intermediate supports in the centre of the beams

Application with R18 deflection support

An existing steel beam of a hall is strengthened because of new roof loads. The R18 deflection support is applied concentrically creating a higher lever arm and therefore a higher prestressing moment. When the available space permits the use, this method can be a good solution.

Application of R18 deflection support and corrosion protection

Fastening of end anchorage

Quality Control

At the production facility

Under the re-fer ISO quality assurance concept, recovery stress (prestressing force) is confirmed in the temperature chamber (1). In addition, a certified test institute measures the tensile strength of each batch to assume the quality of the final product.

1

2

On the load-bearing substrate

The quality of the bearing substrate is determined with a concrete test hammer (2). For strengthening with re-plate, a measured compressive strength >25 N/mm^2 is required. For lower concrete qualities the strengthening options, applications and anchorage details must be agreed with the re-fer engineer.

3

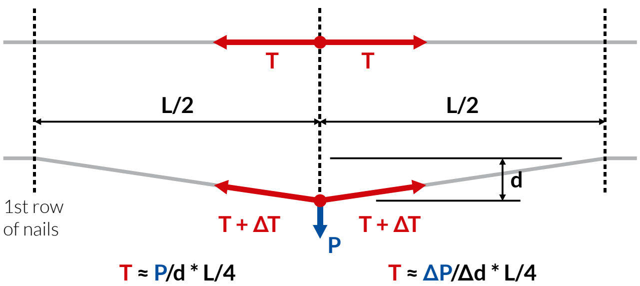
Temperature checks during activation

The temperature of the memory®-steel is measured during the heating process. This is done by using a separate hand-held measuring device.

4

Prestressing force check

A special test device (4) has been developed for measuring the prestressing force on the structure. The method is based on the «crossbow principle» for prestressing strands and enables the prestressing force of re-plate and re-bar to be checked quickly and simply immediately after the heat activation.



The measured vertical force **P** and the elongation value **d** are used to derive the resultant tensile forces in the tendon **T + ΔT** through trigonometric ratios.

Product overview

re-fer product list

memory®-steel products

re-plate 120/1.5	Strengthening strip for prestressing
re-bar 10	Prestressing ribbed bar, cross-section 89.9 mm^2
re-bar 16	Prestressing ribbed bar, cross-section 211.2 mm^2
re-bar R18	Prestressing round bar, cross-section 254.2 mm^2

Application equipment and components

re-bolt	Plastic dowel to fix re-bar in load-bearing concrete substrate
re-clip	Plastic clip to fix re-bar to internal reinforcement
re-IR 3000	Infrared heater
re-EL	Electric heater with control module for resistance heating
T-support	Manual deck strut with T-support for temporary re-plate fixing

re-plate end anchorage

Universal nail X-CR 48 P8 S15	Hilti universal nail for end anchorage
DX cartridge 6.8/11 M10 STD (Red)	Cartridges
DX 5 or DX 6	Hilti bolt firing device

Tested Sika products

In combination with re-plate

SikaCem® Pyrocoat	sprayed fire protection mortar
SikaCem® Pyrocoat Base	Sprayed basecoat for the Pyrocoat fire protection mortar
SikaCor® EG-1	Corrosion protection coating: epoxy-based intermediate coating containing MiO
Sikaflex® PRO-3	PU joint sealant for bilateral grouting of re-plate

In combination with re-bar

Sika® FastFix-121	Cement mortar for sealing surface cracks
SikaGrout®-314 N	Shrinkage-free, Class R4 precision grouting mortar for filling formwork holes or cut grooves
Sika® InjectoCem-190	Very fine cement-based crack injection mortar
Sika MonoTop®-412 N/DE, Eco, -4012	Shrinkage-compensated, Class R4 wet sprayed mortar
Sika MonoTop®-422 PCC	Shrinkage-compensated, Class R4 repair mortar
Sika MonoTop®-452 N	Shrinkage-compensated, Class R4 repair mortar for horizontal surfaces
Sika MonoTop®-910 N/ECO, -1010	Reinforcement corrosion protection and bond coat
Sika® Rock Gunit BE-8	Dry sprayed mortar (cementitious, alkali free)
Sika® AnchorFix®-3030	Epoxy adhesive supplied in «cartridge» for anchorage fixings

re-fer memory®-steel has been tested in systems with Sika sprayed concrete repair and grouting mortars, plus Sika fire and corrosion protection products. re-fer gives no guarantee if other mortars and products are used in combination with memory®-steel.

Index of symbols

Latin letters

A_f	cross-sectional area of re-plate or re-bar
A_s	total cross-sectional area of reinforcement
a_s	reinforcement area per metre
b	width of concrete cross-section
d	effective depth of reinforcement
d_f	effective depth of re-plate or re-bar
E_c	elastic modulus of concrete
E_{SMA}	simplified elastic modulus of memory-steel after activation
F_c	concrete compressive force
f_{cd}	design concrete strength
$F_{ms,u}$	memory-steel tensile force for cross-sectional analysis
$F_{p,i}$	memory-steel prestressing force directly after activation at t=0
$F_{p,\infty}$	memory-steel prestressing force after relaxation at t = ∞
F_s	tensile force in reinforcement cross-section
f	estimated maximum concrete slab/beam deflection according to [1]
h_c	thickness of concrete slab
I	moment of inertia
l	concrete slab/beam span
l_b	anchorage length
L	free length of re-plate between the anchorages
ΔL	length change of re-plate up to failure according to [1]
M_{Ed}	design bending moment
$M_{p,BZ}$	prestressing moment from memory-steel in construction state
$M_{p,GZ}$	prestressing moment from memory-steel after relaxation (for limit state calculation)
M_{Rd}	design value bending resistance
m_{Rd}	design value bending resistance of a concrete slab
P_0	prestressing force of a tendon at t=0
P_∞	prestressing force of a tendon at t = ∞
V_{Ed}	design value shear force
V_{Rd}	design value shear resistance
$V_{Rd,s}$	shear resistance of re-plate end anchorage with Hilti X-CR nails
w_{eff}	existing deflection
w_{zul}	allowed deflection
x	depth of compression zone
z	lever arm

Greek letters

ε_0	prestrain of a tendon
ε_c	concrete strain
ε_s	reinforcement steel strain
ε_f	memory-steel strain
$\Delta\varepsilon_f$	memory-steel strain increase due to length change
$\Delta\sigma_f$	stress increase in re-plate
$\Delta\sigma_{p,r}$	prestress loss after relaxation (after 50 years)
σ_c	concrete stress
$\sigma_{p,i}$	initial memory-steel prestressing directly after activation
$\sigma_{p,\infty}$	long-term re-plate prestressing after relaxation

Introduction

Designing with memory®-steel products follows the usual structural design rules for reinforced and pre-stressed concrete structures. The «re-plate» strengthening plate is considered an unbonded external strip with prestressing. A rigid bond between the installed ribbed steel and the surrounding mortar/sprayed concrete can be assumed for the «re-bar» system. Design proposals for the flexural strengthening of structures, in their serviceability and load capacity limit states, are explained below. For clarity of understanding, some examples are also then shown.

