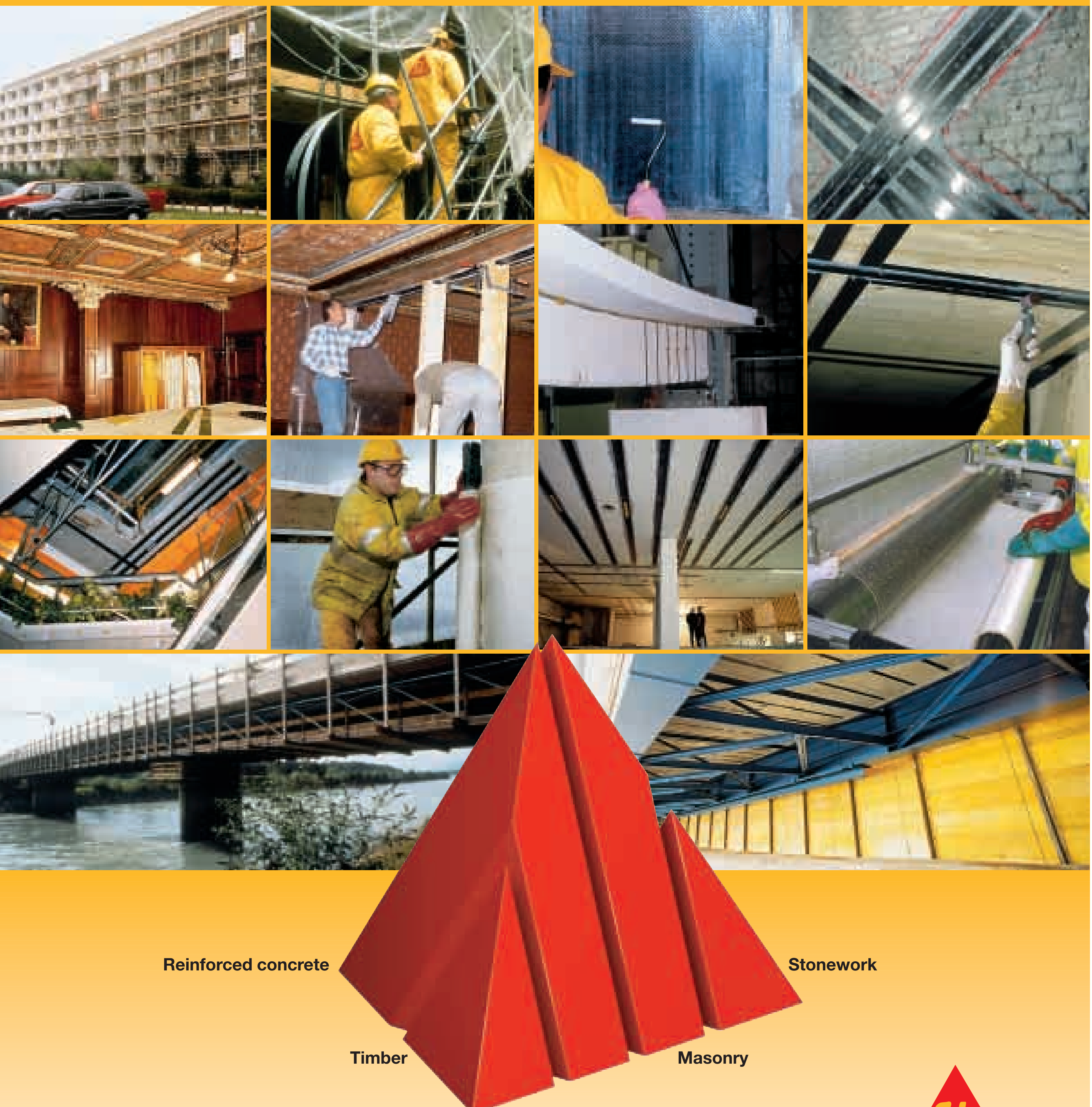
Technology and Concepts for Sika® CarboDur® Structural Strengthening Systems



Structural Strengthening with Sika® CarboDur® Composites

Strengthening System Requirements

Structural Requirements

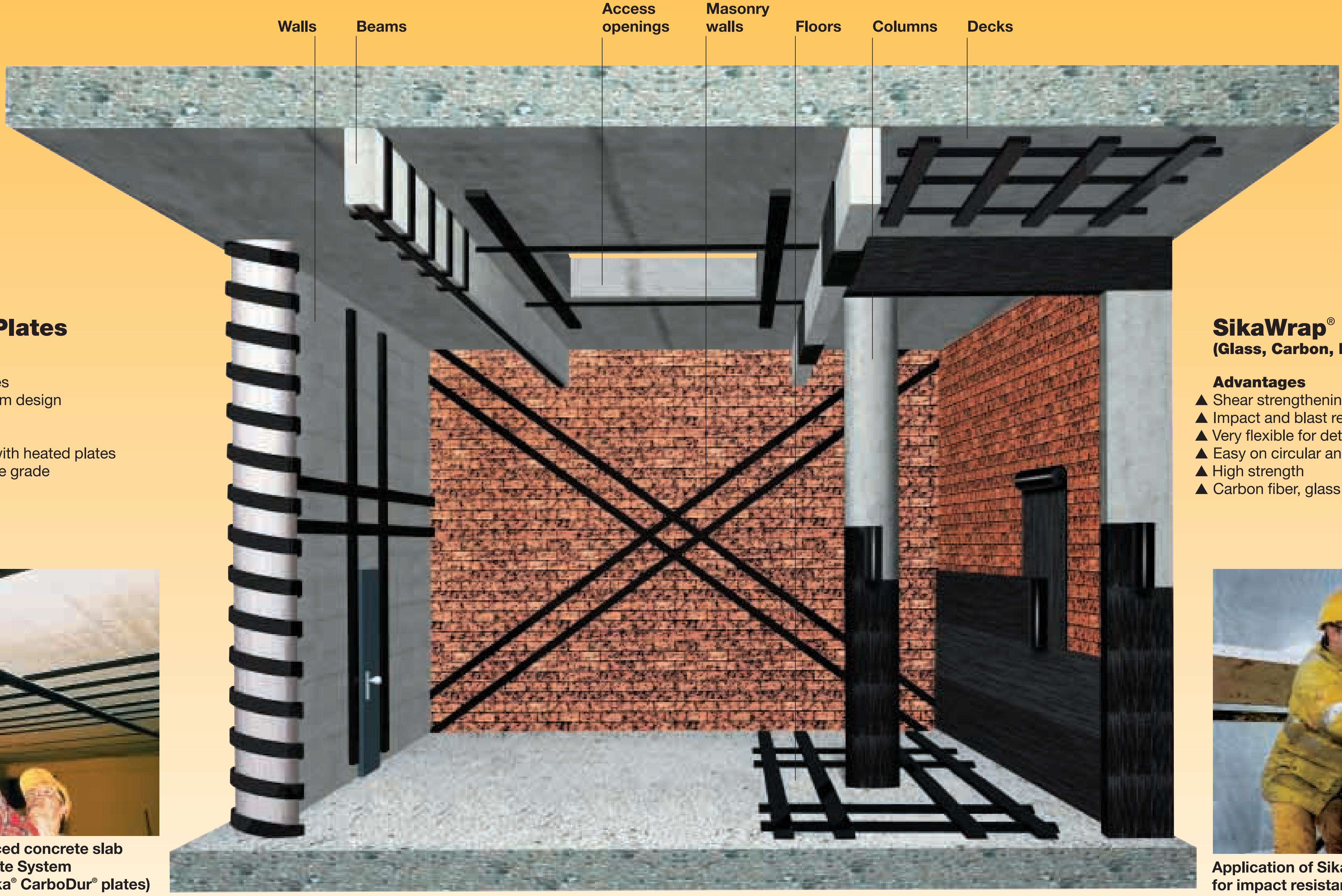
▲ Static loading
▲ Dynamic loading
▲ Crack bridging
▲ Creep
▲ Durability

When the working load is applied, the plates absorb the tensile forces proportionally with the steel reinforcement. An unused load-bearing reserve must be available in the concrete compression zone of the existing structure. The adhesive layer must be capable of levelling out any stress peaks. The better the levelling, the greater is the proportion of load-transmitting adhesive surface.

