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.

Walls
Beams
Access openings
Masonry walls
Floors
Columns
Decks

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

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

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

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

With predefined detachment at peak cracking stress.

**Approval**

- General construction
- German Institute of Construction 07.04.95
- Approval in Germany for steel plate strengthening with Sikadur-30 and locol 277

**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

- High carbon fiber content

**Defined Plate Performance**

1987 – first trials at EMPA.

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

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


**Test certificates**

<table>
<thead>
<tr>
<th>Test certificate</th>
<th>Thesis ETH Zurich</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strengthening of reinforced concrete with carbon fiber</td>
<td>No. 8118</td>
<td>1989</td>
</tr>
<tr>
<td>Reinforced epoxy matrix</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Static and dynamic tests on RC T-beams strengthened</td>
<td>No. 11521</td>
<td>1993</td>
</tr>
<tr>
<td>with Sika CarboDur</td>
<td>(EMPA Report No. 324)</td>
<td></td>
</tr>
</tbody>
</table>

**Defined System Performance During Application and in Service**

- Mean = 165 kN/mm² (Sika® CarboDur® S)
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 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

Thermal Cycle Tests on Cracked Concrete Beams
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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.

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.

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.

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.
Sika® CarboDur® System-optimized Design 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.

Reinforced Concrete Deck
Prestressed Reinforced Concrete Beams
Columns
Stone Pillar
Masonry
Timber Beam

Post-applied Prestressing
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.

\[ \begin{align*}
\text{Sika CarboDur® H} \\
\text{E-modulus} & \quad 300,000 \text{ N/mm}^2
\end{align*} \]

\[ \begin{align*}
\text{Sika CarboDur® M} \\
\text{E-modulus} & \quad 210,000 \text{ N/mm}^2
\end{align*} \]

\[ \begin{align*}
\text{Sika CarboDur® S} \\
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Static and dynamic tests on RC T-beams strengthened with Sika CarboDur (Thesis ETH Zurich 1993 No. 10199 EMPA Report No. 224)

Sika® CarboDur® M
Sika® CarboDur® S
Sika® CarboDur® H
SikaWrap®

Shortened Anchorage
Specially treated plate end allows reduced anchorage length.

Applying the Sika® CarboDur® prestressing system
Prestressed bridge girder

Overloaded bridge girder

Patent pending

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

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

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

EMPA Test Report No. 170569, 1998

Patent pending
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

<table>
<thead>
<tr>
<th>Moment curve</th>
</tr>
</thead>
<tbody>
<tr>
<td>Limits Md</td>
</tr>
<tr>
<td>Md permanent</td>
</tr>
<tr>
<td>Mϕ / g before strengthening</td>
</tr>
<tr>
<td>Mϕ / g after adding concrete</td>
</tr>
<tr>
<td>Mϕ / g of final new cross section</td>
</tr>
</tbody>
</table>

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

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.

Demolition of car park deck after 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 SS12 plates. Advantage: no extra self weight.

Strengthened balcony slabs

Load-deflection curves of balcony slab

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.

Load-deflection curves of balcony slab

Balcony soffit after coating

Structural Strengthening of Masonry Structures

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

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

Plate anchorage in the recess

Configuration of GRP plates on the load-bearing masonry wall

Recess filled with epoxy grout

Existing load-bearing structure before conversion, 2nd floor

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

Strengthening of masonry with heavy duty fiber composite materials

Thesis ETH Zurich 1994

Sika ETH Zurich

SikaTop®-Armatec

Sika®-CarboDur plate

Sikadur®-30

Sikafloor®-82 EpoCem®

Bitumen membrane torching

Existing load-bearing structure after conversion, 2nd floor

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

Strengthening of masonry

Thesis ETH Zurich

Sika®-CarboDur S1212 plates applied at 600 mm centres


Worldwide Projects of Strengthening
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.

- Restoration of stability and serviceability

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

- Coating the plate with Sikadur®-30
- Easy installation of Sika® CarboDur® plate

- Soffit of ribbed beam

Strengthening due to Increased Load and Change of Use

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

Change in structural system due to change of use.

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

- Strengthening of walls
- Heating the 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

- Soffit of strengthened bridge
- Infill of Sika Injektiflex
- Reprofiling with SikaCem-Gunite 133
- Carbonation resistance with Sikagard-550

- Soffit of strengthened bridge

Worldwide Projects of Strengthening

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- Soffit of strengthened bridge
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

Strengthening due to Insufficient Structural Safety

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

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

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 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**

<table>
<thead>
<tr>
<th>Sika® CarboDur® S</th>
<th>Sika® CarboDur® M</th>
<th>Sika® CarboDur® H</th>
</tr>
</thead>
<tbody>
<tr>
<td>E-modulus</td>
<td>165,000 N/mm²</td>
<td>210,000 N/mm²</td>
</tr>
<tr>
<td>Tensile strength</td>
<td>2,000 N/mm²</td>
<td>2,400 N/mm²</td>
</tr>
<tr>
<td>Average measured failure tensile strength</td>
<td>3,050 N/mm²</td>
<td>2,000 N/mm²</td>
</tr>
<tr>
<td>Strain at failure</td>
<td>&gt; 1.7%</td>
<td>&gt; 1.2%</td>
</tr>
</tbody>
</table>

**SikaWrap® Hex Fabrics**

<table>
<thead>
<tr>
<th>SikaWrap® Hex-200C</th>
<th>SikaWrap® Hex-100C</th>
<th>SikaWrap® Hex-100G</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile strength of fibers</td>
<td>3,500 N/mm²</td>
<td>2,500 N/mm²</td>
</tr>
<tr>
<td>Tensile modulus of fibers</td>
<td>230,000 N/mm²</td>
<td>230,000 N/mm²</td>
</tr>
</tbody>
</table>

**Sikadur® Epoxy Adhesives and Mortars**

<table>
<thead>
<tr>
<th>Sikadur®-30</th>
<th>Sikadur®-41</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compressive strength</td>
<td>&gt; 95 N/mm²</td>
</tr>
<tr>
<td>Adhesive strength on steel</td>
<td>&gt; 26 N/mm²</td>
</tr>
<tr>
<td>Adhesive strength on concrete</td>
<td>&gt; 4 N/mm² (concrete failure)</td>
</tr>
<tr>
<td>E-modulus</td>
<td>12,800 N/mm²</td>
</tr>
</tbody>
</table>

**Test Certificates/Reports**

- Static and dynamic tests on RC T-beams strengthened with Sika CarboDur (EMPA Report No. 224, 1993).
- Fire tests with Sika CarboDur strengthened RC beams (EMPA Test Report No. 167185, 1994).
- Testing the Sika roll-on process on voids by infrared thermography (EMPA Test Report No. 154495/1, 1995).
- Static loading tests on concrete beams strengthened with Sika CarboDur (EMPA Test Report No. 108195, 1996).

**Technical Articles**

- Strengthening of the Qualet-Muirgen/Rhine bridge. R. Walser, W. Steiner, 1996.

**Approvals**

- General construction approval in Germany for steel plate strengthening with Sikadur®-30 and local 277.
- General construction approval in Germany for Sika CarboDur (EMPA Report No. 224, 1994).
- German Institute of Construction 07/06.1-30 11/11.08.
- German Institute of Construction 07/06.1-29 11/11.08.

**Your Local Sika® Company**

Internet: http://www.sika.com