Theoretical design principles

re-plate

Construction state

At construction state, it is important to check for possible cracking on top of the slab due to prestressing. The initial memory-steel prestressing $\sigma_{p,i}$ is applied in this case. The prestressing can be set as a constant bending moment $M_{p,BZ}$ between the anchorages, to be compared with the cracking moment.

$$M_{p,BZ} = F_{p,i} * z = \sigma_{p,i} * A_f * z \qquad (1)$$

(A_f = re-plate area, z = lever arm)

Serviceability limit state

For the serviceability limit state over a long period, the initial prestressing $\sigma_{p,i}$ must be reduced due to relaxation. Over a period of 50 years this can be estimated at 15%. The following equation applies:

$$\sigma_{p,\infty} = \sigma_{p,i} * \left(1 - \frac{\Delta\sigma_{p,r}}{\sigma_{p,i}}\right) \approx \sigma_{p,i} * 0.85 \qquad (2)$$

The constant bending momen $M_{p,GZ}$ between the anchorages can therefore be described as:

$$M_{p,GZ} = F_{p,\infty} * z = \sigma_{p,\infty} * A_f * z \qquad (3)$$

Ultimate limit state

In the re-plate system, the forces are transmitted to the structure through the two end anchorages; in the free length there is no bond with the concrete substrate. This means that a conventional cross-sectional analysis with strain compatibility is not possible. Two alternatives are possible:

a) Calculation without stress increase in re-plate

This simplified calculation method assumes the tensile force $F_{ms,u}$ in the re-plate to be constant as the structural deformation increases. This assumption means that the force equilibrium in the cross-section is obtained by conventional cross-sectional analysis and the load capacity can be deduced. This calculation can be done manually, by data processing, e.g. Excel, or by computer software. This simplification is also used in standard design software with cross- sectional analyses.

$$F_{ms,u} = \sigma_{p,\infty} * A_f \qquad (4)$$

This conservative assumption underestimates the actual load. The concept is suitable for cases where the serviceability limit state is critical for the structural design.

b) Calculation with stress increase in re-plate

A second method is based on estimating the additional re-plate length change as the load increases band on the slab deflection. The basis is an empirical design approach obtained from loading tests on concrete beams with unbonded strand prestressing [1]. To summarise, based on the cross-section dimensions an additional maximum deflection f which causes a length change ΔL in the re-plate is estimated. The method assumes that all the deformation in a single-span beam is concentrated in a cracked cross-section in the centre of the beam. This length change can be converted to additional re-plate elongation $\Delta\varepsilon_f$ which then gives the stress state $\sigma_{p,\infty} + \Delta\sigma$ in the lamella cross-section from the known stress-strain curve after activation. To simplify this, a reduced elastic modulus E_{SMA} of 70 GPa can be applied here to calculate the definitive stress through the change in elongation.

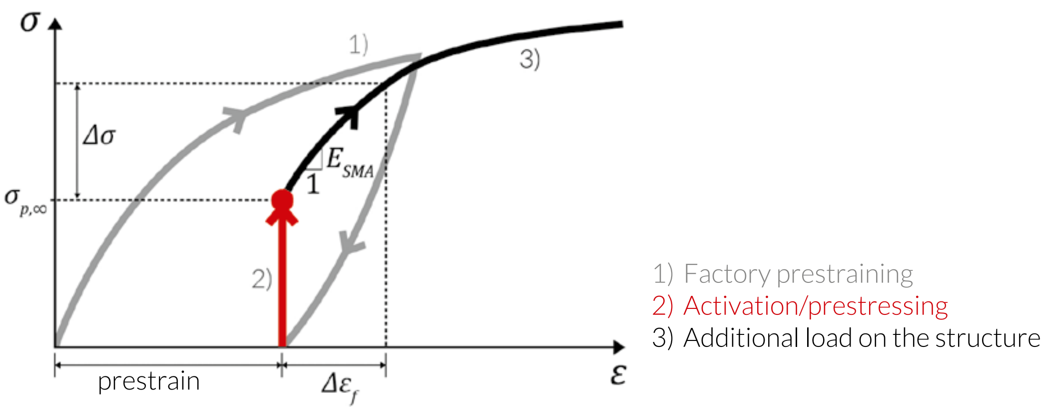


Figure 1: re-plate stress-strain diagram with pre-straining, activation, and subsequent loading

The following applies:

$$f = 0.9 * d - e_v < 0.02 * L \quad (5)$$

(d = effective depth, e_v = 0 in the case of straight lamellas, L = free length of re-plate between the anchorages)

$$\Delta L = \frac{4 * f * z}{L} \quad (6)$$

$$\Delta\varepsilon_f = \frac{\Delta L}{L} \quad (7)$$

Based on the known additional strain and therefore additional stress, the tensile force in the re-plate is also known and a force equilibrium in the cross-section can be calculated. Hence the maximum load capacity is determined. The specific national design principles for concrete structures (concrete compression and tensile failure of the reinforcement) apply, with adapted material parameters.

Anchorage

The additional tensile force in the re-plate at ultimate load must be compared with the anchoring resistance.

$$F_{ms,u} = \left(\sigma_{p,\infty} + \Delta\sigma_f\right) * A_f \leq V_{Rd,s} = \frac{108kN}{1.3} = \mathbf{83.1kN} \quad (8)$$

Note: The anchoring resistance at ultimate load is the controlling value for standard structure's geometries. An explicit verification can be neglected in most cases. The anchoring resistance of 108 kN count for 12 Hilti X-CR nails and is reduced by a safety factor of 1.3 (recommendation re-fer). The specification applies for concretes with a measured compressive strength (cube) of >20 N/mm^2. The re-fer engineering support can be contacted for cases with lower concrete qualities.

re-bar

Construction state

Usually, re-bar is anchored bilaterally in the anchorage regions at both ends through a Sika mortar layer on the bearing substrate and the intermediate regions are prestressed. The structural behavior is the same as for the re-plate, since the exposed area acts as an external tie rod. By analogy, equation (1) can be applied to re-bar with the corresponding cross-sectional area.

Serviceability limit state

After initial activation/prestressing of the re-bar, the regions between the anchorages are grouted, resulting in a firm bond with the load-carrying structure. Calculation can be done by conventional cross-sectional analysis with deduced strain compatibility and force equilibrium. The initial prestressing $\sigma_{p,i}$ must be reduced for the serviceability limit state, due to the relaxation under equation (2).

For calculations of deflection reduction due to prestressing, a homogeneous bending moment can again be assumed (see equation (3)), for example to solve the problem with the principle of virtual work.

Ultimate limit state

The same principles of cross-sectional analysis apply to calculating the structural safety. Depending on the situation, re-bar now has additional strain/stress added to the initial prestressing. The strain change in the re-bar consists of the additional strain between the application/prestressing date and the failure state ($\Delta\varepsilon_f$).

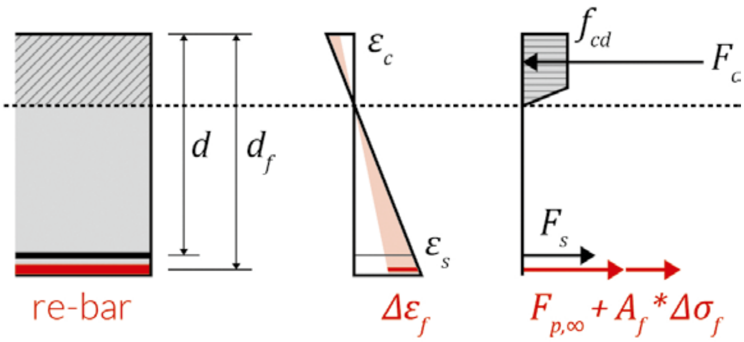


Figure 2: Schematic diagram for cross-sectional analysis of the ultimate limit state

The force equilibrium is then carried out with an equivalent force in the re-bar, which is made up as follows. For simplicity, a reduced elastic modulus E_{SMA} of 70 GPa can again be applied. The final force must be smaller as the maximum tensile force of re-bar.

$$F_{ms,u} = F_{p,\infty} + A_f * \Delta\sigma_f = A_f * \left(\sigma_{p,\infty} + \Delta\varepsilon_f * E_{SMA}\right) \quad (9)$$

Anchorage

The re-fer guidelines suggest values for the embedded anchorage length of re-bar. The anchorage regions depend on the anticipated tensile forces, bar diameters and application (in cut grooves, cover concrete or sprayed concrete). Standard requirements for the adhesive strength, roughness etc. must also be met. Class R3 and R4 mortars from Sika according to EN regulations for concrete repair are used for existing load bearing substrates. A pull-off strength of the concrete substrate of 1.5 N/mm² is recommended.

