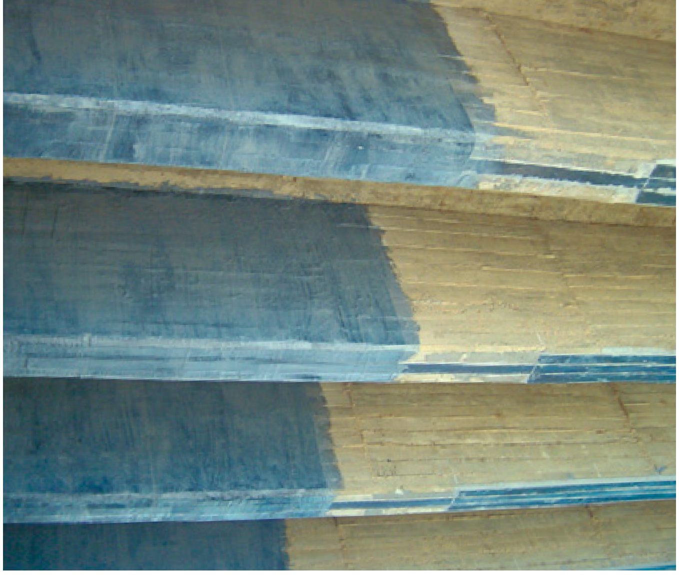
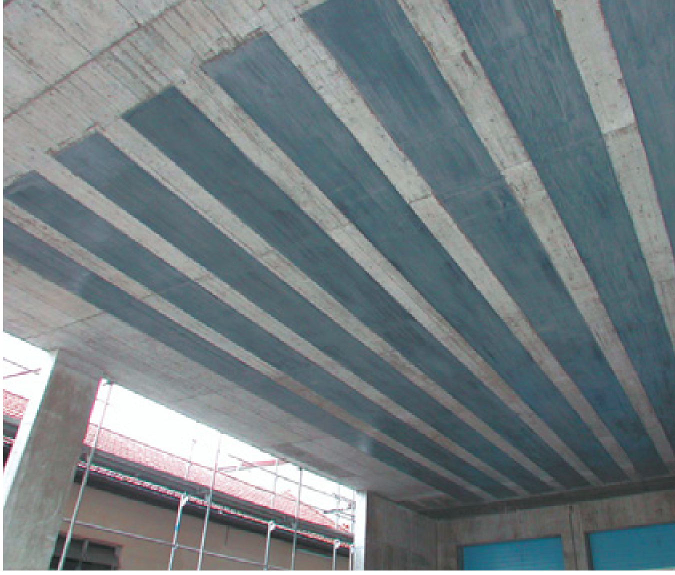
Construction


Structural Strengthening
with SikaWrap® Fabric Systems

Strengthening Fibers, SikaWrap® Fabrics and Sikadur® Resins

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.