Requirements under Environmental Influences

▲ Temperature
▲ Moisture
▲ Frost
▲ Freeze/thaw
▲ Corrosion
▲ Ultra violet radiation

Corrosion resistance is an important factor in long life. The Sika CarboDur plates have high chemical resistance to the pollutants normally occurring on structures. In particular, there is no risk of underrusting.



Sika® CarboDur® Plates

Advantages

▲ Defined performance properties
▲ Range of dimensions – optimum design
▲ Choice of modulus
▲ Factory prepared for use
▲ Low temperature application with heated plates
▲ Elevated temperature in service grade
▲ Can be prestressed
▲ Very high strength

Strengthening of the reinforced concrete slab with the Sika® CarboDur® Plate System (Sikadur-30 adhesive and Sika® CarboDur® plates)

SikaWrap® Fabrics

(Glass, Carbon, Hybrid) Wet/Dry Application

Advantages

▲ Shear strengthening
▲ Impact and blast resistance
▲ Very flexible for details
▲ Easy on circular and square sections
▲ High strength
▲ Carbon fiber, glass and hybrid fabrics available

Application of SikaWrap® Fabric System for impact resistance on a bridge column

**Sika® CarboDur® Composite Strengthening Systems.
A Global Alliance between Sika® and Hexcel®.**

Sika® CarboDur® – the only Long-term Tested Strengthening System

Sikadur® – the Long-term Tested, Durable, Epoxy-based Adhesive

Sikadur is a high-quality epoxy adhesive with outstanding physical and chemical properties. Its high mechanical strength and glass transition point prevent creep and guarantee a durable bond between the jointing parts.

In use as a bridge adhesive since 1960.
Tested to FIP standards:

- ▲ Compressive and tensile strength
- ▲ E-modulus
- ▲ Shear strength
- ▲ Pot life
- ▲ Open time
- ▲ Sag flow
- ▲ Groutability
- ▲ Wet adhesion
- ▲ Glass transition point

Certified Quality System ISO 9001/EN 29001 since 1986


Strengthening with steel plates

With predefined detachment at peak cracking stress.

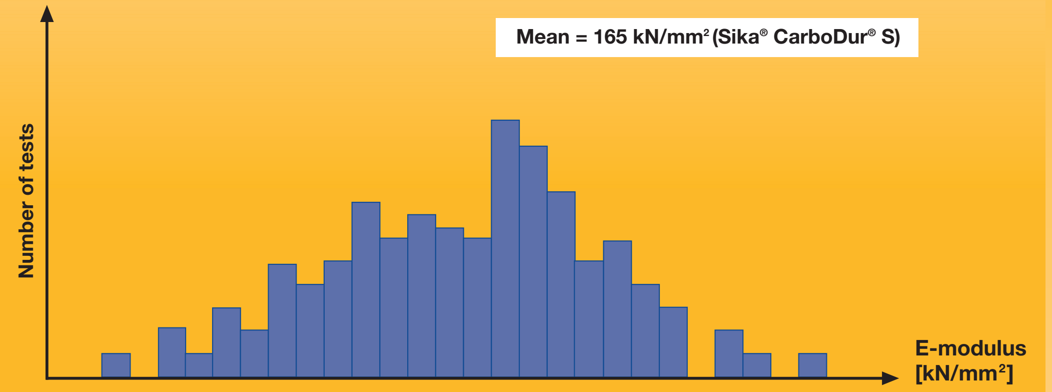
Approval

General construction approval in Germany for steel plate strengthening with Sikadur-30 and Icosit 277	German Institute of Construction 7 - 36.1 - 30	07. 04. 95

Defined Adhesive Performance

Sika® CarboDur® Plate – the Long-term Tested, Durable CRP Plate

Long experience in the production of Sika CarboDur plates using high-quality carbon fibers. Continuous checks during and after production of the plates.



Quality Checks

- ▲ Tensile strength
- ▲ E-modulus
- ▲ Glass transition point
- ▲ Geometry

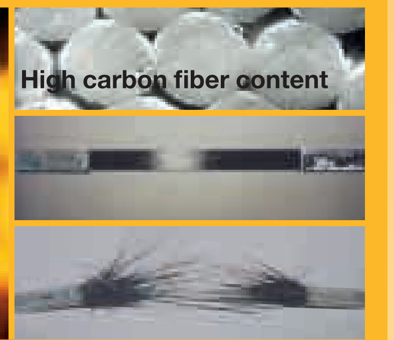
Certified Quality System ISO 9001/EN 29001 since 1986

Approval

General construction approval in Germany for Sika CarboDur	German Institute of Construction 7 - 36.12 - 29	11. 11. 97

Defined Plate Performance


Measuring tensile properties


High carbon fiber content

Sika® CarboDur® – the Long-term Tested Strengthening System

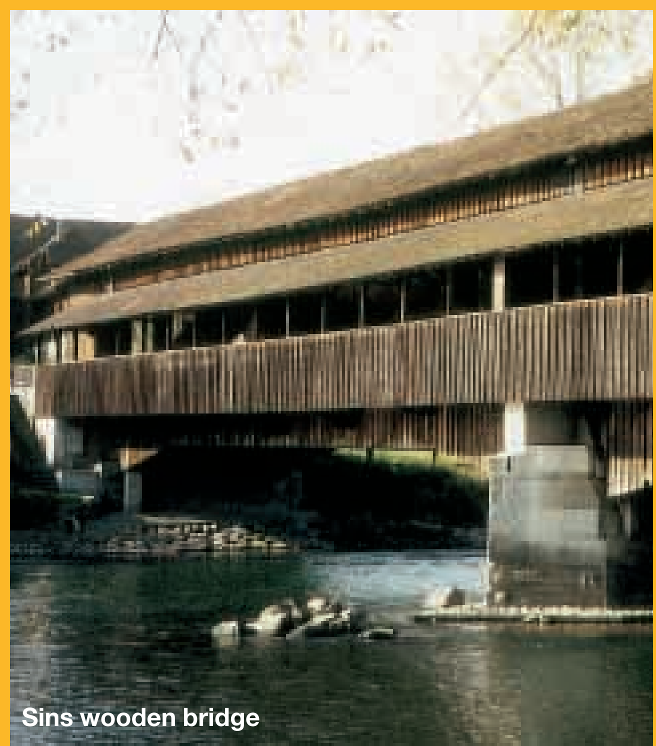
1987 – first trials at EMPA.

Test certificates

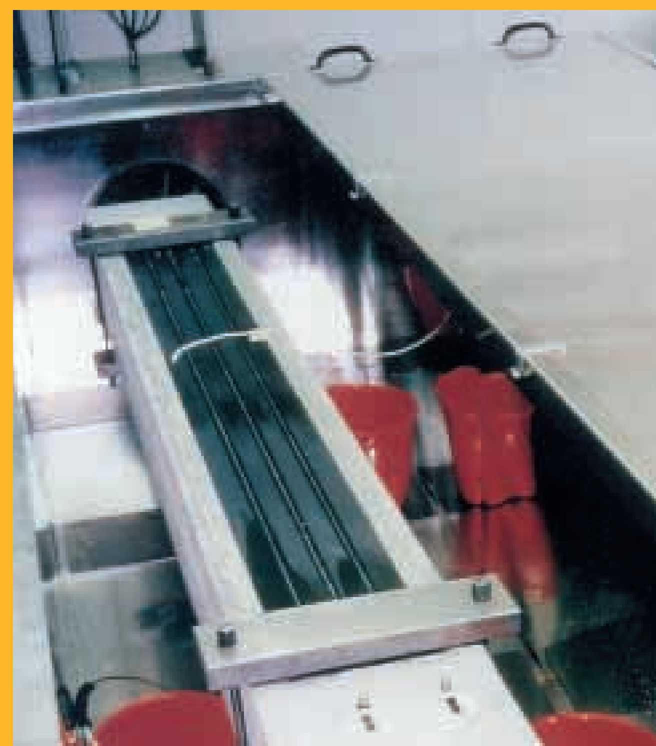
Strengthening of reinforced concrete with carbon fiber reinforced epoxy resins	Thesis ETH Zurich No. 8918	1989
Static and dynamic tests on RC T-beams strengthened with Sika CarboDur	Thesis ETH Zurich No. 10199 (EMPA Report No. 224)	1993

Defined System Performance During Application and in Service

1991 – first uses by EMPA on a reinforced concrete and wooden bridge.