Flexural strengthening must be anchored behind or on the zero-moment position. Transfer of the prestressing force to the load-bearing concrete substrate is normally achieved purely through the mortar bond. Alternativ anchoring systems or special solutions are shown on page 27.

Notes

Specific product parameters should be taken from the current national product data sheets as required. Values used in design examples may vary from the current material parameters due to product and standard updates and should always be checked. The re-fer engineering support assists if anything is unclear and/or for specific design situations. For further information please visit our website: www.re-fer.eu (e.g. regarding our technologies, references, technical data sheets, tender specifications, test reports etc.). Alternatively, please contact our Technical Support team directly for specific advice and assistance.

Corrosion

Appropriate measures should be taken in locations with chloride exposure and contamination, despite the good corrosion resistance of memory®-steel (risk of stress crack corrosion). Mortar cover on the rebar should be re-assessed and increased if necessary. For re-plate products, a special coating is applied at the production facility (SikaCor® EG-1), which then limits the maximum heat temperature to 165°C and therefore this also limits the maximum prestressing force.

Fire protection

Fire protection is always required for strengthening measures if the load standard fire load cannot be met without strengthening. The table below is a simple comparative example of the residual safety margins for fire protection on a load-bearing structure with «low» and alternatively «high» strengthening levels.

Load examples [kN/m²]	**Before strengthening**	**After strengthening**	
		«Low» strengthening level **+3.0**	«High» strengthening level **+5.0**
Dead load/applied load	5.0	5.0	5.0
Live load	3.0	3.0 **+ 3.0** = 6.0	3.0 **+ 5.0** = 8.0
Service load	**8.0**	**11.0**	**13.0**
Example with global safety factor	8.0 * 1.5 = 12.0	11.0 * 1.5 = 16.5	13.0 * 1.5 = 19.5
Load capacity to be covered	**12.0**	16.5	19.5
Fire protection Criterion: new working load must be <12.0 (existing load capacity)	-	**11.0 < 12.0** Not required	**13.0 > 12.0** Required

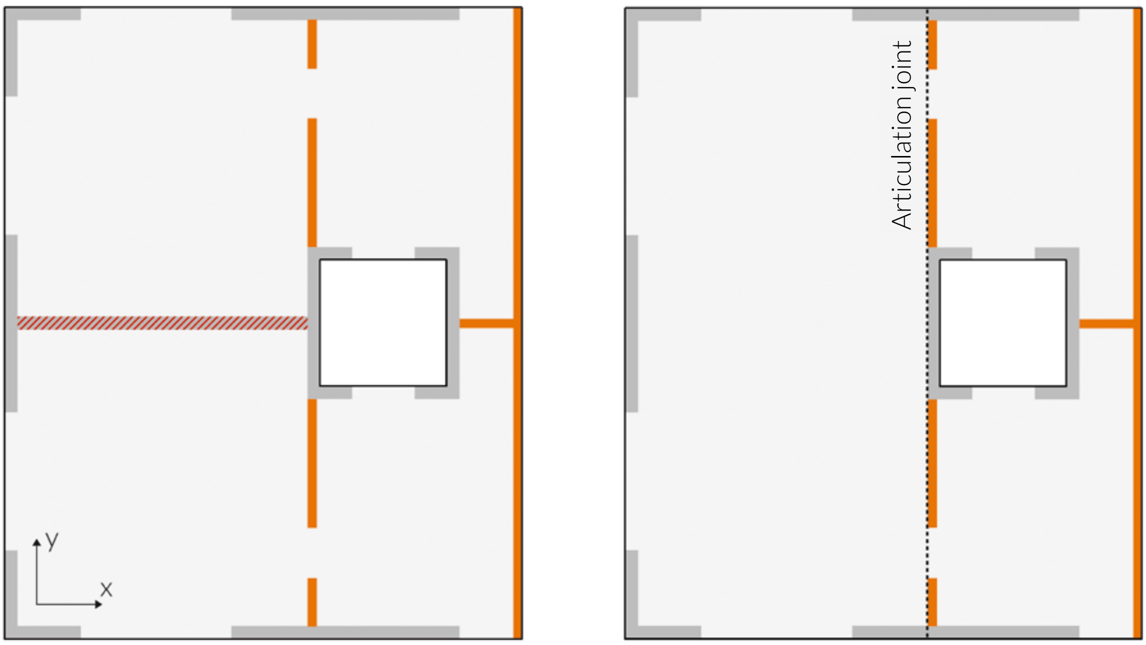
If a «high» strengthening load level has to be reached, the retrofitting measure must also carry load in a fire scenario; a fire protection is then necessary for the strengthening product. The same regulations and standards apply to re-bar in concrete or cementitious mortar as for conventional steel reinforcement. A sprayed, cement-based fire protection mortar is typically used for re-plate (SikaCem® Pyrocoat).

Design examples

Flexural strengthening with re-plate

At the client's request, the structural walls (marked red) are to be removed to merge two existing rooms into one large living room. This change in the static system of the load-bearing structure would inevitably cause bending moment problems in the deck slab. The example below shows the flexural strengthening measure of the concrete slab. Other verifications such as the load transfer to the walls and lower floors, shear forces, punching issues etc., are not considered. The structural condition is not investigated.