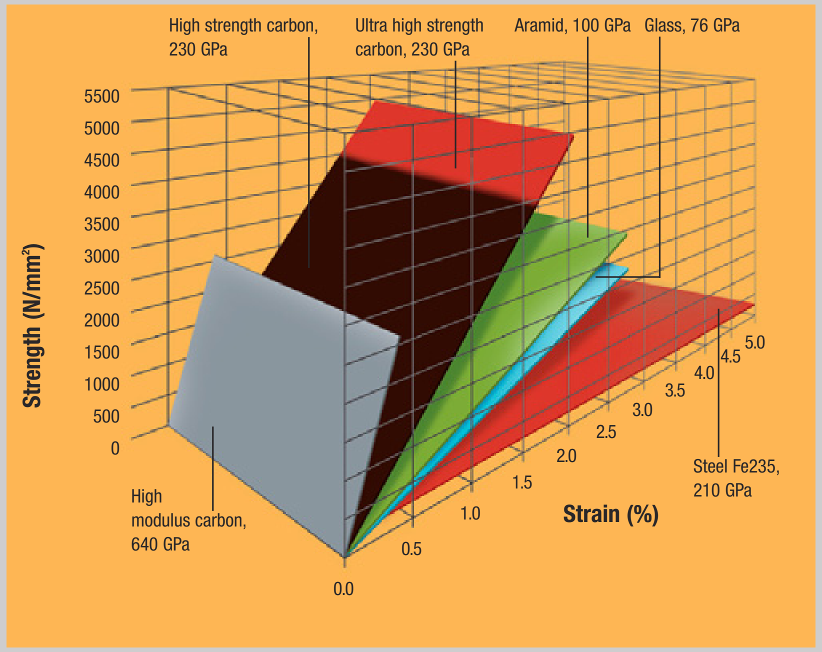
Aramid Fibers

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 fiber types 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 chioce

SikaWrap® Fabric Types

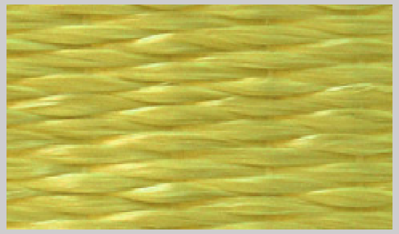
SikaWrap® fabrics are available in many areal weights, production types and fiber alignments. They are selected by the type of strengthening and the loading requirements.

Differentiation by Production

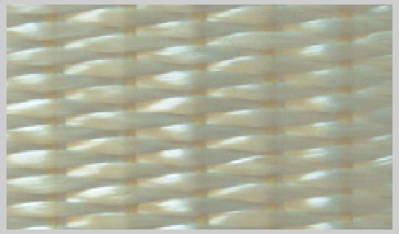
Woven Fabrics

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).

Carbon: SikaWrap-300C, 300 g/m²



Aramid: SikaWrap-300A, 300 g/m²



E-Glass/Aramid: SikaWrap-107G, 955 g/m²

Non-woven Carbon Fiber Fabrics

These have the best fiber alignment (no deviations) which is of great importance for stiffening applications. This non-crimp arrangement allows utilization of the full stiffness capacity of the fiber.

HS carbon: SikaWrap-200C NW, 200 g/m² or
HM carbon: SikaWrap-400C HiMod NW, 400 g/m²

Differentiation by Fiber Alignment

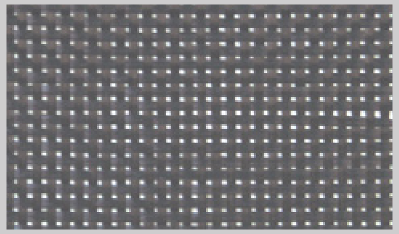
Unidirectional Fabrics

- Majority of fibers in one direction

Most **SikaWrap®** fabrics are unidirectional which is ideal for strengthening needs. They are easy to combine in several layers and can easily be applied in different directions.

Multi-directional Fabrics

- Fibers in more than one direction



Carbon: SikaWrap-160C 0/90, 160 g/m²

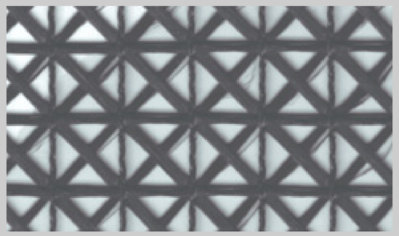
Hybrid Fabrics:

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

Extended SikaWrap® Range

Beside 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.



Impregnating Resins

Depending on the fabric type and areal weight, the optimized impregnation resin can be selected. **Sikadur®** epoxy resins are especially formulated products to meet the needs of the contractor as well as the structure. Durability and easy application are important issues for the long-term success of a strengthening project.

Mid-viscous Resins

Creamy, pasty 2-component impregnation resins with a thixotropic behaviour (e.g. **Sikadur®-330**). To be used with the dry application method or as a sealer for the wet application. Best application properties on walls and for overhead applications.

Low-viscous Resins

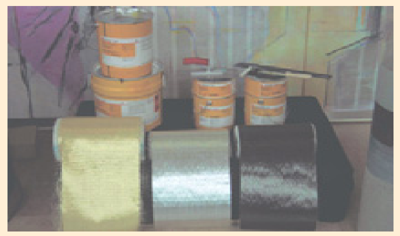
Honey-like 2-component impregnation resins (e.g. **Sikadur®-300**) for use with the wet application of heavy-weight woven and for non-woven fabrics.