Sins wooden bridge

1991 – start of long-term system testing under extreme climatic conditions.



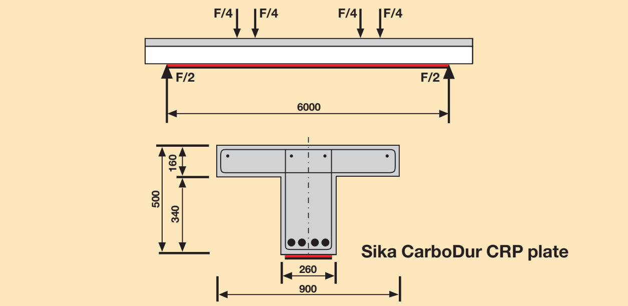
Since 1994 – global market launch. Worldwide support by Sika.

The Sika® CarboDur® System with Tested Serviceability

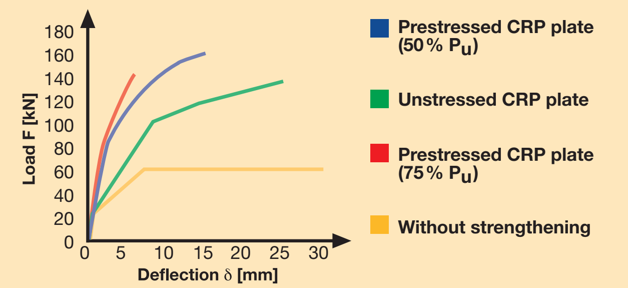
Static Loading on Large T-beams

The Sika CarboDur system has been successfully tested by the EMPA on innumerable reinforced concrete beams.

Flexural strengthened T-beam

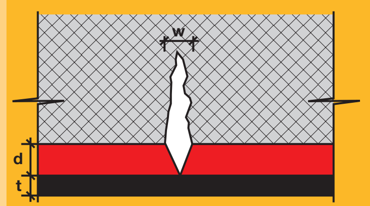


Load deflection diagram

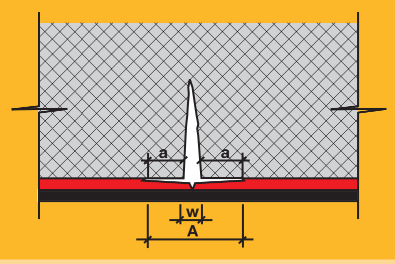


The mechanism of the crack bridging capacity of the Sika CarboDur strengthening system was also tested on both cracked and uncracked beams. Initially the cracks are bridged by shearing strain in the adhesive. When the crack is enlarged, detachment of the adhesive occurs first, followed by formation of a rupture key.

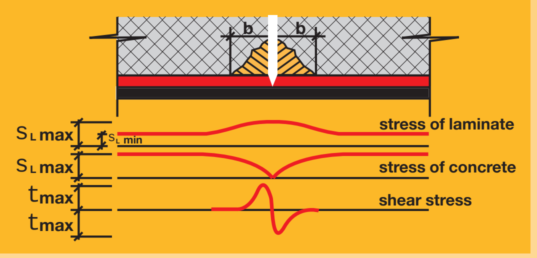
Phase 1: Shearing strain



Phase 2: Detachment



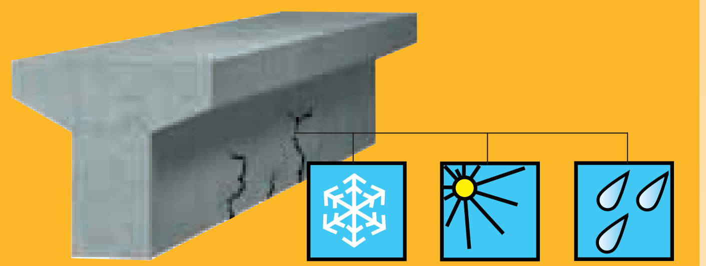
Phase 3: Key formation



Thesis ETH Zurich No. 8918, 1989

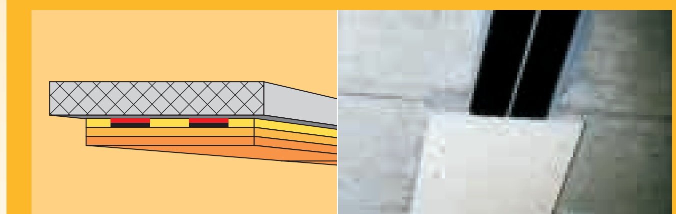
Thermal Cycle Tests on Cracked Concrete Beams

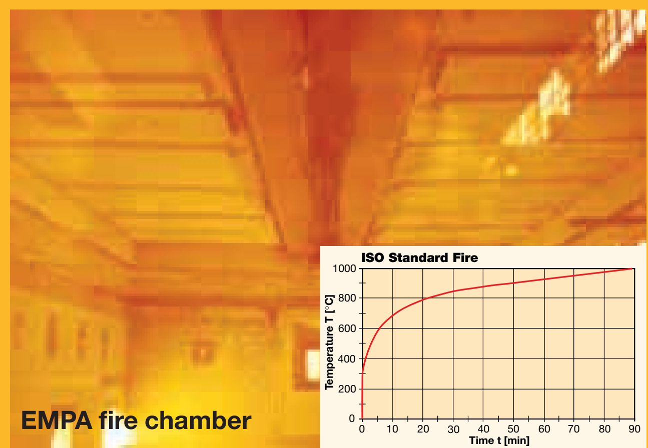
Static and dynamic stress tests were carried out on various reinforced concrete beams strengthened with Sika CarboDur. The beams were subjected to high relative humidity levels and extreme temperatures of –25 °C to +40 °C.
Ice was observed in the cracks during the freeze cycle. Despite this, the subsequent stress tests showed no weakening of the strengthening system.



The Fire Properties of the System

The Sika CarboDur system was tested in the EMPA fire chamber with an ISO standard fire. There was almost no smoke development throughout the period of the test. The plates do not have to be protected from falling because the weight is very small. It was clear that the CarboDur plates can be successfully protected against fire with fire-resistant boards.





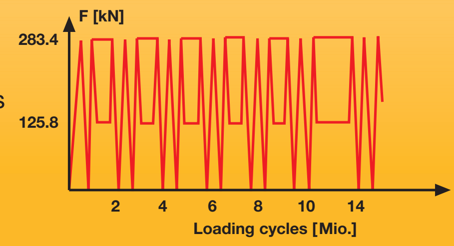
EMPA fire chamber

EMPA Test Report No. 148795, 1994

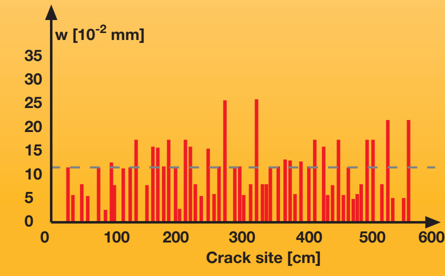
Dynamic Stress on Large T-beams

Reinforced concrete beams strengthened with the Sika CarboDur system were subjected to dynamic stress with high load cycle amplitudes. After a large number of load cycles, the tensile reinforcement bars failed first due to friction corrosion. The behaviour of the Sika CarboDur system was outstanding. The stress amplitude of the internal reinforcement can be reduced by strengthening with the Sika CarboDur system.

