

## STRUCTURAL STRENGTHENING WITH FRP

AYDIN KHAJEPUR SIKA PARSIAN, TM REFURBISHMENT



#### **OVERVIEW**

- Rigid Bonding
  - Fields of Use
  - Product Range of Sikadur<sup>®</sup>
- Anchoring
- Structural Strengthening
  - Reasons for strengthening
  - CarboDur<sup>®</sup> System
  - SikaWrap<sup>®</sup> System



#### CONTENTS

- Shear Strengthening
  - SikaWrap<sup>®</sup>
  - CarboShear
- Column Confinement
- Dry and Wet application Process
- Seismic Strengthening
- Protection & Durability





# **RIGID BONDING**



#### **RIGID BONDING**

#### LOAD TRANSMISSION

- Stiff bond between two or more elements
- Possible materials are hardened, green and fresh concrete, masonry, natural stone, steel, other metals, wood and GFRP structures
- Small repair or levelling works, especially when under time constraints





#### **RIGID BONDING: USES**

 Segmental Bridges: Almost homogeneous, monolitic material properties



Joining of elements





#### **RIGID BONDING: USES**

Injection, Structural repair



Installing fibers





#### **RIGID BONDING: DIFFERENT SETUPS**



#### Tensile- and Compressive Stress



#### **RIGID BONDING: DIFFERENT REQUIREMENTS**



Low application temperatures



Applicable under water



Resistant against high temperatures



**Damp substrates** 



Very fast or slow curing



Thick or thin layers



**Different viscosities** 



Machine application (in large quantities)



#### **TYPES OF ADHESIVES**

- Bonding of Elements (same or different materials)
- Bonding of fresh or cured concrete
- Repair mortars
- Anchoring
- Grouts
- Injections
- Bonding of composite materials
- Impregnation of fibre fabrics





### SIKADUR<sup>®</sup> PRODUCT RANGE

- Sikadur<sup>®</sup>-31
  - Structural adhesive for various substrates
- Sikadur<sup>®</sup>-32
  - Bonding agent for old and fresh concrete
- Sikadur<sup>®</sup>-30, -30 LP, -330, 300
  - Adhesives for structural strengthening
- Sikadur<sup>®</sup>-41, -43
  - Epoxy based mortars





### **RIGID BONDING: RANGE OF APPLICATION**

Almost homogeneous, monolitic material properties







#### BONDING OF ELEMENTS – SEGMENTAL BRDGES SIKADUR<sup>®</sup>-31 SBA

- Solvent-free, moisture tolerant, thixotropic, structural two part adhesive, based on epoxy resin
- Different Versions:
  - SBA 02
  - SBA 03
  - SBA 04
  - SBA 07
  - SBA 08





# ANCHORING



#### **TYPES OF ANCHORS**





### SIKA ADHESIVE SYSTEMS FOR ANCHORING





- Polyester (styrene free)
  Sika AnchorFix<sup>®</sup> -1
- Epoxy Sika AnchorFix<sup>®</sup>-3<sup>+</sup>
- Epoxy-acrylate (Hybrid) Sika AnchorFix<sup>®</sup>-2
- Polyester (styrenated)
  Sika AnchorFix<sup>®</sup>-S

Advantages: More flexibility for

- Anchor type
- Anchor diameter
- Drill hole depth



#### **ANCHORS ARE EVERYWHERE!**









#### ANCHORING: SIKA ANCHORFIX®





# STRUCTURAL STRENGTHENING



### **REASONS STRUCTURAL STRENGTHENING**

- Load Increase
- Repair of damaged members
- Modification of structural system
- Improvement of structure
- Errors in design and construction





# SHEAR STRENGTHENING





#### **INSPECTION 20 YEARS AFTER CONSTRUCTION**



95% of 1300 precast girders of trestle spans show shear cracks

Structural Safety

Deficient in shear and torsion

#### Durability

- Aggressive marine environment
- Direct access for moisture and chlorides to prestressed strand



#### FULL SCALE LOAD TESTING



Full-scale AASHTO Type IV precast girder, 21% increase of shear capacity









#### SHEAR STRENGTHENING OF BEAMS AND COLUMNS





### SHEAR STRENGTHENING FULLY-WRAPPING CONFIGURATION



Completely wrapped (Drill through slab)





#### CARBOSHEAR L



- Easy installation
- Leg length is adjustable: up to 80cm (bottom) and 150cm (side)



### SHEAR STRENGTHENING SIKA CARBOSHEAR®







#### ANCHORAGE TESTS





Tensile force

Free length	Resistance	Efficiency
650 mm	126	100%

Anchorage length	Resistance	Efficiency
100 mm	77 kN	61%
150 mm	100 kN	79%
200 mm	121 kN	96%

Design force at 0.4% strain: 45 kN



# **COLUMN CONFINEMENT**





#### BRIDGE COLUMN FAILURE DUE TO EARTHQUAKE







### COLUMN CONFINEMENT EXTERNAL CONFINEMENT OPTIONS



#### CARBON FIBRE REINFORCED POLYMER (CFRP) JACKET





Strengtheing of nodes with CFRP fabric Design: Fib Bulletin 35



### COLUMN CONFINEMENT EFFICIENCY

Unlike other reinforcement systems, confinement effectiveness strongly depends on the geometry of the cross-section.