Figure 3: Model floor plan



a) Before

b) After removing the wall

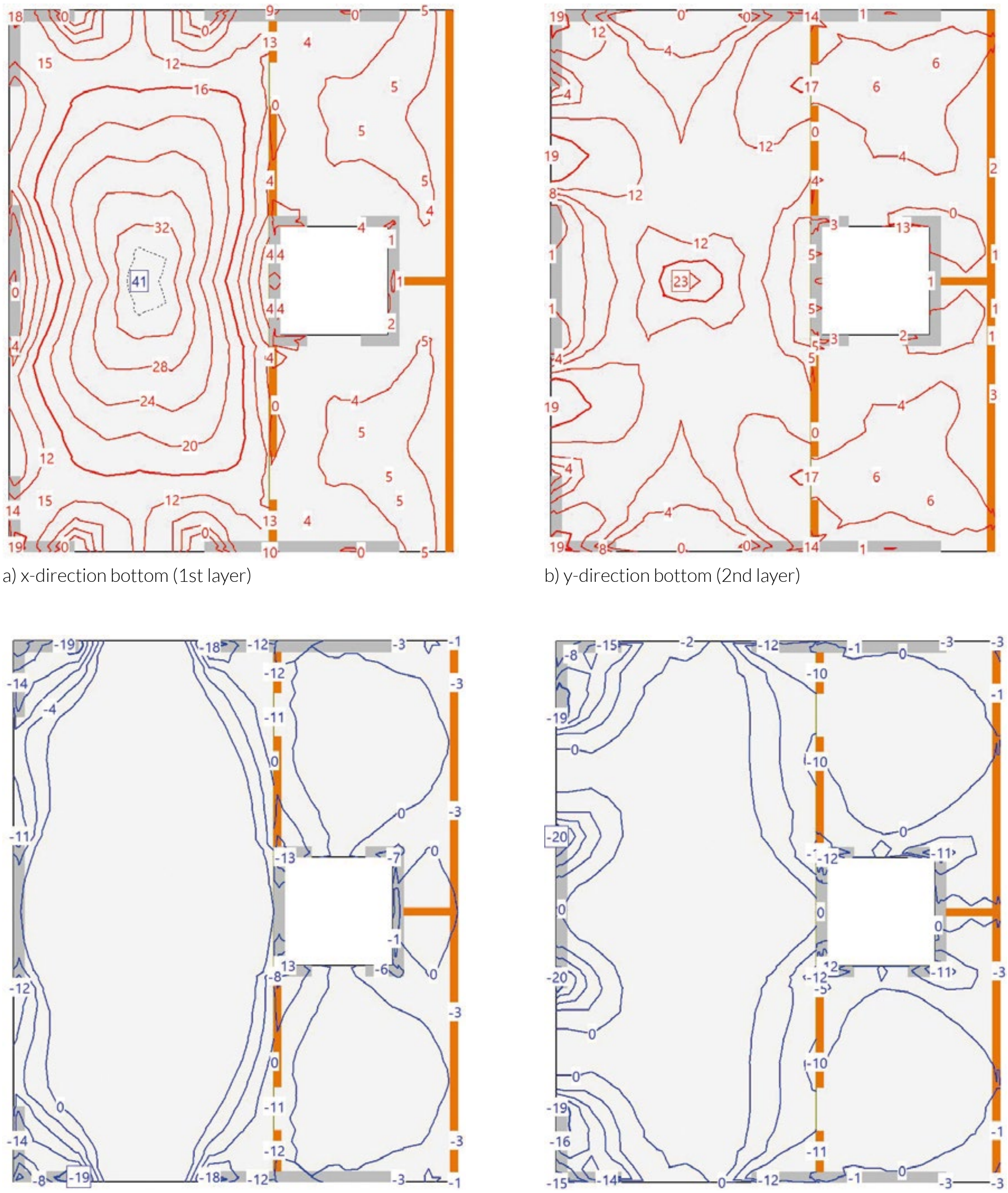
In the existing slab, reinforcement of Ø10@150 (a_s = 524 mm²/m') was used and located in all layers. Concrete slab thickness is h_c = 200 mm, concrete quality C30/37 and the reinforcement cover 30 mm. R60 fire resistance is required for the load-bearing elements.

With these design data, bending resistance of m_{Rd} = 36 kNm/m' is obtained for the existing 1st/4th layers (x-direction). In the 2nd/3rd layers the bending resistance is 32 kNm/m'. With the new floor plan, the existing reinforcement (4th layer) is going to yield under the new permanent load. Therefore, an articulation joint is modelled in these regions to transfer that moment to the span (see Figure 3 b)).

Verification at service load level

Under service loads, the new floor plan shows the following bending moments in x- and y-directions. At midspan in the main load-bearing direction, the bending resistance of the existing reinforcement is slightly exceeded. The strengthening system therefore must be fire protected. This is described in the Fire Protection section that follows.

Figure 4: Plots of bending moments under permanent service load



a) x-direction bottom (1st layer)

b) y-direction bottom (2nd layer)

c) x-direction top (4th layer)

d) y-direction top (3rd layer)

A further factor in serviceability is deflection. Here, the cracked concrete cross-section under service load in the example has an effective deflection of 16.6 mm. The standards give the admissible value:

$$w_{zul} \leq \frac{l}{300} = \frac{4'600mm}{300} = 15.3mm$$

Due to the prestressing, a constant moment can be applied at midspan across the approx. 3.0 m wide slab strip. Here, the established formula from the literature for a constant moment on a simple beam can be used. For more specialised cases (e.g. continuous beam), the design can be established by the principle of virtual work.

$$w = \frac{M * l^2}{8 * E_c I}$$

A simplified assumption is made that the whole concrete cross-section is cracked. This reduces the value $E_c I$ to $E_c I/3$. The actual equation then becomes:

$$w = w_{eff} - w_{zul} = 16.6mm - 15.3mm = 1.3mm \leq \frac{M_{p,GZ} * l^2}{8 * \left(\frac{E_c I}{3}\right)}$$

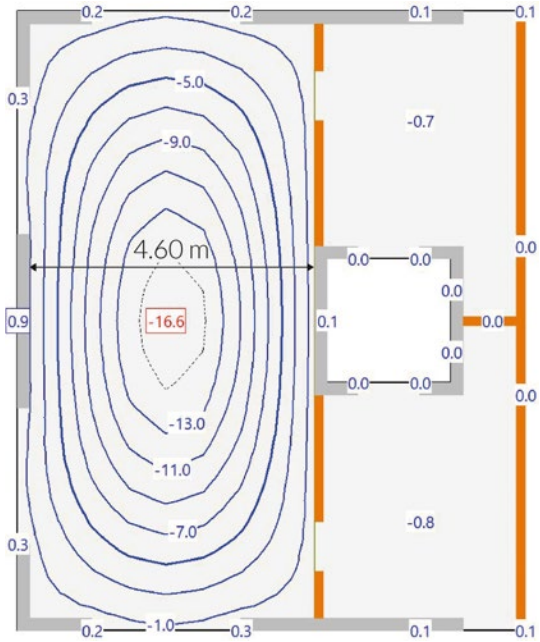


Figure 5: load deflection

That equation is solved according to $\boldsymbol{n}$ (the number of re-plate plates per metre):

$$w = \frac{M_{p,GZ} * l^2}{8 * \left(\frac{E_c I}{3} \right)} = \frac{\left(\sigma_{p,i} * 0.85 * A_f * z * \boldsymbol{n}\right) * l^2}{8 * \left(\frac{E_c * h_c^3 * b}{12 * 3} \right)}$$