Long-term Experience

Sikadur® epoxy-resin-based structural resins and adhesives are proven on segmental bridge construction and for structural strengthening projects worldwide since 1960.

Sika® CarboDur® Composite Strengthening Systems

Since the early 1990's **Sikadur®** structural resins and adhesives for FRP applications are sold under the brand **Sika® CarboDur®** composite strengthening systems.



Structural Applications

General

SikaWrap® fabrics are a group of strengthening materials that can fulfil 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.

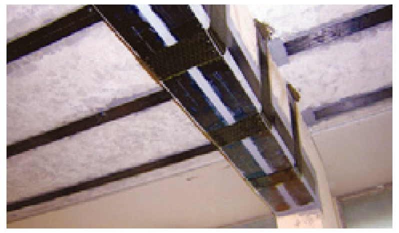
Confinement

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.

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.



Impact Strengthening

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

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.

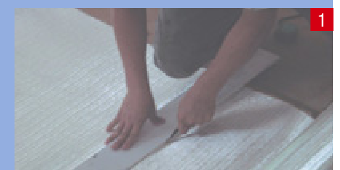
Flexural Strengthening

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.

Application Process

Dry	Wet
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.	**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: easy application.	**Advantage: ideal system for large applications and heavy and tight woven fabrics.**

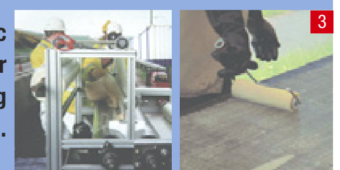
- **The substrate must be clean, free from oil, grease, dust, cement laitance, coatings etc. Prepare substrate by means of sandblasting or grinding. Clean the substrate thoroughly and remove friable or loose particles as well as dust.**
- **Inject cracks. Cracks wider than 0.25 mm must be stabilized using epoxy injection methods.**
- **The substrate must be level (better than 15 mm over 1 m length). In case re-profiling of the surface is required, the repair mortars or resins must be allowed to cure fully prior to application of fabrics.**
- **Round off all edges according to the fabric applied or as per the project specifications (>20 mm).**
- **Minimum concrete tensile strength according to the fabric applied or as per the project specifications.**
- **Special attention should be paid to the ambient conditions. Observe temperatures of substrate, atmosphere and materials as well as dew point. Ambient and substrate temperature during application must be at least 3 °C above dew point.**



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

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

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



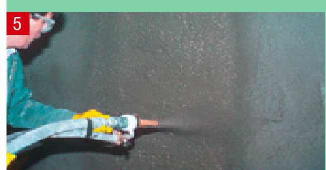
Impregnating the fabric manually on a table or with a saturator using Sikadur®-300 resin.

Dry fabric is applied to the coated substrate.

Pre-wetted fabric is applied on the sealed surface.

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 cementitous coating is applied to the fabric surface.

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

SikaWrap® System Selection

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:

- ❷ Total ExA/m width [MN/m, all layers]
- ❸ Material cost (fabric, primer, resin) for all layers [cost/m²]
- ❹ Installation cost without coating [cost/m²]
- ❺ Materials and installation cost (❸ and ❹) without coating [cost/m²]

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

I The **pink horizontal line** ❶ 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).

II It can be seen that this stiffness value can be reached by several materials with a different number of layers (blue columns ❷ of sets **A** to **D** and **F**) but not by set **E** where one layer only is not enough.