### COLUMN CONFINEMENT INFORMATION TO BE SUPPLIED BY THE DESIGNER

#### **CFRP JACKET DEFINITION**

Necessary SikaWrap E-modulus Necessary SikaWrap ultimate stress and strain Necessary SikaWrap thickness



#### **ARRANGEMENT (POSITION, LAYERS...)**

Number of layers Continous jacket or discrete strips Splice length and position





### SIKAWRAP® FABRIC TYPES AND APPLICATION



#### COMPARISON GLASS - CARBON MATERIAL PROPERTIES

**Glass Fibre Fabric** 

**Carbon Fibre Fabric** 

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E-Modulus	75 kN/mm²	230 kN/mm <sup>2</sup>
Tensile strength	2500 N/mm <sup>2</sup>	4300 N/mm <sup>2</sup>
Resistance to alkalinity + permanent stress	Limited	Excellent
Main application	Seismic	All



#### FABRIC STRENGTHENING SYSTEM







### SIKAWRAP<sup>®</sup> SYSTEM



SikaWrap®

#### **INSTALLATION OF SIKAWRAP®**





Dry application Light fabrics Sikadur<sup>®</sup>-330





Wet application Heavy fabrics Sikadur<sup>®</sup>-300

![](_page_40_Picture_7.jpeg)

### SATURATING THE SIKAWRAP<sup>®</sup> FABRICS

#### Saturating: Producing the composite

![](_page_41_Picture_2.jpeg)

Manual - wet

![](_page_41_Picture_4.jpeg)

Automated - wet

Manual - dry

![](_page_41_Picture_7.jpeg)

**BUILDING TRL** 

### DRY APPLICATION / WET APPLICATION

#### Light – Shear strengthening

	Dry Application	Wet Application
Fabric	1 x SikaWrap <sup>®</sup> -300C	1 x SikaWrap <sup>®</sup> -300C
Primer	Sikadur <sup>®</sup> -330	Sikadur <sup>®</sup> -330
	1.3 kg/m2	0.6 kg/m2
Saturant	-	Sikadur <sup>®</sup> -300
		1 x 0.7 kg/m2
Material cost	100%	96%
Labor	30 Min/m <sup>2</sup>	35-40 Min/m <sup>2</sup>

![](_page_42_Picture_3.jpeg)

### DRY APPLICATION / WET APPLICATION

#### Heavy Strengthening – column wrapping

	Dry Application	Wet Application
Fabric	4 x SikaWrap <sup>®</sup> -300C	2 x SikaWrap <sup>®</sup> -600C
Primer	Sikadur <sup>®</sup> -330	Sikadur <sup>®</sup> -330
	1.3 kg/m2	0.6 kg/m2
Saturant	Sikadur <sup>®</sup> -330 (additional layer)	Sikadur <sup>®</sup> -300
	3 x 0.8 kg/m2	2 x 0.75 kg/m2
Material cost	100%	75%
Labor	110 Min/m <sup>2</sup>	60 Min/m <sup>2</sup>

![](_page_43_Picture_3.jpeg)

### SIKAWRAP<sup>®</sup> CORPORATE RANGE

- Carbon fibre fabrics
  - SikaWrap<sup>®</sup>-150C
  - SikaWrap<sup>®</sup>-200C
  - SikaWrap®-230C
  - SikaWrap<sup>®</sup>-300C
  - SikaWrap<sup>®</sup>-530C
  - SikaWrap®-600C
  - SikaWrap®-900C

![](_page_44_Picture_9.jpeg)

- Glass fibre fabrics
  - SikaWrap<sup>®</sup>-430G
  - SikaWrap<sup>®</sup>-930G

![](_page_44_Picture_13.jpeg)

![](_page_44_Picture_14.jpeg)

#### SIKAWRAP<sup>®</sup> PDS VALUES

#### Mechanical / Physical Properties

Dry Fibre Properties	Values in the longitudinal direction of the fibres (according to ISO 10618)		
	Tensile Modulus	Minimum Value	230'000 N/mm <sup>2</sup>
	Tensile Strength	Minimum Value	4'000 N/mm <sup>2</sup>
	Elongation at break		1.7 %
Laminate Properties (related to fibre	Values in the longitudinal direction of the fibres (according to EN 256 Single layer, minimum 27 samples per test series		
(hickness)	Laminate thickness (nominal)    →    0.129 mm      Design cross section per 1000 mm width    129 mm <sup>2</sup>		
	Topcilo Modulus	Average	225 kN/mm <sup>2</sup>
	Tensile Modulus	Characteristic	220 kN/mm <sup>2</sup>
	Topcilo Strongth	Average	3500 N/mm <sup>2</sup>
	rensie strength	Characteristic	3200 N/mm <sup>2</sup>