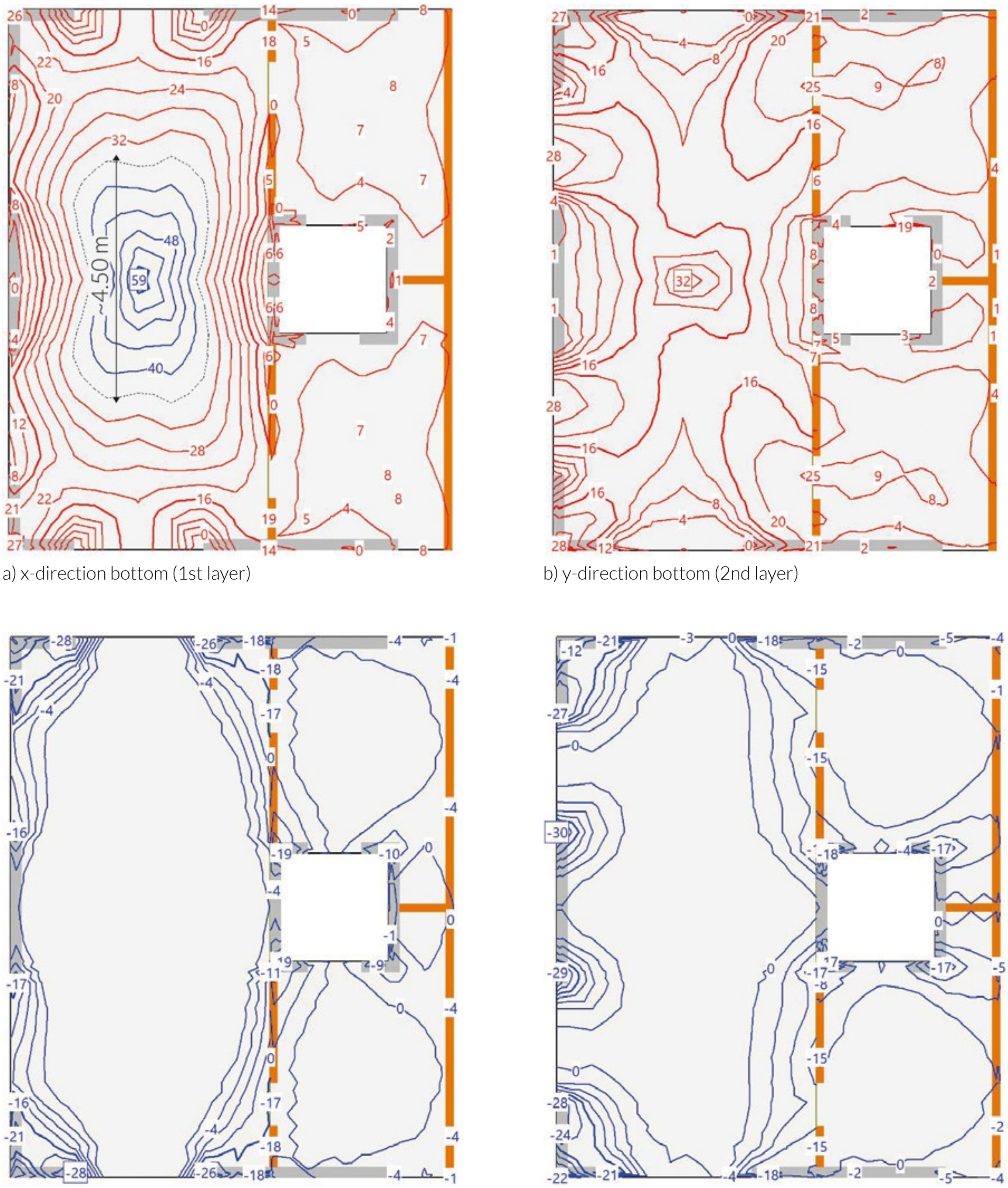
$$\rightarrow \boldsymbol{n} = \frac{w * 8 * E_c * h_c^3 * b}{12 * 3 * \sigma_{p,i} * 0.85 * A_l * z * l^2} = \frac{1.3mm * 8 * 33.6GPa * (200mm)^3 * 1.0m}{12 * 3 * 380 \frac{N}{mm^2} * 0.85 * 120mm * 1.5mm * \frac{200mm}{2} * (4.6m)^2} = \mathbf{0.63}$$

At least 0.63 re-plates per metre over the width are required at the midspan. Unless the structural safety check indicates a larger figure, the strengthening plates therefore are applied every approx. 1.6 m.

Verification of structural safety at ultimate limit state

The structural safety verification is carried out using the calculation with stress increase in the re-plate. The bending moments to be covered are shown as follows:

Figure 6: Plots of bending moments at structural safety ultimate limit state



a) x-direction bottom (1st layer)

b) y-direction bottom (2nd layer)

c) x-direction top (4th layer)

d) dy-direction top (3rd layer)

To do this, firstly the elongation growth in the re-plate is calculated. The value for L (free length of re-plate between the anchorages) is obtained from the bilateral reduction in anchorage length (400 mm) and a safety margin (100 mm):

$$L = 4.6m - 2*\left(400mm + 100mm\right) = 3.6m$$

$$f = 0.9*d - e_v = 0.9*\left(0.9*200mm\right) - 0 = 162mm < 0.02*L = \mathbf{72mm}$$

$$\Delta\varepsilon_f = \frac{\Delta L}{L} = \frac{4 * f * z}{L^2} = \frac{4 * 72mm * (0.9 * 200mm)}{(3.6m)^2} = \mathbf{0.4\%}$$

The bending moment for strengthening is therefore derived with the final force $F_{ms,u}$ in $\boldsymbol{n}$ re-plates through an internal lever arm z of about 0.9 * h_c:

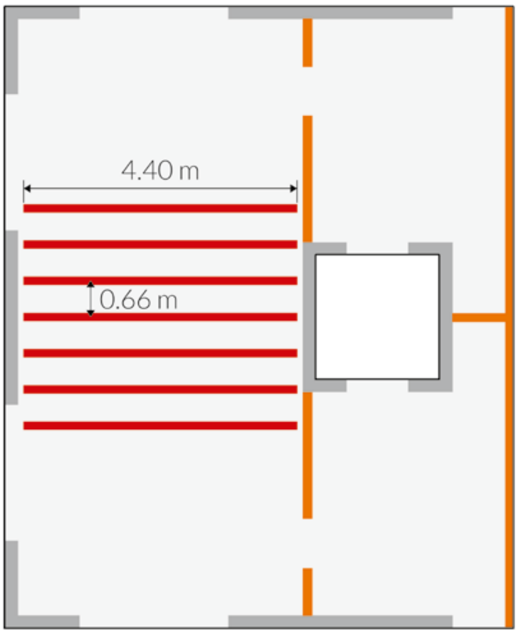
$$F_{ms,u} = (\sigma_{p,\infty} + \Delta\sigma) * A_f = (\sigma_{p,i} * 0.85 + \Delta\varepsilon_f * E_{SMA}) * A_f =$$

$$\left(380\frac{N}{mm^2} * 0.85 + 0.004 * 70GPa\right) * 120mm * 1.5 = 108.5kN < \mathbf{83.1kN}$$

$$M_{p,GZ} = \boldsymbol{n} * F_{ms,u} * z = \boldsymbol{n} * 83.1kN * 0.9 * 200mm \geq 58.6kNm - 36.0kNm = 22.6kNm$$

$$\rightarrow \boldsymbol{n} = \frac{M_{p,GZ}}{F_{ms,u} * z} = \frac{22.6kNm}{83.1kN * 0.9 * 200mm} = \mathbf{1.5}$$

Hence, to cover the structural safety requirements in the overstressed regions (around 4.5 m), 1.5 re-plates are necessary per metre over the width– i.e. one plate every 0.66 m (a total of 7).



7 x re-plate
l=4.40 m, every 0.66 m
with fire protection

Figure 7: Position of re-plate strengthening

Fire protection

For fire, the quasi-permanent loads must be covered. As the flexural load capacity in the existing structure is insufficient, the strengthening measures are protected for R60. The sprayed, cement-based fire protection mortar SikaCem® Pyrocoat is used with a layer-thickness according to the current table in the re-plate data sheet.

Strengthening of a T-beam with re-bar

Due to a change of use and additional loads, various T-beams in a factory building need structural strengthening. This calculation example illustrates the method for excessive deflection in the main span and strengthening for flexural and shear problems in an individual beam of this kind. Additional verifications are omitted in this example. The beams covered two spans of 12.00 and 8.00 m and were simply supported.