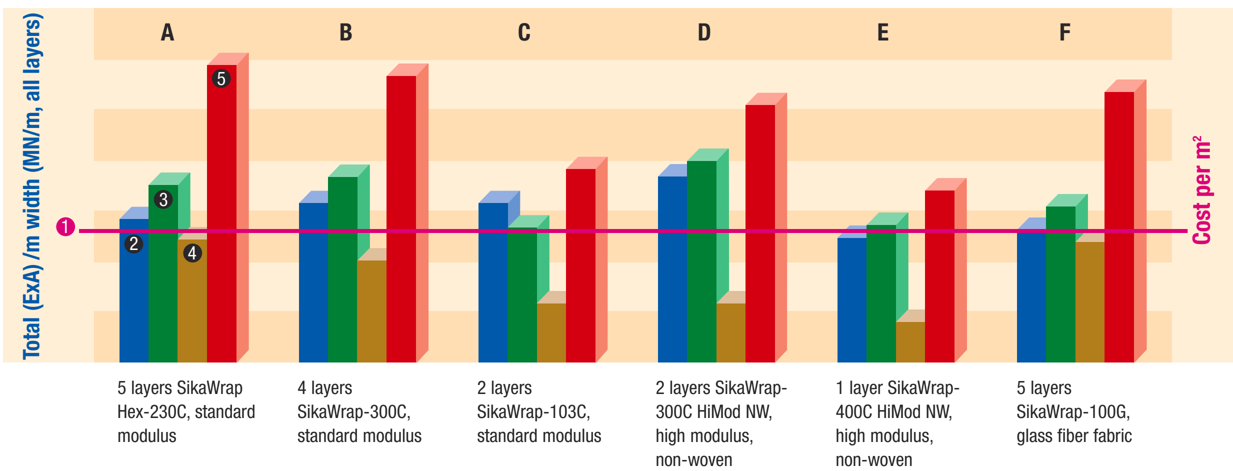
III Based on the assumptions for the local material and labour cost the height of the red column ❺ is the scale for the final decision based on the mechanical properties.

IV 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 fulfil 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 fiber fabric. Despite the advantages in low fabric material cost, the low elastic modulus of the glass fibers cannot be compensated in a cost efficient way.

Total (ExA) per m width (MN/m, all layers)
Material cost (fabric, primer, resin) for all layers
Installation cost
Materials and installation cost without coating



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 should not 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.

Quality Control

Laboratory testing of cured laminates in tension to determine the mechanical properties is a delicate process. It can be done according to e.g. ISO 527-5 or ASTM D3039 or similar. To achieve the full laminate strength according to the theory is rarely possible due to many influences, such as:

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

Quality control on-site: It is recommended to produce so-called witness panels, according to a predetermined sampling plan. They are cured in the same conditions as the applied strengthening system. After curing on-site, the panels can be sent to a laboratory for testing tensile strength and modulus and have to meet the agreement set by the responsible designer.

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):

Project Specification Examples									SikaWrap Alternatives®								
Job Type Description	Fiber Strength (MPa)	Fiber Stiffness (GPa)	Areal Weight (g/m²)	Fiber Density (g/cm³)	Fabric Thickness (mm)*	Number of Layers	E x A (MN/m) **	F_u (kN) ***	Sika Fabric Type	Fiber Strength (MPa)	Fiber Stiffness (GPa)	Areal Weight (g/m²)	Fabric Thickness (mm)*	Number of layers	E x A (MN/m) **	F_u (kN) ***	
Stiffness driven																	
Shear Strenghening of a RC Beam	(3800)	230	300	1.80	0.167	3	115.0	–	SikaWrap-400C HiMod NW	(2600)	640	400	0.187	1	119.7	–	Material and application cost can be reduced
Shear Strengthening of a RC Beam	(2600)	640	250	2.12	0.118	1	75.5	–	SikaWrap-300C NW	(3900)	230	300	0.166	2	76.4	–	Material cost can be reduced
Strength driven																	
Confinement of RC Columns	3500	(230)	400	1.80	0.222	5	–	3885	SikaWrap-103C	3900	(230)	610	0.337	3	–	3943	Material and application cost can be reduced

* Fabric areal weight / fiber density ** E × A = number of layers × fiber stiffness × fabric thickness × width *** F = number of layers × fiber strength × fabric thickness × width

- As mentioned, these examples give only ideas of how the large **SikaWrap**® fabrics range can be selected, depending on the situation
- Obviously the comparisons can end with a different result than shown in the examples above, depending on the local cost level

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, Design, Approvals

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.

