Structural Strengthening
with SikaWrap® Fabric Systems
Strengthening Fiber Types

Three different main types of fibers are suitable for the use in civil engineering: carbon, glass and aramid fibers. Depending on the structural requirement, job site and environmental conditions, the best suited material can be selected. The main differences are the fiber stiffness and the damage tolerance.

Carbon Fibers
Carbon fibers are available in different stiffness grades. They all have a perfect linear-elastic behaviour and high strength. Typical examples:
- High strength (HS), “standard” elastic modulus 230 GPa
- High modulus (HM), elastic modulus 440 to 640 GPa

Main use: Active strengthening (constantly loaded)
Carbon fibers exhibit alkali, acid and UV resistance, high fatigue strength and a low thermal expansion coefficient. They do not suffer stress corrosion.

Glass Fibers
Glass fibers are most commonly used for general purpose structural applications. They are available in different types, the most common one is E-glass. Elastic modulus is 76 GPa.

Main use: Passive strengthening (e.g. seismic)
E-Glass fibers have the disadvantage of low alkali resistance. To overcome this weak point a considerable amount of zirconia is added to produce alkali resistance AR-glass.

Glass fiber fabrics often lead to the cost-optimized system. The disadvantage of low stiffness can be compensated by combining several fabric layers.

Aramid Fibers
Highly specialized fiber with high fracture energy. Elastic modulus is 100 GPa.

Aramid fabrics can protect bridge columns from collapsing due to the impact of vehicles. Another important application field is blast mitigation.

Mechanical Properties of Fibers used for SikaWrap® Fabrics
A wide range of reinforcing fibers from the cost-efficient glass fiber to the tough aramid and from the strong carbon fiber to the very stiff high modulus carbon fiber is available. The perfect fiber type for every strengthening requirement can be found in the SikaWrap® fabric range. In the graph below the mechanical properties of aramid, glass and the main carbon fibers are shown. The differentiation in the elastic modulus can be seen clearly. When considering various fiber-reinforced polymer (FRP) systems for a particular application, the FRP systems should be compared on the basis of equivalent stiffness only.

Other Fiber Properties that are important for the Selection Process
For the long-term success of a strengthening project, some further properties other than mechanical values are of importance: durability, weathering and corrosion resistance.

Criteria
Fiber Composites made of Carbon Fibers Aramid Fibers E-Glass Fibers
Long-term behaviour very good good adequate
Fatigue behaviour excellent good adequate
Alkali resistance very good good inadequate
Impact resistance low very good good
Stress corrosion low medium high
Wear behaviour adequate very good good
Passive strengthening (x) (x) x
Active strengthening (constantly loaded) x (x) –
Splash zone strengthening x (x) –
Electrical conductivity / Galvanic cell concerns yes no no

X = preferred choice

SikaWrap® Fabric Types
SikaWrap® fabrics are available in many areal weights, production types and fiber alignments. They are selected by the type of strengthening and the loading requirements.

Differentiation by Production
Woven Fabrics
These have the best handling properties and are easy to impregnate with the thixotropic mid-viscous resin Sikadur®-330 (areal weights up to 300 g/m²) or with Sikadur®-300 (300 g/m² or more).

Multi-directional Fabrics
Fibers in more than one direction

Hybrid Fabrics:
Combinations of different fibers, usually multi-directional
Can be woven or non-woven fabrics

Extended SikaWrap® Range
Besides the regular range of SikaWrap® fabrics, other areal weights and combinations of fibers as well as woven and non-woven fabrics can be produced on request. Examples:
- Bi-directional fiber fabric can be the ideal arrangement for a combined flexural/shear strengthening of a concrete beam. Thanks to the arrangement of fibers in two directions an efficient application with one fabric layer can be achieved.
- Hybrid fabrics with different types and content of fibers in all the directions can be customized e.g. for seismic applications.

Sika® CarboDur® Composite Strengthening Systems
Since the early 1990’s Sika® CarboDur® structural resins and adhesives for FRP applications are sold under the brand Sika® CarboDur® composite strengthening systems.
Dry

In the dry application process the dry SikaWrap® fabric is applied directly into the mid-viscous Sikadur®-330 resin which has been applied uniformly onto the concrete surface.

Advantage: easy application.

Wet

SikaWrap® woven fabrics with an areal weight above approx. 300 g/m² and all the non-woven fabrics are applied by the wet application process. The SikaWrap® fabric is preimpregnated with Sikadur®-300 epoxy resin either in a saturator machine or on a working table and applied “wet” to the sealed substrate.