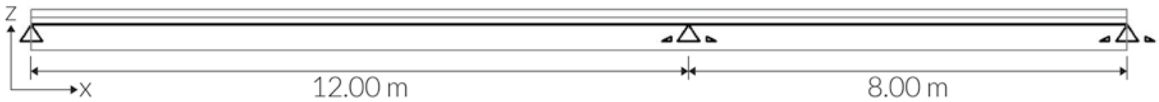
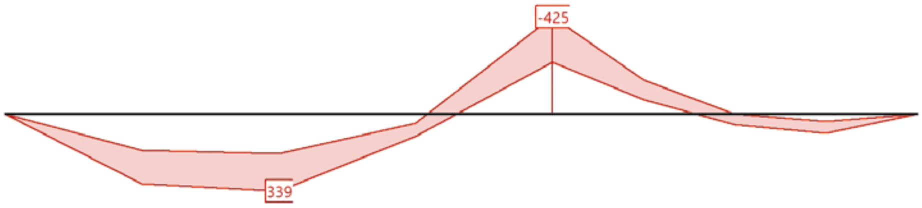


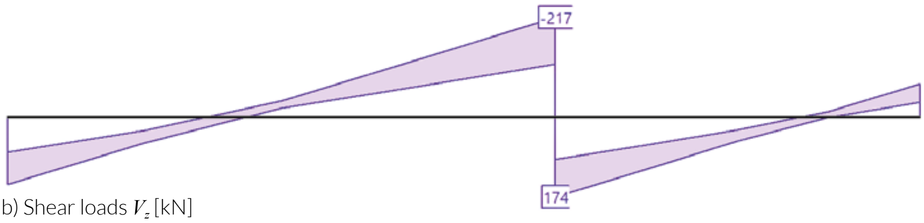
Figure 8: Two span beam in the factory building

The previous static forces (bending moments and shear forces) are shown below; there are no additional normal or torsion forces.

Figure 9: Internal forces at structural safety ultimate limit st



a) Bending moment M_y [kNm]



b) Shear loads V_z [kN]

In line with the original loadings, the beams were designed and reinforced as shown in Figure 10. The resultant deflection in the cracked concrete cross-section met the required standard specifications (w_{eff} = 32 mm/w_{zul} = 34 mm).

Due to the client's new requirements, live loads are increased. A higher dead load also must be supported due to the additional mortar layer to be added. The resulting static forces for the structural safety ultimate limit state are as follows:

	Previous internal forces		Previous resistance		New internal forces	
Bending moment [kNm]	M_{Ed}	+339 -425	M_{Rd}	+355 -440	M_{Ed}	+449 -550
Shear force [kN]	V_{Ed}	217	V_{Rd}	230	V_{Ed}	285

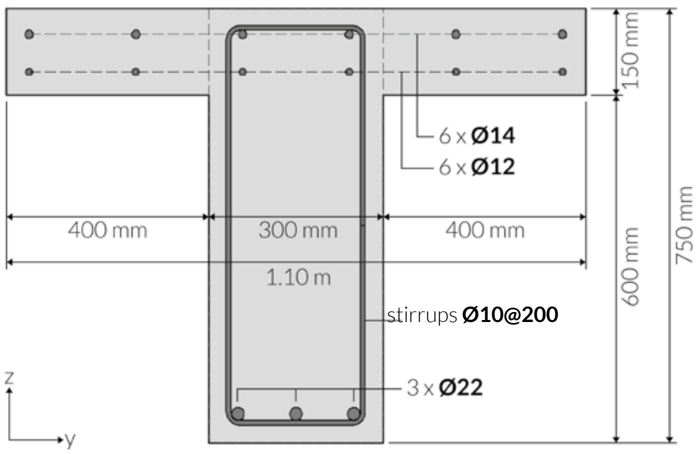
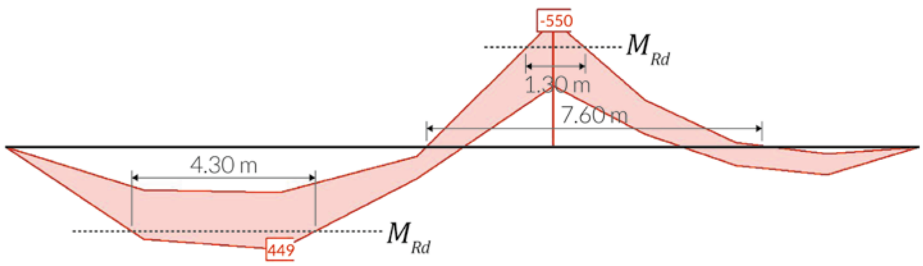


Figure 10: Existing cross-section of T-beams

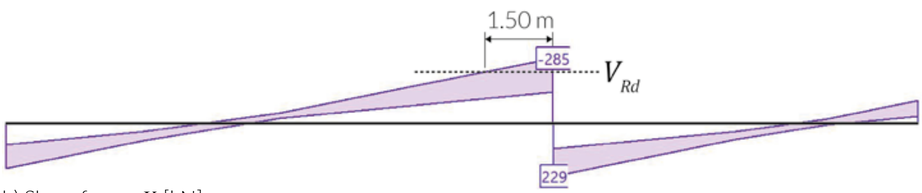
Verification of structural safety at ultimate limit state

Firstly, the structural safety ultimate limit state is investigated. The new internal forces are also shown in detail below.

Figure 11: New internal forces at structural safety limit state



a) Bending moment M_y [kNm]



b) Shear forces V_z [kN]

Due to the additional loads, a shear problem occurs in a region about 1.5 m wide adjacent to the central point of support. The missing transverse shear strength of ca. 55 kN/m' is accommodated using re-bar 10 U-profiles. For simplicity, only the prestressing force (no strain increase up to shear failure) on the double shear stirrups is assumed.

$$V_{Rd,s} = \frac{2 * \sigma_{p,\infty} * A_f}{s} * z * \cot(45°) = \frac{2 * 350 \frac{N}{mm^2} * 0.85 * 89.9 mm^2}{0.5\ m} * \sim 0.7 m * \cot(45°) = 75 kN/m'$$

Accordingly, a total of three re-bar 10 U-profiles at a 0.5 m interval are necessary to strengthen the region. The stirrups are guided around the existing, roughened concrete surface and over the additional longitudinal re-bar. They are then embedded in sprayed mortar/grouted in the flange (anchorage over the neutral axis). The re-bar shear stirrups are electrically heated/activated from above. Spacers are installed to ensure that there is no contact with the existing reinforcement (electric tension loss during heating process).

In the larger sub-span, the new bending effect exceeds the previous resistance by some 94 kNm. Over the whole span, three re-bar 16 are installed on the bottom side of the web and embedded in sprayed mortar. Across the central support, the negative bending moment exceeds the permitted load over a length of ca. 1.3 by approx. 110 kNm. In that zone, four re-bars 10 are placed in fresh concrete cover (Note: anchorage of strengthening behind the zero-moment line). The strengthening bars are grouted in the anchorage region and heated after hardening, e.g. with a gas burner. Finally, the remaining zones are also embedded.

Flexural verification of the new cross-section can be done with standard design software. The new resistance levels are listed in the table below.

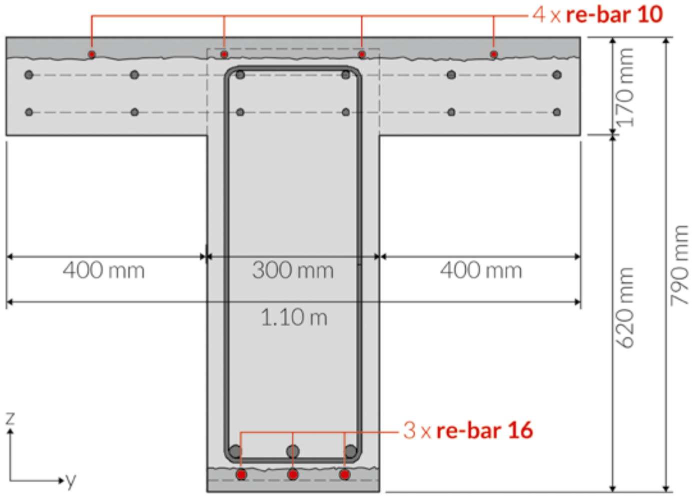


Figure 12: New cross-section of T-beams with re-bar flexural strengthening

	Previous internal forces		Previous resistance		New internal forces		New resistance	
Bending moment [kNm]	M_{Ed}	+339 -425	M_{Rd}	+355 -440	M_{Ed}	+449 -550	M_{Rd}	+569 -553
Shear force [kN]	V_{Ed}	217	V_{Rd}	230	V_{Ed}	285	V_{Rd}	315