Strengthening for shear with CFRP fabric SikaWrap® Hex-230C/ Sikadur®-330.

Swiss Federal Laboratories for Materials Testing and Research, EMPA: Report No. 405552.

Seismic retrofitting of corrosion-damaged RC columns.

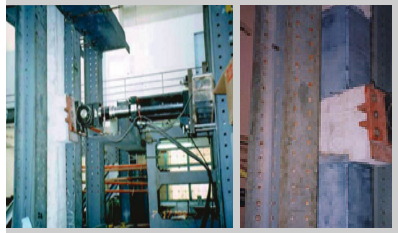
Patras University, Greece.

Testing of masonry walls externally re-inforced 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.



Seismic behaviour of RC columns with CFRP fabrics SikaWrap® Hex-230C/ Sikadur®-330.

National Technical University of Athens, Greece.

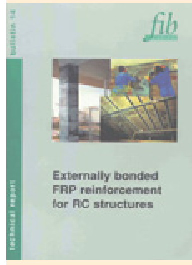
Design

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

fib (fédération internationale du béton)

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

fib 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
ICBO Evaluation Service, Inc.: Evaluation Report ER-5558

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

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

SikaWrap® Reference Projects

Masonry Strengthening

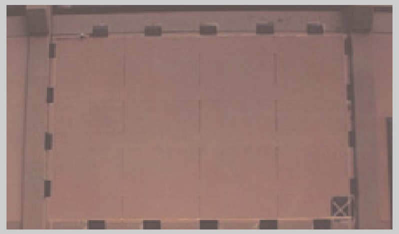
Project
Old Navy Store in Salt Lake City, Utah (USA)

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.

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.

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



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.

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.

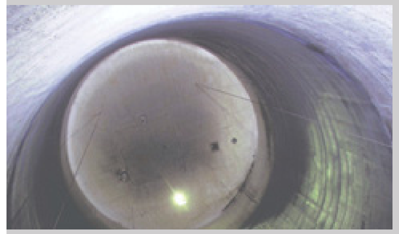
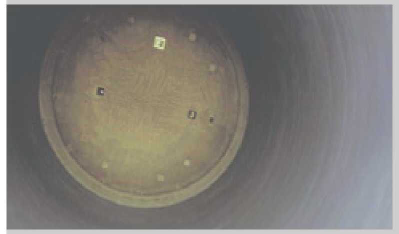
SikaWrap® Reference Projects

Silo, Pylon and Tower Strengthening

Project
Strengthening of Albany silos (AUS)

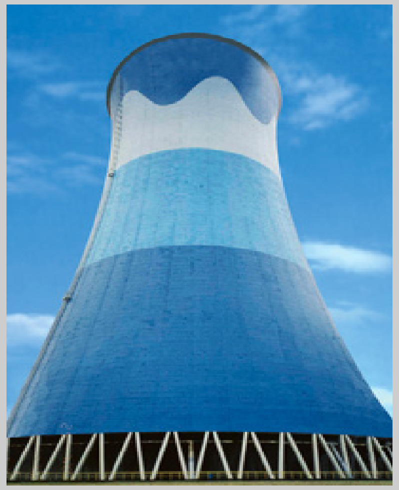
Sika Solution
Large vertical cracks in cell walls occurred due to inadequate design value of horizontal pressure.
Material quantity involved: approx. 16 000 m^2 **SikaWrap® Hex-230C** carbon fiber fabrics and 22 000 kg impregnating resin **Sikadur®-330.**



Project
Refurbishment of 92 severely damaged columns supporting the cooling tower concrete shell at Łaziska 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.



Confinement and Shear Strengthening

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
Shear strengthening of the girders of Karababa and Göksu bridges on Bozova-Adiyaman 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 m^2 **SikaWrap® Hex-230C** and 6250 m **Sika® CarboDur® S1012** were used.





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 m^2 **SikaWrap®-100G** glass fiber fabric and **Sikadur®-300** epoxy resin, followed by 2 layers of coating to protect against weathering.