Loading programme



Crack site



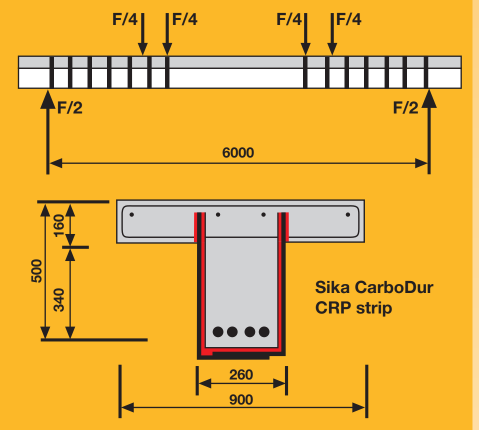
Thesis ETH Zurich No. 10199, 1993

Shear Strengthening

CarboDur stirrups were post-applied in the zones under shear stress instead of the internal reinforcement stirrups. The load-deflection curves showed similar load-bearing properties to those found in the earlier control tests with steel plate strengthening.

Loaded T-beam at the EMPA

EMPA Test Report No. 169219/1+2, 1998/Patent pending



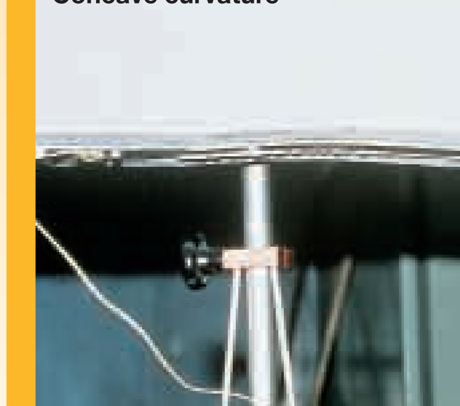
Shear strengthened T-beam

The Sika® Roll-on Process

The maximum design concave curvature of a concrete surface was tested on a reinforced concrete beam.

The efficient Sika roll-on process enables the CarboDur plates to be applied in a very short time. This can save considerable working time and also gives greater flexibility in construction planning for strengthening work.

Concave curvature

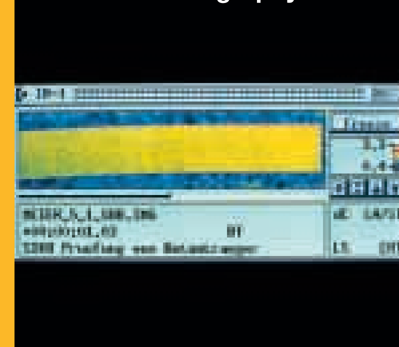


EMPA Test Report No. 154490/1, 1996

Applying pressure with the roller

EMPA Test Report No. 154490, 1994

Infrared thermography



Sika test on concrete beam

Sika® CarboDur® System-optimized Desi gn Solutions

Different Rigidities

The strengthening of a structure can be optimized by using different CarboDur plate modules. The most suitable plate can be selected according to the type of structure and its loading and span.

Reinforcement Strain Relief

The reinforcement can have improved strain relief and the crack widths can be reduced by using high-module plates.

Deflection

If strengthening is necessary due to high deflection, for example on timber beams, the Sika CarboDur H plate is used.

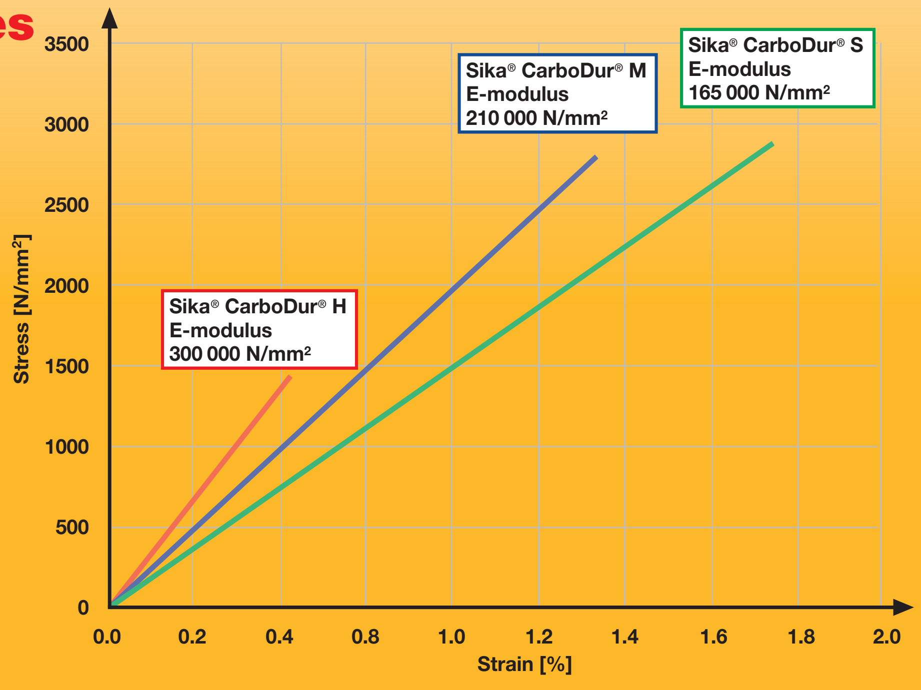


Plate under Compressive Stress

The behaviour of the Sika CarboDur plates in the compression zone is extremely good. Unlike a steel plate, it adheres to the substrate until total destruction of the concrete in the compression zone.

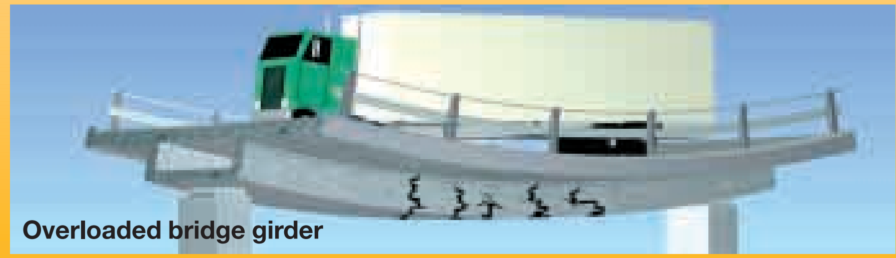
Static and dynamic tests on RC T-beams strengthened with Sika CarboDur	Thesis ETH Zurich No. 10199 (EMPA Report No. 224)	1993

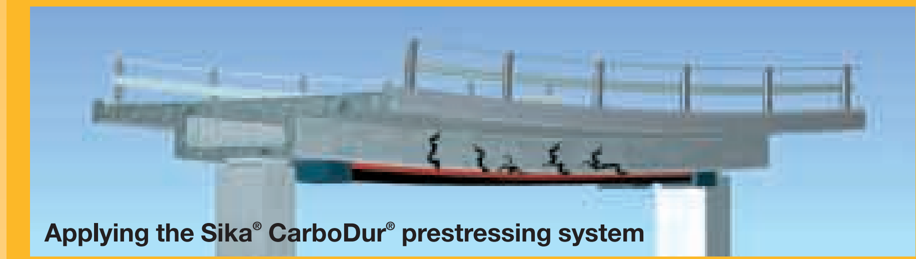
Reinforced Concrete Deck

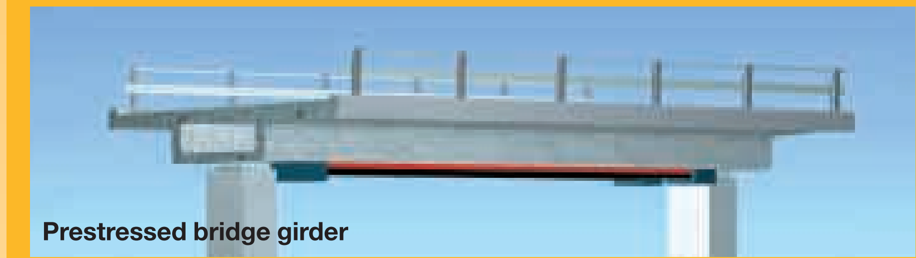
Prestressed Reinforced Concrete Beams

Columns

Post-applied Prestressing


Overloaded bridge girder


Applying the Sika® CarboDur® prestressing system


Prestressed bridge girder

The Sika CarboDur plates can also be prestressed before bonding. This reduces the risk of the plate peeling off due to concrete shear failure in the tension zone, which increases the structural safety. Serviceability can then be further improved compared with a plate bonded without tension. The pre-stressing force in the plate relieves the strain on the internal steel reinforcement and reduces the deflection and crack widths.

