STRENGTHENING OF STRUCTURES WITH THE CARBOSTRESS® SYSTEM

F. Fischli 1, R. Clénin 2, A. De Silva 3* and P. Chaemmangkang 4

1 VSL (Switzerland) Ltd., Industriestrasse 14, CH-4553 Subingen, Switzerland.
2 Corporate Con., Sika Services AG, Tüffenwies 16-22, Zürich, Switzerland.
3 Structural Preservation Div.–Asia Pac., 25 Senoko Way, Woodlands, Singapore. Email: adesilva@vsl-sg.com

ABSTRACT

In situations where the structure to be strengthened can be overstressed when load changes are anticipated, a passive-repair technique may not be applicable as unloading or service shut-down of the structure may be required. Additionally, only the stress due to the live-load portion may be reduced. In structures where the ratio of dead-load to live-load is large, an active-repair technique, including prestressing may be the only choice. Intensive development work by Sika and VSL has resulted in a new post-tensioning system, using CFRP tension members, called the CarboStress System, which represents a more effective way of utilizing the CFRP material. Such the system consists of the tensile member made entirely out of CFRP; thus, corrosion resistant, and can be used as bonded or unbonded system depending upon the existing condition of the structure.

KEYWORDS

Passive- and Active-Repair Techniques, Prestressed CFRP, Bonded and Unbonded Prestressed CFRP, CarboStress System

INTRODUCTION

Strengthening techniques may generally be categorized into passive and active, depending on how loads interact with materials used to strengthen the structure. Techniques in which no participation in stress sharing commences until additional loads are applied and/or until additional deformation occurs are called passive. Among many different passive-repair methods, bonded non-prestressed Carbon Fiber Reinforced Polymer (CFRP) is one of the most-commonly adopted applications.

In many situations, the structure can be overstressed when load changes are anticipated, and hence the bonded non-prestressed CFRP may not be applicable. To eliminate such conditions, an active-repair technique, including prestressed CFRP, which will immediately reduce the stress by sharing the loads, may be the only choice.

Intensive development work by Sika and VSL has resulted in a new post-tensioning system, using CFRP tension members. The CFRP plate are anchored in CFRP anchorages; thus, forming a tensile member made entirely out of CFRP. Non-stressing (dead end) and stressing load-transfer bodies are available covering all structural cases, which require strengthening by means of external tensile elements.

Such the CFRP prestressing system, called the CarboStress System, can be used as bonded or unbonded system, and has been used in important strengthening projects such as bridges, industrial and high-rise buildings, historical buildings and monuments, structures requiring seismic strengthening and in a nuclear power plant in Switzerland.

This paper presents the development work of the system carried out so far. It describes the characteristics of the system and summarizes advantages of using the post-tensioned (Active) CFRP plates. It also presents practical applications of the system.
DEVELOPMENT WORK

In the early development phase (1999 to 2001), numerous tests were carried out at the Swiss Federal Institute of technology in Zurich, Switzerland. These tests included:

- Short-term tensile tests using steel and various plastic heads with different types of CFRP plates (80mm x 2.4mm and 60mm x 2.4mm)
- Load cycle tensile tests
- Long-term tensile tests
- Load transfer tests from load-transfer bodies to the concrete, and
- Load transfer tests from CFRP plate to CFRP anchor heads

Later in 2004, additional tests were performed at the School of Engineering and Architecture in Horw/Lucerne, Switzerland. The tests included:

- Practical handling tests, i.e. overhead placing and fixing with mortar of steel transfer bodies
- Tensile tests with loads up to bursting
- Testing of ultimate capacity of the load-transfer dowel

THE CARBOSTRESS® SYSTEM

The CarboStress System uses CFRP plates anchored in CFRP anchor heads, so called StressHead, on both ends. These heads are anchored in load-transfer bodies made of steel, anchoring the prestressing force in the structure to be strengthened. A general view of the load-transfer body as well as the information of the system, including the CarboDur® CFRP plate and the StressHead, is presented in Figure 1, Table 1 and Figure 3, respectively. The application of a bonded-prestressed CFRP plate using the CarboStress System can be summarized as follows:

1. Preparation of the concrete surface in the same way as for conventional glued CFRP plates application.
2. Connection of the CFRP plate to the CFRP anchor heads, i.e. StressHead. Mistakes in manipulation are prevented by the design of the StressHead; hence, the connection will always reach the necessary capacity. It should be noted that this process is performed under controlled environment in the factory. End-to-end length of the CFRP plate with anchor heads has to be pre-measured on site.
3. The CFRP anchor heads are connected to the concrete structure to be strengthened using stressing/non-stressing load-transfer bodies. (Figures 2a-2e)
4. Application of the epoxy adhesive to the CFRP plate and the concrete surface in the same way as for the conventional glued CFRP plates application. (Figure 2c)
5. Pre-stressing of the CFRP plate at the stressing anchor head by using a hydraulic jack. The prestressing force is controlled through the use of a pressure gauge in the same way as for the conventional prestressing application, after which the elongation of the CFRP plate is measured and compared with the theoretical value. (Figure 2f)
6. Removal of the prestressing equipment.
7. Pressing of the CFRP plate onto the concrete surface in the same way as for the conventional glued CFRP plates application.