\* modification sample with 50 mm

![](_page_45_Picture_4.jpeg)

## **CARBODUR PLATES**

![](_page_46_Picture_1.jpeg)

#### CARBODUR® PLATES

![](_page_47_Picture_1.jpeg)

- E-modulus: Standard type and Medium type
- Dimensions, width & thickness
- Profiles: rectangular and round

![](_page_47_Picture_5.jpeg)

### SIKA CARBODUR® SYSTEM

#### CarboDur<sup>®</sup> plate

	E-Modulus	Dimensions
CarboDur <sup>®</sup> S	165 GPa	Thickness      1.2 – 2.6 mm        Width      50 – 150 mm
CarboDur <sup>®</sup> M	210 GPa	Thickness1.4 mmWidth50 – 120 mm
CarboDur <sup>®</sup> BC rods	148 GPa	Diameter 6-12 mm

#### Sikadur<sup>®</sup>-30 resin

	Application Temperature
Sikadur <sup>®</sup> -30	8 – 35 °C
Sikadur <sup>®</sup> -30 LP	25 – 55 °C

![](_page_48_Picture_5.jpeg)

# SEISMIC STRENGTHENING

![](_page_49_Picture_1.jpeg)

#### FAILURE MODES OF MASONRY STRUCTURES

#### In-plane failure

![](_page_50_Picture_2.jpeg)

### STRENGTHENING WITH GLASS FIBRE FABRIC

#### SikaWrap-430G

![](_page_51_Picture_2.jpeg)

![](_page_51_Picture_3.jpeg)

#### Test at ZAG, Slovenia, 2010

![](_page_51_Picture_5.jpeg)

# Durability

### SIKADUR<sup>®</sup> EPOXY ADHESIVE

1966 Sikadur for Segmental Bridge Construction

![](_page_53_Picture_2.jpeg)

1966 Viaduc de Chillon, Switzerland

![](_page_53_Picture_4.jpeg)

#### 40 YEARS CREEP TEST SIKADUR® ADHESIVE

![](_page_54_Picture_1.jpeg)

1970 Long Term Test at EMPA, Switzerland (still running)

![](_page_54_Picture_3.jpeg)

#### LONG TERM EXPERIENCE

- SikaWrap<sup>®</sup>
  - **1991**

- CarboDur<sup>®</sup>
  - **1994**

CarboStress<sup>®</sup>2000

![](_page_55_Picture_6.jpeg)

![](_page_55_Picture_7.jpeg)

![](_page_55_Picture_8.jpeg)

#### **RESULTS AFTER 100 AGING CYCLES**

Tensile Properties CarboDur<sup>®</sup>

![](_page_56_Figure_2.jpeg)

Lap Shear Strength CarboDur<sup>®</sup> + Sikadur<sup>®</sup>-30

![](_page_56_Figure_4.jpeg)

	$f_f$ [MPa]	$E_f[MPa]$
Sample before aging	3195	179781
Sample after aging	3158	172000
Comparison	× 0,988	× 0,957

	τ <sub>mov</sub> [MPa]
Sample before aging	11.69
Sample after aging	14.15
Comparison	× 1.21

![](_page_56_Picture_7.jpeg)

### DURABILITY CARBODUR<sup>®</sup> + SIKADUR<sup>®</sup>-30 ON CONCRETE

Lap shear test

Pull off test

![](_page_57_Picture_3.jpeg)

Temperature: 40° C Relative humidity: 95%

![](_page_57_Picture_5.jpeg)

### PROTECTION OF STRENGTHENING SYSTEMS

Situation	Special need	Sika <sup>®</sup> solution
Direct sunlight	UV protection	Sikagard <sup>®</sup> -550 W Elastic Sikagard <sup>®</sup> -675 W ElastoColor
Use near/in water - Immersion in water	Protection against water ingress.	Sikagard <sup>®</sup> -63N
Use near/in water with direct sunlight	Protection against ingress of water and UV	SikaCor® EG5
Improved reaction to fire	Fire protection	Sikacrete®-213F Sika MonoTop®
Resistance to fire	Fire protection	Sikacrete <sup>®</sup> -213F

![](_page_58_Picture_2.jpeg)

![](_page_59_Picture_0.jpeg)

# **QUESTIONS?**

![](_page_59_Picture_2.jpeg)

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![](_page_60_Picture_3.jpeg)