▲ Closing the cracks partially
▲ Smaller cracks
▲ Reinforcement strain relief
▲ Increase in serviceability and structural safety

Patent pending

Shortened Anchorage

Patent pending

Specially treated plate end allows reduced anchorage length.

Stone Pillar

Masonry

Timber Beam

Sika® CarboDur® System-optimized Project Solutions

Flexible in Installation

With the flexible Sika CarboDur plates, strengthening work can be carried out without dismantling existing services. This reduces the construction period and also saves money.

Around Services

- ▲ Water pipes
- ▲ Gas pipes
- ▲ Electric cables
- ▲ Compressed air pipes
- ▲ Ventilation ducts

Through Wall Openings

- ▲ Anchorage lengthening
- ▲ Non-load bearing walls
- ▲ Change in the structural system
- ➜ Long plates
- ➜ Confined spaces

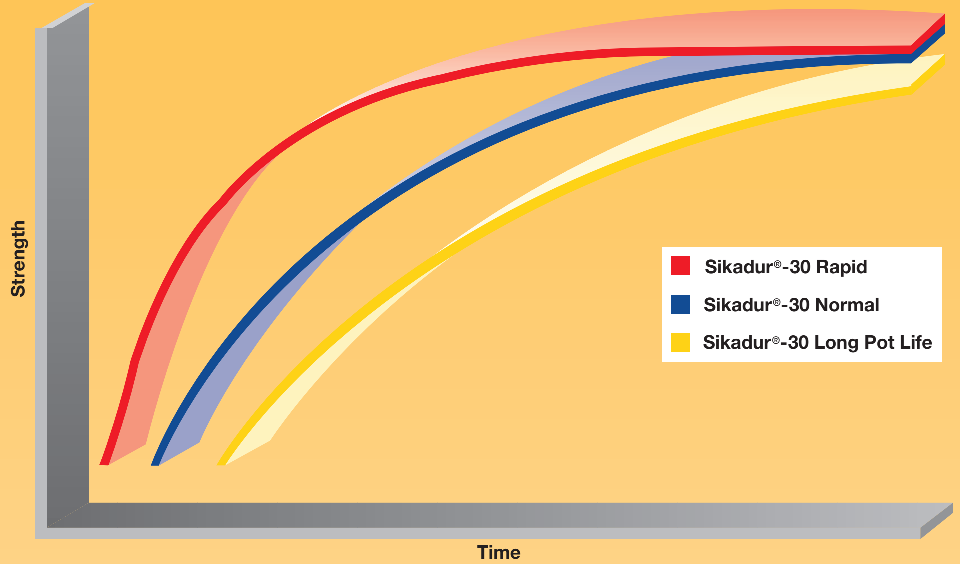
In Lift Shafts and Stairwells

- ▲ Confined spaces
- ▲ Intersected plates

Quick to Use

Temperature-based Strength Development

The type of adhesive appropriate for the temperature on the site is used. The installation properties are designed to suit the specific temperature conditions, so that rapid hardening is achieved.



Low Temperatures

Sikadur-30 Rapid type can be used in low temperatures. Its accelerated chemical reaction provides sufficient strength within a short time.

Patent pending

Brief Interruption

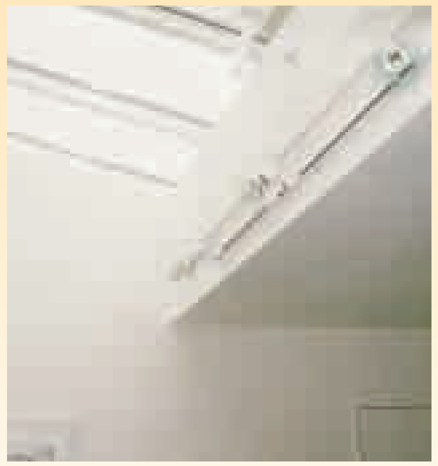
When the Sika CarboDur heating device is used, the Sikadur-30 will harden within hours. The glass transition point is improved at the same time. This allows strengthening work to be carried out with short interruption during the night.

Curing Within Hours

- ▲ High glass transition point (Sikadur-30 Long Pot Life)
- ▲ Night working
- ▲ Strengthening without traffic loads
- ▲ No interruption in fabrication
- ▲ At low temperatures

EMPA Test Report No. 170569, 1998

Appearance



The very thin Sika CarboDur plates can be concealed or integrated within the existing load-bearing structure without expensive operations.

- ▲ Coating the plates
- ▲ Covering with mortar
- ▲ Covering with timber boarding
- ▲ Inserting into a slot

Worldwide Projects of Strengthening

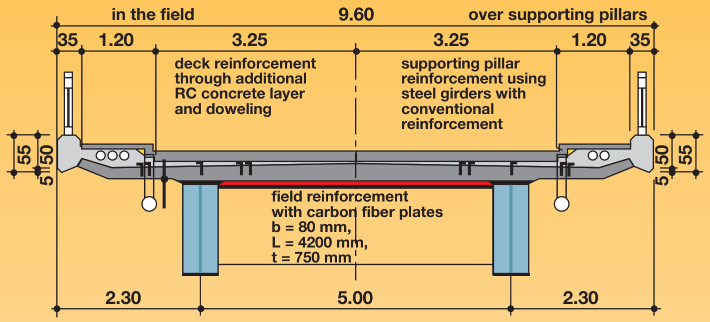
Strengthening of a Bridge Slab due to Increased Traffic Load

Repairs to the bridge Oberriet-Meiningen over the Rhine (Switzerland/Austria)

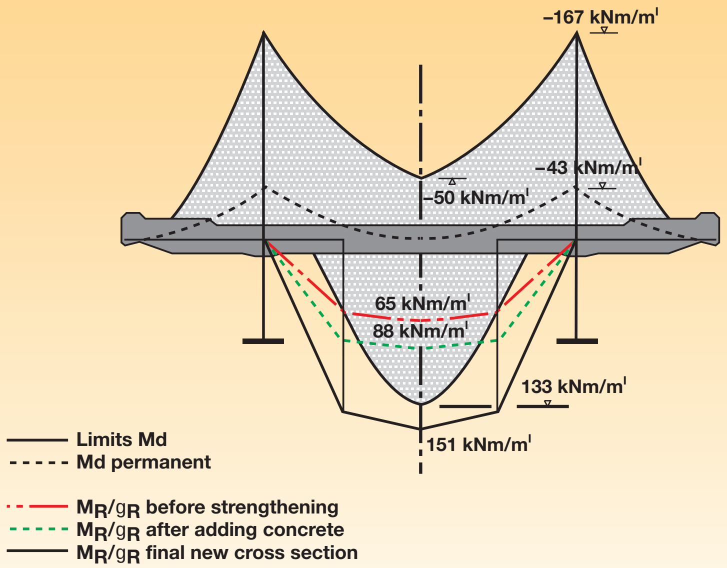
Strengthening the reinforced concrete bridge slab in the transverse direction by:

- ▲ Increasing the concrete compression zone
- ▲ Bending reinforcement with Sika CarboDur S812 at 750 mm centres
- ▲ Total strengthening factor 2.4
  - – by the concrete compression zone 1.4
  - – by the plates 1.7

Cross-section of composite bridge



Moment curve



Slab strengthening by concrete overlay.
Bottom reinforcement strengthening with CRP plates.