Advantage: ideal system for large applications and heavy and tight woven fabrics.

Confinement

Confinement is generally applied to members in compression, with the aim of enhancing their load-carrying capacity or, in cases of seismic upgrading, to increase their ductility.

SikaWrap® FRP composite materials are reliable confinement devices for reinforced concrete elements.

Seismic Strengthening

This is often a combination of all the available application types as described above. An important field historically and now is the wrapping of bridge columns to prevent premature failure in a seismic event.

Impact Strengthening

SikaWrap® fabrics based on aramid fibers can absorb the high energy rates caused by the impact of a car in order to protect the column from collapsing.

Seal the substrate with Sikadur®-300 (smooth substrate) or Sikadur®-330 epoxy resin (rough substrate).

Application of Sikadur®-330 resin to the substrate with trowel or roller.

Cutting the fabrics using fabric scissors or sharp utility knife. Add enough material for overlaps.

Pre-wetted fabric is applied on the coated substrate.

The fabric is carefully rolled with a plastic impregnating roller strictly in the fiber direction.

Overlapping in fiber direction > 100 mm (depending on fabric type) or as per the project specifications.

A coloured or a cementitious coating is applied to the fabric surface.

Fire boards or paints/mortars can improve the resistance to high temperatures.

Application Process

General

SikaWrap® fabrics are a group of strengthening materials that can fulfill most of the needs for strengthening or refurbishing civil engineering structures. Reasons for the application can be a change of use and/or loading, modification of the structural system as well as prevention or repair of structures in seismically endangered zones.

Structural Applications

Shear Strengthening

The flexibility of the SikaWrap® fabric allows application to irregular cross sections which can be present in RC beams and columns. The combination of a shear strengthening with high-modulus carbon fiber fabrics together with a flexural strengthening with CFRP plates Sika® CarboDur® is optimal.

Flexural Strengthening

Structural elements may be strengthened in flexure not only with steel or Sika® CarboDur® CFRP plates but also with SikaWrap® fabrics, especially if substrate properties are low. Special attention has to be given to the correct alignment of the load-carrying fibers in the case of long fabrics for flexural strengthening.

Sealing the substrate with Sikadur®-300 (smooth substrate) or Sikadur®-330 epoxy resin (rough substrate).

Impregnating the fabric manually on a table or with a saturator using Sikadur®-300 resin.

Dry fabric is applied to the coated substrate.

The fabric is carefully rolled with a plastic impregnating roller strictly in the fiber direction.

Overlapping in fiber direction > 100 mm (depending on fabric type) or as per the project specifications.

A coloured or a cementitious coating is applied to the fabric surface.

Fire boards or paints/mortars can improve the resistance to high temperatures.

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SikaWrap® woven fabrics with an areal weight above approx. 300 g/m² and all the non-woven fabrics are applied by the wet application process. The SikaWrap® fabric is preimpregnated with Sikadur®-300 epoxy resin either in a saturator machine or on a working table and applied “wet” to the sealed substrate.

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Application of Sikadur®-330 resin to the substrate with trowel or roller.

Cutting the fabrics using fabric scissors or sharp utility knife. Add enough material for overlaps.

Pre-wetted fabric is applied on the coated substrate.

The fabric is carefully rolled with a plastic impregnating roller strictly in the fiber direction.

Overlapping in fiber direction > 100 mm (depending on fabric type) or as per the project specifications.

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Pre-wetted fabric is applied on the coated substrate.

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**General Aspects**

It isn’t possible to give general advice for which type of strengthening fabric should be used. Many options exist to optimize the overall cost depending on the project requirements. It is an important factor if the application is strength or stiffness driven. With the large SikaWrap® fabric range the designer can select the most appropriate fabric type and the best suited fiber for the structural needs. In addition long-term and environmental conditions have to be taken into account during this process.

**Cost Efficiency**

Cost efficiency can be defined as the cost of the applied system (including materials, preparation and installation) in relation to the mechanical performance of the strengthening that can be achieved. Very important is to include material and application as well as safety factors according to the design guidelines.