The following input parameters are used, amongst others, for the modelling:

Tendon attributes:

– Prestraining ε_0 = 0.57 % for re-bar 10 and 0.46 % for re-bar 16 (which gives theoretical prestressing respectively of *E-Modul* * ε_0 = 400 N/mm², and 320 N/mm²)
– Prestressing with bond
– Loss factor P_∞/P_0 = 0.85 (relaxation)

Material properties::

– *E-Modul* = 70 kN/mm² (re-bar elastic modulus after activation)
– $f_{p0.1k}$ = 520 N/mm² (Design value reduced by safety factor)
– ε_{ud} = 30%

Verification at service load level

By installing prestressed strengthening elements embedded in mortar, crack openings are limited at the surface, and load is removed from the existing reinforcement. In addition to the improved durability, this example also investigates the deflection. Due to the new loads, the vertical deflection in the large span is calculated about 39 mm. Flexural strengthening with three re-bar 16 implies a constant bending moment, which counteracts the deflection. The resulting 5 mm (w_{eff} = 39 mm/w_{zul} = 34 mm) should be eliminated with this measure.

The deformation of the statically indeterminate system implied by the prestressing can be calculated in various ways. Here, the principle of virtual work for the statically indeterminate system is used. As a basic system (BS), an articulated joint is introduced at the central support. For simplicity, the prestressing in the negative bending region is not included, though it would also have a positive effect.

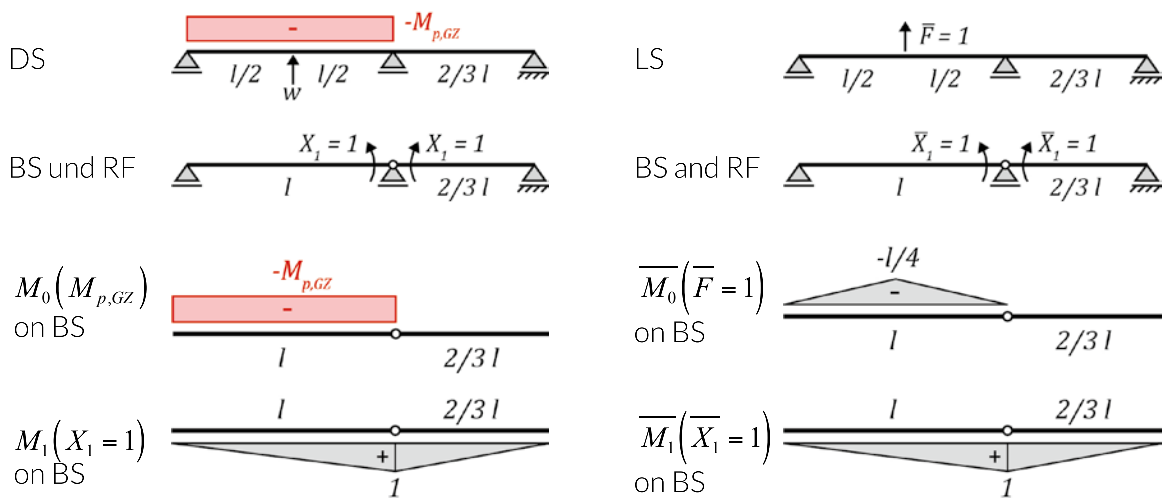


Figure 13: Simplification and reduction of the statically indeterminate system and principle of virtual work

$$\delta_{10} = \int M_1 * \frac{M_0}{E_c I} dx = \frac{1}{2} * (+1) * (-M_{p,GZ}) * \frac{l}{E_c I} + 0 = -\frac{M_{p,GZ} * l}{2 * E_c I}$$

$$\delta_{11} = \int M_1 * \frac{M_1}{E_c I} dx = \frac{1}{3} * (+1)^2 * \frac{\left(1 + \frac{2}{3}\right) l}{E_c I} = \frac{5 * l}{9 * E_c I}$$

$$\delta_{10} + X_1 * \delta_{11} = 0 \rightarrow X_1 = -\frac{\delta_{10}}{\delta_{11}} = \mathbf{\frac{9}{10} M_{p,GZ}}$$

The deformation w can be deduced from this as follows:

$$w = \int \overline{M_0} * \frac{M_0}{E_c I} dx + X_1 * \int \overline{M_0} * \frac{M_1}{E_c I} dx = \frac{1}{2} * \left(-\frac{l}{4}\right) * (-M_{p,GZ}) * \frac{l}{E_c I} + \left(\frac{9}{10} M_{p,GZ}\right) * \frac{1}{4} * \left(-\frac{l}{4}\right) * (+1) * \frac{l}{E_c I} =$$

$$\frac{M_{p,GZ} * l^2}{E_c I} * \left(\frac{1}{8} - \frac{9}{160}\right) = \mathbf{\frac{11 * M_{p,GZ} * l^2}{160 * E_c I}}$$

Equation (3) gives the constant bending moment $M_{p,GZ}$ across the 12.00 m span:

$$M_{p,GZ} = F_{p,\infty} * z = \sigma_{p,\infty} * A_f * z = 3*320\frac{N}{mm^2}*0.85*211.2mm^2*\sim 0.66m = 114kNm$$

In addition, a reduced, cracked bending stiffness of the concrete cross-section is estimated ($E_c I_{gerissen} = E_c I/3$) and included in the equation.

$$w = \frac{\mathbf{11 * M_{p,GZ} * l^2}}{\mathbf{160 * \left(E_c I / 3\right)}} = \frac{11*114kNm*(12.00m)^2}{160*\frac{647'000kNm^2}{3}} = 5.2mm$$

The three re-bars installed to increase the structural safety consequently contribute to a reduction in the deflection of around 5 mm. The verification is achieved.

Verification of anchorage regions

The negative and positive bending resistances were determined by a cross-sectional analysis software. The maximum tensile force in the re-bar and a tensile adhesion strength of the concrete of 1.5 N/mm² is used to design the anchoring zone. The resistance is reduced by a safety factor of 1.5. Four re-bar 10 are applied for the negative bending. Out of this, the following calculation for the necessary bond length l_b results:

$$F_{p,i}(negative) = 4*\sigma_{p,i} * A_f = 4*520\frac{N}{mm^2}*89.9mm^2 = 187kN$$

$$F_{p,i} \leq \frac{l_b*1.10m*1.5\frac{N}{mm^2}}{1.5} \rightarrow l_b = \mathbf{170mm}$$

The strengthening measure is embedded entirely in mortar. The anchorage region is assumed to be 300 mm of length.

In the case of strengthening against positive bending, three re-bar 16 are mounted on the bottom side of the web (width 300 mm). Again, the total maximum tensile force of the re-bars is anchored.

$$F_{p,i}(positive) = 3*\sigma_{p,i} * A_f = 3*520\frac{N}{mm^2}*211.2mm^2 = 329.5kN$$

$$F_{p,i} \leq \frac{l_b*300mm*1.5\frac{N}{mm^2}}{1.5} \rightarrow l_b = \mathbf{1'098mm}$$

This value can be optimized by using special solutions. As an example, the effect of the vertical prestressing by three re-bar U-profiles is presented. The tensile adhesion strength (1.5 N/mm²) increases due to the vertical force of the prestressed U-profile in double shear (relaxation prestressing force 0.85/safety factor 1.5).

$$F_{p,i} = 329.5kN \leq \frac{l_b * b * \left(1.5\frac{N}{mm^2} + \frac{3*2*\sigma_{p,\infty} * A_f}{l_b * b}\right)}{1.5} =$$

$$\frac{l_b * 300mm * \left(1.5\frac{N}{mm^2} + \frac{3*2*0.85*350N/mm^2 * 89.9mm^2}{l_b * 300mm}\right)}{1.5} \rightarrow l_b = \mathbf{742mm}$$

Analogue to the intermediate support B, a shear strengthening with re-bar 10 U-profile is applied for support A, too. The anchorage zone is embedded in mortar over a length of 750 mm.