Application of Sika® CarboDur® plates

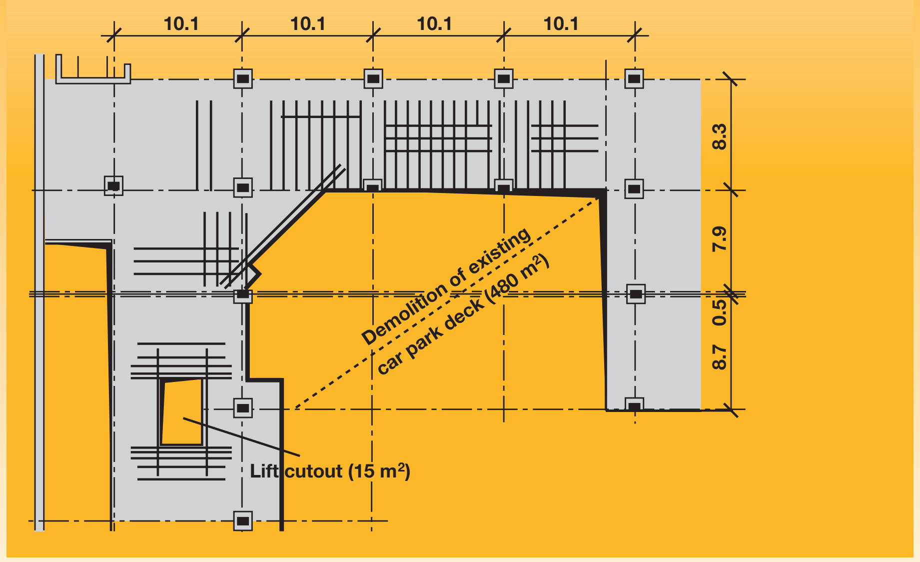
Bridge soffit

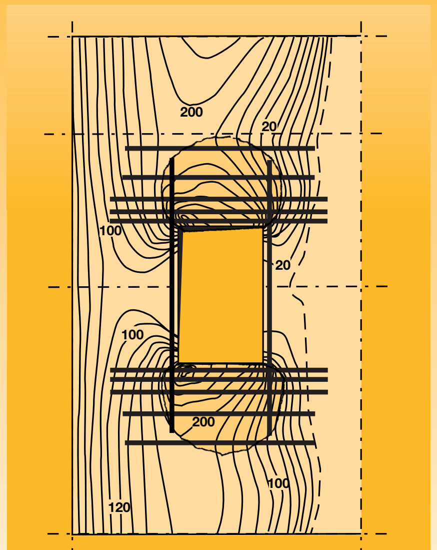
Cross-section through core from pull-off test

Change in the Structural System due to Change of Use

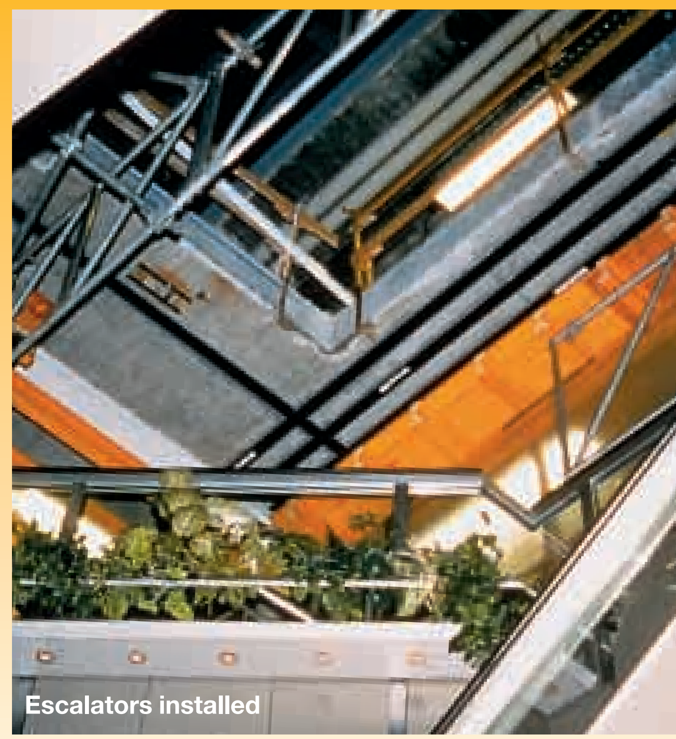
Conversion of a shopping centre in Winterthur (Switzerland). Application of 1.7 km Sika® CarboDur® plates.

Enlargement of retail areas. Installation of escalators and lift.





Lift cutout with moment isolines



Escalators installed

Demolition of car park deck after strengthening

Lift installation

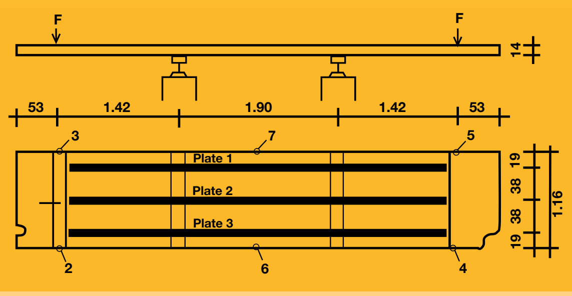
Worldwide Projects of Strengthening

Structural Strengthening due to Inadequate Design

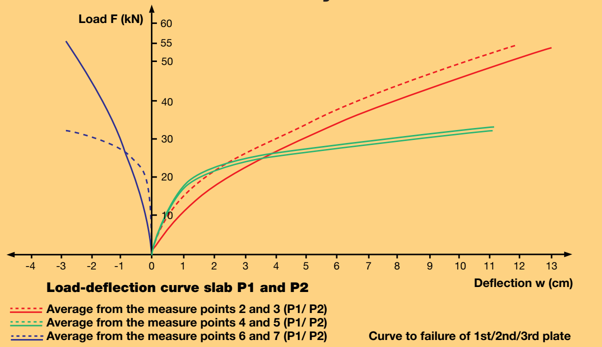
Sagging balcony slabs in Magdeburg (Germany)

Prestressed balcony slabs with insufficient bending reinforcement

➔ Sagging balcony slabs with surface water strengthening with 3 Sika CarboDur S512 plates. Advantage: no extra self weight.

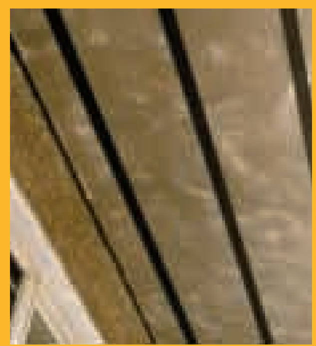


Load deflection curves of balcony slab



IBMB Test Report No. 1448/325, 1995

Strengthened balcony slabs

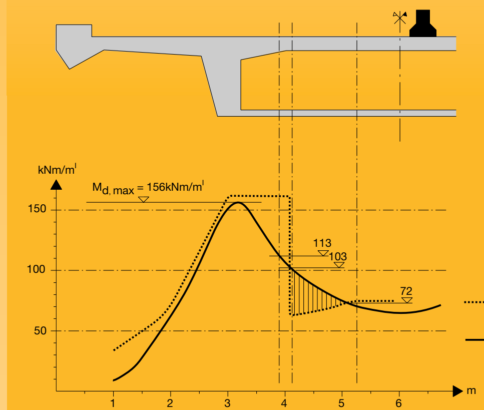


Balcony soffit after coating

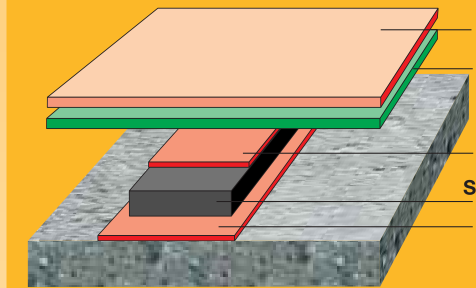
Structural Strengthening due to Insufficient Reinforcement

Repairs to the Horgen transporter bridge (Switzerland)

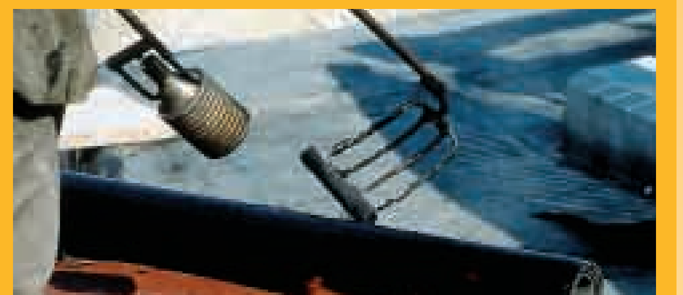
Reinforcement cross section too low on the bridge slab on one side. Missing reinforcement supplemented. System tests at laboratory and on site. Positive results for bitumen membrane torching.