In the following graph a cost/efficiency comparison for some of the unidirectional standard SikaWrap® fabrics is shown. The graph has been prepared for a stiffness-driven application. For every set (A – F) of fabric/number of layers the following columns are presented:

1. Total ExA/m width [MN/m, all layers]
2. Material cost (fabric, primer, resin) for all layers [cost/m²]
3. Installation cost without coating [cost/m²]
4. Materials and installation cost (3 and 4) without coating [cost/m²]

How to read the graph in the example below, step by step:

1. The pink horizontal line represents the designed value ExA per meter width to stiffen the structure as required. ExA is the multiplication of fiber stiffness with fiber cross section per meter (without reduction with safety factors).
2. It can be seen that this stiffness value can be reached by several materials with a different number of layers (blue columns) of sets A to D and F) but not by set E where one layer only is not enough.
3. Based on the assumptions for the local material and labour cost the height of the red column is the scale for the final decision based on the mechanical properties.
4. The lowest height of the red column (lowest materials and installation cost) can be achieved with the application of only two layers heavy-weight standard modulus carbon fabric SikaWrap® 103C, set C.

Remarks (not general, but valid for this example):

- The whole situation would change if the stiffness requirement would be slightly lower so that the system based on one layer of high modulus fabric (set E) would also fulfill the requirement. Under the assumptions of this example this combination would suddenly be the most cost-efficient one, owing to the low installation cost for only one layer.
- The system at the right end (set F) is based on a glass fabric fiber. Despite the advantages in low fabric material cost, the low elastic modulus of the glass fibers cannot be compensated in a cost efficient way.

**Influences to Cost Efficiency**

Many more examples could be presented. Of great importance is that all the application steps have to be taken into account when calculating cost and cost efficiency of strengthening work. The cost of the impregnated layer of SikaWrap® fabric is only one factor when selecting a strengthening system.

The “best” system is always the one that has been selected carefully having in mind not just cost but also durability aspects. Next to that it has to be application-friendly enough so that application can be carried out on site with as few mistakes as possible.

**Design**

Since all design procedures limit the strain in the FRP material, the full ultimate strength of the material is not utilized in service. Therefore it shouldn’t be the only basis of comparison between material systems. The same cost/efficiency graphs can also be produced based on reduced strength or values confirmed in laminate testing.

Important for any comparison is that all the different materials involved are compared at the same type of load level, based on either (reduced) fiber or laminate values.

- The level of the fiber parallelity in the laminate
- The type of resin and overall application quality

Below are Examples of how to optimize Project Specifications

Some ideas of how project specifications or proposed designs can be optimized to cost-efficient Sika systems (values based on fiber properties):

**Conclusion**

The full laminate build-up becomes more cost-effective by considering the following guidelines:

- High modulus carbon fiber fabrics are expensive but owing to the fewer layers, more economical in many cases
- Heavy-weight standard modulus fiber fabrics are more economical than several layers of low weight fabrics
- A heavy-weight standard modulus fiber fabric can compensate the stiffness of high modulus carbon fiber fabrics

For additional Information see corresponding Product Data Sheets
System Testing
Many structural tests have been carried out in order to show the benefits of the SikaWrap® systems compared to conventional strengthening methods.

Effectiveness of RC beam columns connection strengthening using Carbon- FRP jackets.
Democritus University of Thrace, Xanthi, Greece.


Seismic retrofitting of corrosion-damaged RC columns.
Patras University, Greece.

Testing of masonry walls externally reinforced with SikaWrap® fabric systems.
University of Delaware, Structural testing, Inc., USA.

Carbon-fiber-reinforced polymers (CFRP) for strengthening and repairing under seismic actions.
European Laboratory for Structural Assessment ELSA, Ispra, Italy.

National Technical University of Athens, Greece.

Design
Design of structures to be strengthened can be done according to international design guidelines:

(‘Fédération internationale du béton)

Design and use of externally bonded fiber-reinforced polymer reinforcement (EBR FRP) for reinforced concrete structures.

Task Group 9.3 FRP (fiber-reinforced polymer) reinforcement for concrete structures.

ACI (American Concrete Institute)
Guide for the design and construction of externally bonded FRP systems for strengthening concrete structures.

ACI Committee 440.2R-02

Approvals
USA

France
SODOTEC, Direction des techniques et des méthodes: Rapport d'enquête technique, cahier des charges Sika® CarboDur® et SikaWrap®

Poland
Road and Bridges Research Institute, IBDM Technical Approval No. AT/2003-04-336

SikaWrap® Reference Projects

Masonry Strengthening
Project
Old Navy Store in Salt Lake City, Utah (USA)

Sika Solution
The unreinforced masonry (URM) walls in this project were seismically strengthened with 2 layers of ± 45° SikaWrap®-116G glass fiber fabric to offer resistance against in-plane shear loads.