Sika® System Solutions

SikaWrap® Fabrics Product Range

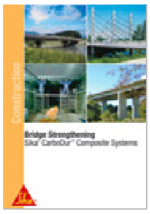
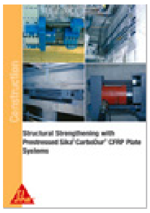
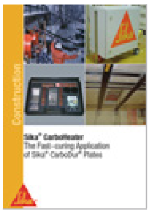
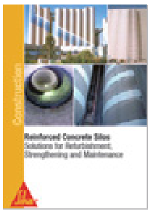
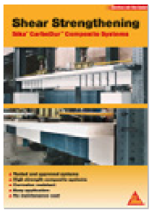
Product Name SikaWrap®	Fiber Type	Fiber Strength (MPa)	Fiber Stiffness (GPa)	Areal Weight (g/m²)	Fabric Thickness (mm)*	Style (UD: unidirectional)	Preferred Application Method **
SikaWrap®-200C	Carbon	3900	230	200	0.111	Woven UD	Dry
SikaWrap® Hex-230C	Carbon	4100	230	220	0.122	Woven UD	Dry
SikaWrap®-300C	Carbon	3900	230	300	0.166	Woven UD	Dry or wet
SikaWrap®-103C	Carbon	3900	230	610	0.337	Woven UD	Wet
SikaWrap®-200C NW	Carbon	3900	230	200	0.111	Non-woven UD	Wet
SikaWrap®-300C NW	Carbon	3900	230	300	0.166	Non-woven UD	Wet
SikaWrap®-160C 0/90	Carbon	3800	230	160	0.046 (per direction)	Woven bidirectional	Dry
SikaWrap®-201C	High strength carbon	4900	230	200	0.110	Woven UD	Dry
SikaWrap®-231C	High strength carbon	4900	230	230	0.127	Woven UD	Dry
SikaWrap®-301C	High strength carbon	4900	230	300	0.167	Woven UD	Dry or wet
SikaWrap®-300C HiMod NW	High modulus carbon	2600	640	300	0.140	Non-woven UD	Wet
SikaWrap®-400C HiMod NW	High modulus carbon	2600	640	400	0.187	Non-woven UD	Wet
SikaWrap®-100G	E-Glass	2300	76	935	0.358	Woven UD	Wet
SikaWrap®-107G	E-Glass / Aramid	2300	76	955	0.347	Woven UD	Wet
SikaWrap®-430G	E-Glass	2300	76	430	0.172	Woven UD	Dry
SikaWrap®-300A	Aramid	2880	100	300	0.206	Woven UD	Wet
SikaWrap®-450A	Aramid	2880	100	450	0.309	Woven UD	Wet

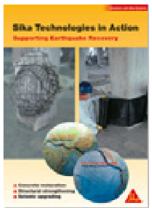
* Based on total unidirectional fiber content ** All dry applied fabrics can also be wet applied

Sikadur® Impregnation Resins

	Sikadur®-300	Sikadur®-301	Sikadur®-330
Description	■ Low-viscous, solvent-free, 2-component impregnation resin on epoxy base ■ Long pot life for saturator use	■ Thixotropic, solvent-free, 2-component impregnation resin on epoxy base	■ Thixotropic, solvent-free, 2-component impregnation resin on epoxy base
Use	■ Impregnation resin for the wet application method ■ Primer for smooth substrate surface	■ Impregnation resin for the wet application method	■ Impregnation resin for the dry application method ■ Primer for rough substrate surface
Application Temperature Range (°C)	+15 ... + 40	+10 ... + 35	+10 ... + 35
Tensile Strength (MPa)	45	35	30
Pot Life (min./°C)	240 / +23	40 / +23	60 / +23
Tensile Modulus (MPa)	3500	3300	4500

For additional Information see corresponding Product Data Sheets
Also available from Sika



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Your local Sika Company

Our most current General Sales Conditions shall apply. Please consult the Product Data Sheet prior to any use and processing.

Certified Quality System ISO 9001/EN 29001 since 1986

Certified Management System ISO 14001 since 1997