Moment curve



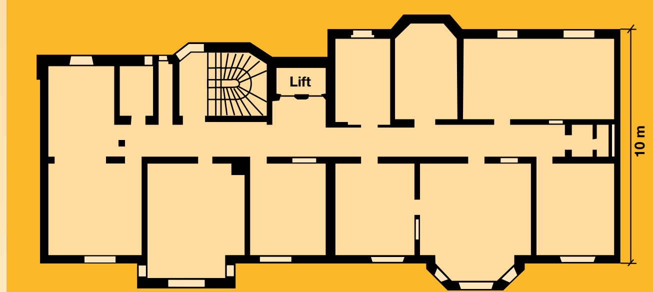
Sika® CarboDur® S1212 plates applied at 600 mm centres



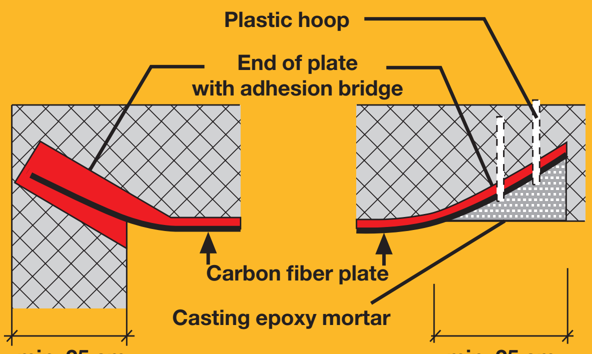
Bitumen membrane torching

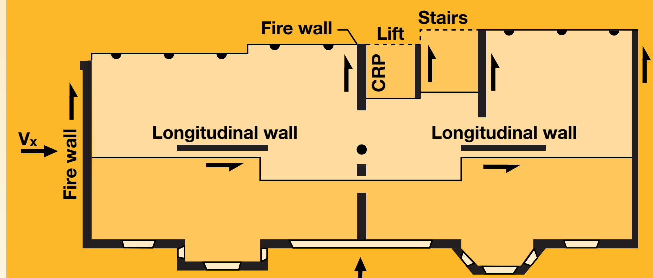
Structural Strengthening of Masonry Structures

Conversion of a residential building to an office building in Zurich (Switzerland)



Existing load-bearing structure before conversion, 2nd floor





Load-bearing structure after conversion, 1st to 4th floors

Strengthening of masonry walls on one side for guaranteed earthquake resistance

- ▲ Crossbanding of Sika CarboDur S1012 plates
- ▲ Anchorage in the reinforced concrete supports
- ➔ Ductility of the masonry increased
- ➔ Earthquake resistance increased many times over

Strengthening of masonry with heavy duty fiber composite materials	Thesis ETH Zurich No. 10672 (EMPA Report No. 229)	1994

Recess filled with epoxy grout

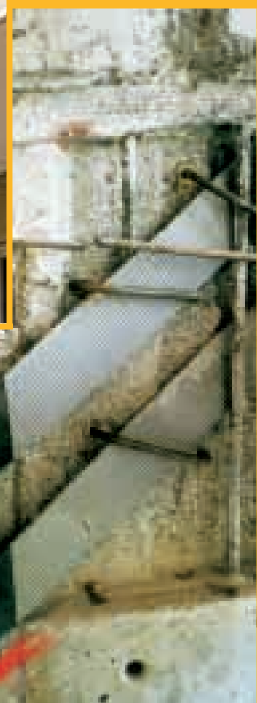
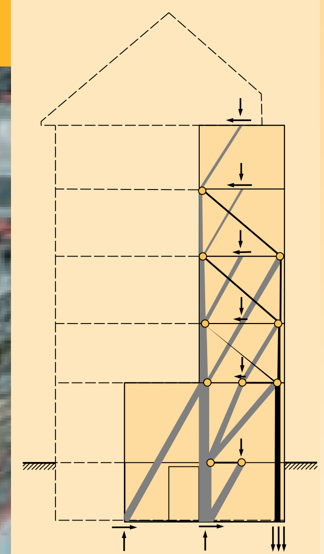


Plate anchorage in the recess

Configuration of CRP plates on the load-bearing masonry wall

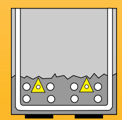


Worldwide Projects of Strengthening

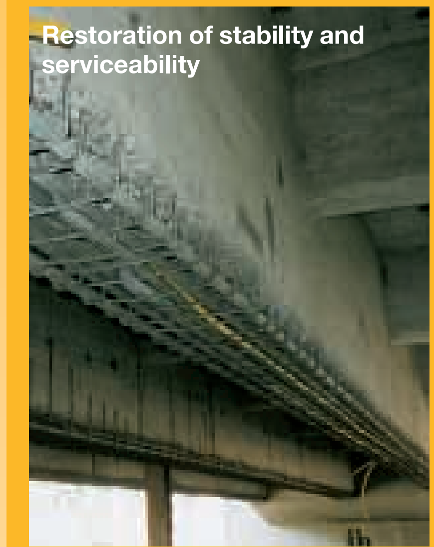
Guarantee of Structural Stability Following Reinforcement Corrosion

Serious concrete damage and reinforcement corrosion on a reinforced concrete frame bridge in Dresden (Germany)

Replacement of corroded bending steel reinforcement. Reinforcement by three Sika CarboDur S512 plates per beam.



Infill of Sika Injectoflex. Reprofiling with SikaCem-Gunite 133. Carbonation resistance with Sikagard-550.



Restoration of stability and serviceability

Installation of Sika® CarboDur® S 512 plate

Soffit of strengthened bridge

Strengthening due to Increased Load and Change of Use

Conversion of a factory into a laboratory and office building in Dübendorf (EMPA, Switzerland)

Strengthening of walls

Change in structural system due to change of use.

Application of the Sika CarboDur during cold temperature with the Sika CarboDur heating device.

Heating the plate

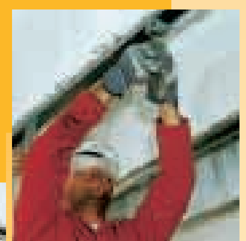
Strengthening of Existing Roof Beam to take new Floor Loading

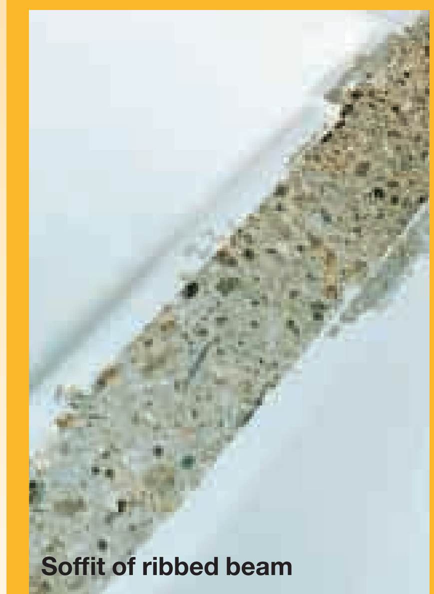
Strengthening of ribbed beams at a hospital training centre in London (England)

Ribbed beams eleven metres long 600 mm centres

Doubling of working load by strengthening the beams with Sika CarboDur S512 plates

Pressed into position by roller





Soffit of ribbed beam

Coating the plate with Sikadur®-30

Easy installation of Sika® CarboDur® plate

Restoration of Original Load-bearing Capacity

Damaged beams in a car park at a shopping mall in Boston (USA)

Strengthening the beams damaged by overloading during construction.