Material quantity involved: 2000 m² SikaWrap® Hex-230C and 2100 kg of Sikadur®-330 as impregnation resin.

A model was produced and loaded at the local university until the first cracks appeared. Then strengthening took place, followed by a further successful load test.

Project
Strengthening of infill brick walls against out-of-plane bending from seismic action in Gebze, Kocaeli (TR)

Sika Solution
SikaWrap® Hex-230C carbon fiber fabric was applied in a grid to the brick walls. Anchorage to the RC frame was provided by using steel angles at the edges.

Project
Strengthening of a masonry dome in S. Vitale Church in Parma (I) due to cracks from seismic activity

Sika Solution
The vertical cracks with a width of up to 10 mm were sealed using Sikadur® epoxy resins. Two layers of SikaWrap® Hex-230C carbon fiber fabrics were applied around the dome’s base with Sikadur®-330 resin.

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National Technical University of Athens, Greece.
**SikaWrap® Reference Projects**

**Silo, Pylon and Tower Strengthening**

**Project**
Strengthening of Albany silos (AUS)

**Sika Solution**
Large vertical cracks in cell walls occurred due to inadequate design value of horizontal pressure.

**Material quantity involved:** approx. 16 000 m² SikaWrap® Hex-230C carbon fiber fabrics and 22 000 kg impregnating resin Sikadur®-330.

**Project**
Refurbishment of 92 severely damaged columns supporting the cooling tower concrete shell at Laziska Power Plant (PL)

**Sika Solution**
First all the columns were refurbished with sprayed concrete, Sika MonoTop repair system and leveled with Sikagard-720 EC pore sealer. Subsequently strengthened with SikaWrap® Hex-230C, bonded with Sikadur®-330. Finally all surfaces were protected with Sikagard®-680 S Betoncolor coating, which gave the final aesthetic look and durability for the construction.

**Project**
Strengthening of concrete transmission towers in Brauchburg, NJ (USA)

**Sika Solution**
The existing vertical cracks were first injected with Sikadur® low viscosity resin. The pre-cast concrete towers were then wrapped with 3 layers of SikaWrap®-103C carbon fiber fabric to provide additional strength and stability.

**Project**
General rehabilitation of shops and offices in Athens (GR)

**Sika Solution**
The higher loads that will be introduced in the structure will develop shear and flexural forces in the joints greater than those that the structure was designed for. Shear strengthening of beams near the beam column and beam-to-beam joints with SikaWrap®-300C HiMod NW carbon fiber fabric and Sikadur®-300 and Sikadur®-330 impregnating resins.

**Project**
Seismic strengthening of I-57 bridge at Cairo, Illinois (USA)

**Sika Solution**
A total of 50 bridge piers and 158 columns were seismically strengthened with approx. 9000 m² SikaWrap®-100G glass fiber fabric and Sikadur®-300 epoxy resin, followed by 2 layers of coating to protect against weathering.

**Project**
Shear strengthening of the girders of Karababa and Gıksu bridges on Bozova-Adıyaman Road (TR)

**Sika Solution**
Heavy turbines of approx. 270 tons had to pass over the bridges, strengthening was necessary due to these heavy loads. Flexural strengthening with Sika CarboDur® CFRP plates and shear strengthening with SikaWrap® Hex-230C carbon fiber fabrics. 3800 m² SikaWrap® Hex-230C and 6250 m² Sika CarboDur® S1012 were used.
SikaWrap® Fabrics Product Range

<table>
<thead>
<tr>
<th>Product Name</th>
<th>Fiber Type</th>
<th>Fiber Strength (MPa)</th>
<th>Fiber Stiffness (GPa)</th>
<th>Area Weight (g/m²)</th>
<th>Fabric Thickness (mm)</th>
<th>Style (UD: unidirectional)</th>
<th>Preferred Application Method **</th>
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* Based on total unidirectional fiber content
** All dry applied fabrics can also be wet applied

Sikadur® Impregnation Resins

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<tr>
<th>Description</th>
<th>Sikadur®-330</th>
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<table>
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For additional Information see corresponding Product Data Sheets

Also available from Sika

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Your local Sika Company

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