Schematic drawing

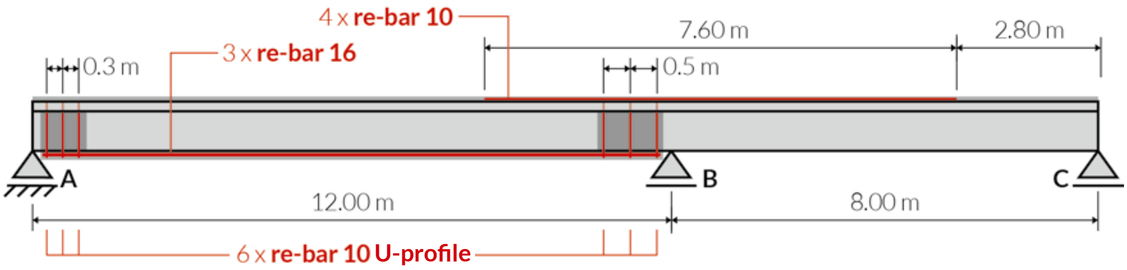


Figure 14: Sketch of strengthening works with re-bar longitudinal reinforcement and re-bar shear stirrups

The end regions of the re-bar flexural strengthening could also be made by conventional, slack-applied stirrups (steel B500B).

Current calculation examples and a simple design tool can be found online.

Referenzen

[1] Bruggeling, A.S.G., Voorspanning zonder aanhechting, enkelstrengsystemen. 1976, TU Delft: Delft, The Netherlands

Our global research

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Downloads & patents

The most current versions of the respective documents are always available on the re-fer website (www.re-fer.eu). Specification details for tendering, product data sheets and many other useful and helpful documents can be found under Downloads.

Specification Details for Tendering

1. a) re-plate 120/1.5 steel strip flexural and tensile strengthening mechanically anchored on concrete (for serviceability, fire and ultimate load)
   b) Sika® CarboDur® CFRP laminates flexural strengthening (for ultimate load)
2. Flexural and tensile strengthening with re-bar 10/16 in repair, sprayed or grouting mortar
3. Flexural and tensile strengthening with re-bar 10/16 in cut grooves
4. Shear strengthening with re-bar 10 U-profiles/end anchorage for re-bar
5. Flexural and tensile strengthening in sprayed mortar/shotcrete for tunnel constructions
6. Flexural strengthening in new buildings (internal downstand beam)
7. re-bar R18 round bars flexural and tensile strengthening on steel constructions

Product data sheets

- re-plate «external tensile strip»
- re-bar «internal prestressing»
- re-bar R18 «external tensile bar»

Direct download at
www.re-fer.eu/en/downloads/

Patents

The memory®-steel prestressing technique is patent protected by re-fer.

memory®-steel training for designers and engineers

Our re-fer engineers provide memory®-steel training (online and in-person where appropriate) on several key aspects:

Structural design
Tendering Work
Execution

Online webinar/video training typically lasts 30 – 45 minutes per topic, plus discussion as required, generally this can be done whenever convenient. In the first instance, to arrange training on any aspect, please contact us by e-mail, or use the contact form on our website. Training and support is available in German, French and English.

We are always pleased to provide support for your specific project requirements and questions via phone or video conference. We look forward to hearing from you.

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strengthening solutions

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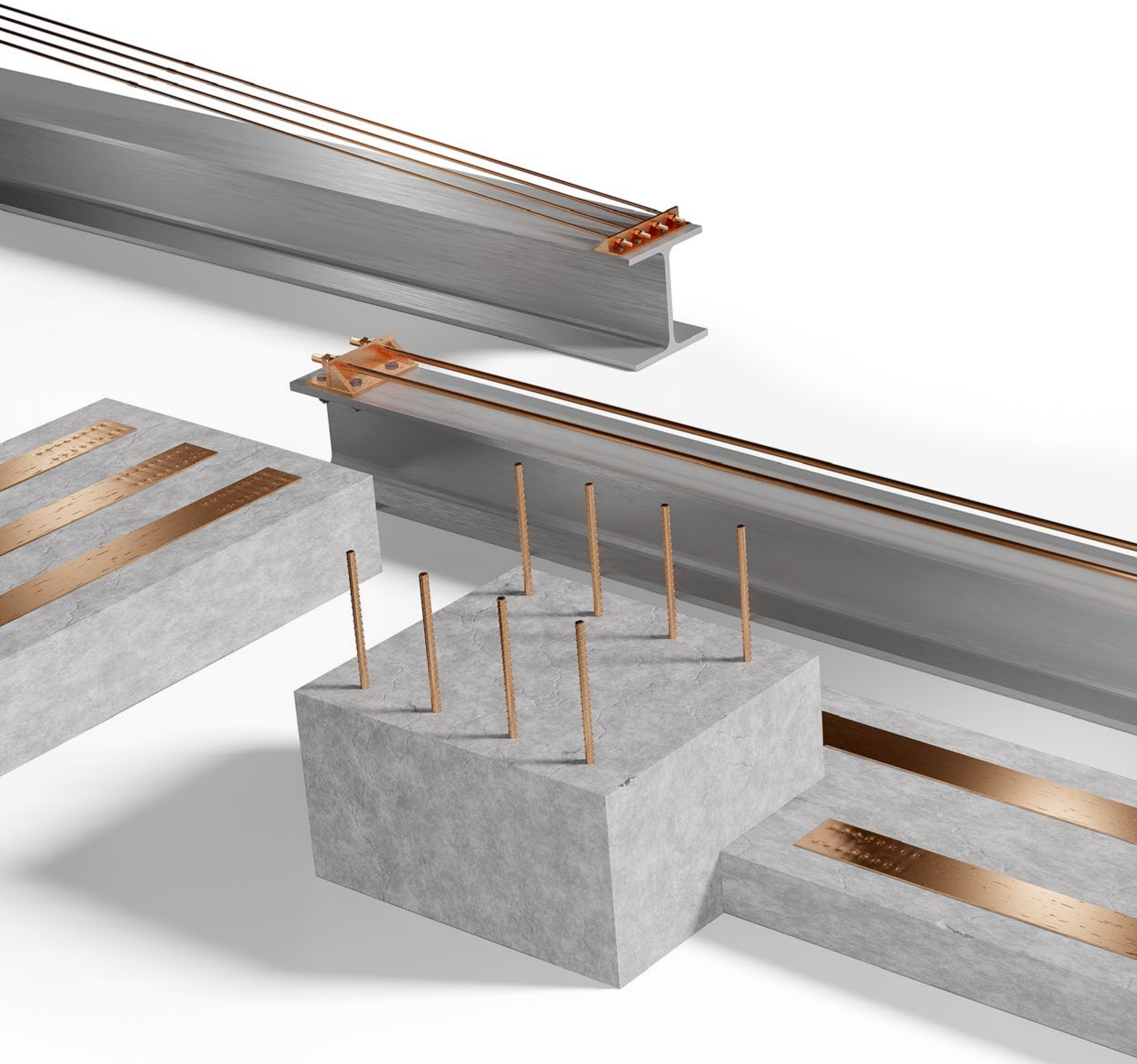

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