Threading between the services

Pressed into position by roller

Worldwide Projects of Strengthening

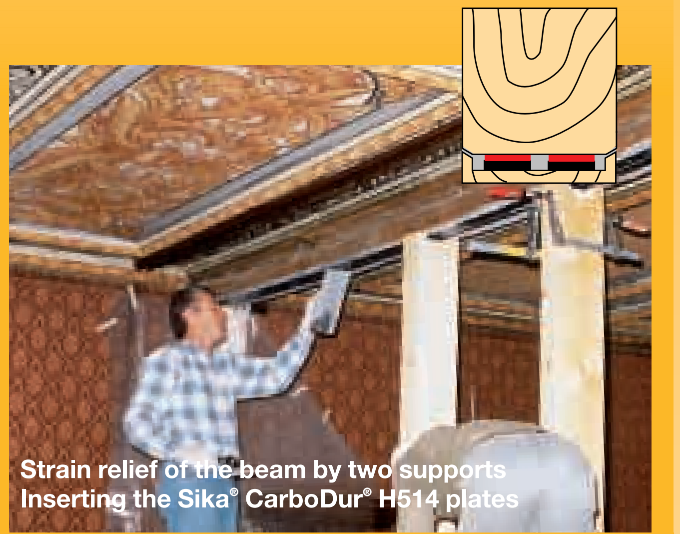
Strengthening of Timber Beams due to Insufficient Bearing Capacity

Crack in an oak beam in a museum in Lucerne (Switzerland)

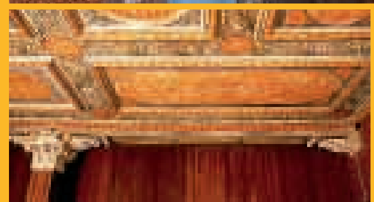
Invisible strengthening of an oak beam

Filling the milled slot with Sikadur®-30

Insufficient structural stability due to conversion in a monastery in Eschenbach (Switzerland)



Strain relief of the beam by two supports
Inserting the Sika® CarboDur® H514 plates



Strengthening of Bridge Deck and Beams due to Increased Service Load

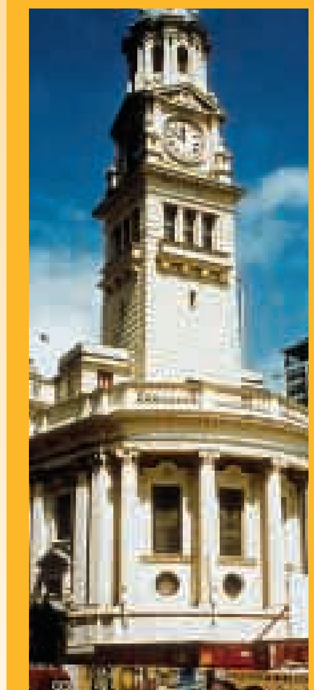
Strengthening of the bridge over Bystry Channel, Augustów (Poland)

Replacement of the carbonated concrete and strengthening of the bridge deck with Sika CarboDur M1214 plates.

Strengthening of the shear zones of the beams with SikaWrap Hex-230C fabrics using Sikadur-330 adhesive.

Strengthening due to Insufficient Structural Safety

Repair works in a Town Hall in Auckland (New Zealand)



Strengthening of floors with
– Sika® CarboDur® S512 plates
– 600 mm centres
– Total length 200 m

Conversion of a residential building into an office building in Budapest (Hungary)

Installing the Sika® CarboDur® S512 plates

Strengthening of Bridge Columns for Heavy Vehicle Impact

Strengthening of the Bible-Christian Bridge, A30 Bodmin-by-Pass, Cornwall (UK)

Concrete prepared and primed with Sikadur Hex-300 low viscosity impregnating and sealing epoxy resin.

Sikadur Hex-306 thixotropic epoxy resin adhesive was applied to the glass fibre fabric SikaWrap Hex-100G sheets.

The designed lengths of fabrics were unrolled onto the column and smoothed into position.

Material Characteristics

Sika® CarboDur® Plates

	Sika®CarboDur® S	Sika®CarboDur® M	Sika®CarboDur® H
E-modulus	165,000 N/mm^2	210,000 N/mm^2	300,000 N/mm^2
Tensile strength	2,800 N/mm^2	2,400 N/mm^2	1,300 N/mm^2
Average measured failure tensile strength	3,050 N/mm^2	2,900 N/mm^2	1,450 N/mm^2
Strain at failure	> 1.7 %	> 1.2 %	> 0.45 %

Sikadur® Epoxy Adhesives and Mortars

	Sikadur®-30	Sikadur®-41
Compressive strength	> 95 N/mm^2	> 75 N/mm^2
Adhesive strength on steel	> 26 N/mm^2	> 10 N/mm^2
Adhesive strength on concrete	> 4 N/mm^2 (concrete failure)	> 4 N/mm^2 (concrete failure)
E-modulus	12,800 N/mm^2	9,000 N/mm^2

SikaWrap® Hex Fabrics

	SikaWrap® Hex-230C	SikaWrap® Hex-103C	SikaWrap® Hex-100G
Tensile strength of fibers	3,500 N/mm^2	3,500 N/mm^2	2,250 N/mm^2
Tensile modulus of fibers	230,000 N/mm^2	230,000 N/mm^2	70,000 N/mm^2

Sikadur® Epoxy Adhesives

	Sikadur®-330	Sikadur® Hex-300/306
Flexural modulus	3,800 N/mm^2	3,120 N/mm^2
Adhesive strength on concrete	> 4 N/mm^2 (concrete failure)	> 4 N/mm^2 (concrete failure)
For additional information see Technical Data Sheets.		

Test Certificates / Reports

Strengthening of reinforced concrete with carbon fiber reinforced epoxy resins	Thesis ETH Zurich No. 8918	1989
Static and dynamic tests on RC T-beams strengthened with Sika CarboDur	Thesis ETH Zurich No. 10199 (EMPA Report No. 224)	1993
Fire tests with Sika CarboDur strengthened RC beams	EMPA Test Report No. 148795	1994
Strengthening of masonry with heavy duty fiber composite materials	Thesis ETH Zurich No. 10672 (EMPA Report No. 229)	1994
Testing the Sika roll-on process on voids by infrared thermography	EMPA Test Report No. 154490	1994
Static loading tests on concrete beams strengthened with Sika CarboDur	EMPA Test Report No. 154490/1	1995
Loading test on timber stairs strengthened with Sika CarboDur	EMPA Test Report No. 161782	1996
Sika CarboDur shear tests on RC T-beams	EMPA Test Report No. 169219/1+2	1998
Application of Sika CarboDur on vibrating RC slabs	EMPA Test Report No. 170569	1998

Technical Articles

Epoxy adhesives for permabond jointing. H. Bänziger, W. Steiner, 1989.
Strengthening of reinforced concrete with tensioned fiber composites. M. Deuring, 1993.
CRP plates in construction. Strengthening of concrete structures. M. Deuring, 1994.
Strengthening of structures with fiber composites. U. Meier, 1994.
Strengthening with CRP plates. M. Deuring, W. Steiner, 1996.
Strengthening of the Oberriet-Meiningen Rhine bridge. R. Walser, W. Steiner, 1996.
Earthquake resistance of masonry structures strengthened with fibre composites. G. Schwegler, P. Kelterborn, 1996.

Approvals

General construction approval in Germany for steel plate strengthening with Sikadur-30 and Icosit 277	German Institute of Construction 7-36.1-30	07.04.95
General construction approval in Germany for Sika CarboDur	German Institute of Construction 7-36.12-29	11.11.97

Your Local Sika® Company

Certified Quality System ISO 9001/EN 29001 since 1986

Certified Management System SQS ISO 14001 since 1997

Internet: http://www.sika.com

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