It should be noted that the CarboStress System can also be used for an unbonded-prestressed CFRP plate; thus, steps 1, 4 and 7 may be disregarded.

Figure 1. General View of the Load-Transfer Body of the CarboStress System: (a) Side View, (b) Top View
The table below (Table 1) provides the product characteristics summary of the CarboStress® CFRP Tendon consisting of the CFRP Plate and CFRP Anchor Head.

Table 1. CarboStress® System Information

<table>
<thead>
<tr>
<th></th>
<th>CarboDur® CFRP Plate</th>
<th>StressHead 220</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>S624</td>
<td></td>
</tr>
<tr>
<td>Dimensions (Width x Thickness)</td>
<td>60mm x 2.4mm</td>
<td></td>
</tr>
<tr>
<td>Cross-sectional Area</td>
<td>144 mm²</td>
<td></td>
</tr>
<tr>
<td>Tensile Strength, min.</td>
<td>2,800 N/mm²</td>
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<tr>
<td>Nominal Breaking Load</td>
<td>400 kN</td>
<td></td>
</tr>
<tr>
<td>E-modulus, min.</td>
<td>165,000 N/mm²</td>
<td></td>
</tr>
<tr>
<td>Elongation at Break, min.</td>
<td>1.7%</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>CFRP Anchor Head (StressHead)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>StressHead 220</td>
<td></td>
</tr>
<tr>
<td>Dimensions (Width x Length)</td>
<td>60/80mm x 110mm</td>
<td></td>
</tr>
<tr>
<td>Weight</td>
<td>0.55 kg</td>
<td></td>
</tr>
<tr>
<td>Tensioning Force, $P_0$</td>
<td>220 kN</td>
<td></td>
</tr>
<tr>
<td>- Tensile Strength at $P_0$</td>
<td>1,540 N/mm²</td>
<td></td>
</tr>
<tr>
<td>- Pre-strain at $P_0$</td>
<td>0.95%</td>
<td></td>
</tr>
<tr>
<td>Guaranteed Maximum Anchor Force, $P_{max}$</td>
<td>300 kN</td>
<td></td>
</tr>
<tr>
<td>- Strain at Maximum Anchor Force, $P_{max}$</td>
<td>1.3%</td>
<td></td>
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</table>

Figure 2. Application of a bonded CFRP plate using the CarboStress System

Figure 3. CarboStress’s CFRP Anchor Head (StressHead 220)
Anchorage System

The concept of non-stressing (fixed) and stressing anchorages (Figures 4a and 4b) with load-transfer bodies is guided by the idea of having a simple and flexible system adaptable for each project. The prestressing force is transferred into the concrete structure by a circular steel profile acting as a dowel with a diameter of 125mm and a length of 255mm placed into a drilled hole.

![Stressing Anchorage Type Ds](image1)

![Non-Stressing (Fixed) Anchorage Type Df](image2)

Figure 4. Anchorage Type D

Other configurations of the load-transfer bodies exist to cope with the requirements and boundary conditions of each project are shown in Figure 5. It should be noted that a 35mm-thick recess is typically required for the CFRP plate to be placed sufficiently close to the concrete substrate, either with or without Sikadur 330 in case of the bonded and unbonded system, respectively, as the height of the StressHead 220 is 60mm. For structures with the concrete clear cover of less than 35mm, this thickness can be reduced by increasing the thickness of the Sikadur 330 or providing more space between the CFRP plate and the concrete surface. Additionally, in case of congested existing steel bars, additional reinforcement may be required for continuity of the load path in the area where the loss of existing bars is expected from making a recess or load-transfer dowel installation.

![Various Types of Stressing and Fixed (Non-Stressing) Anchorages](image3)

Figure 5. Various Types of Stressing and Fixed (Non-Stressing) Anchorages Available for the CarboStress System
The anchorage type F is generally applicable where an unsymmetrical force system can be applied without jeopardizing the structures. It may be used either on top or underside as well as on sides of the structures, such as girders and walls. The anchorage type E, on the contrary, may be used where a symmetrical force system is required and the thickness of the structures is moderate or small. In case of the anchorage type E, the load-transfer dowel is placed through the thickness of the structures, e.g. the whole depth of the slab or the web of the girder. The anchorage type G is applicable where the anchorage is required to be rest on the end of the structures. In addition, as it has a threaded transfer body, the CFRP plate can be stressed and anchored on a very short distance behind the support, which is suitable for the structures with tight work space. The anchorage type D is suitable for the structures with slopes, e.g. slabs or girders with haunches. Applications of the anchorages type F, E, G and D are illustrated in Figures 6a-6d, respectively.

![Figure 6. Applications of the Anchorages (a) Type F, (b) Type E, (c) Type G and (d) Type D](image)

**STRENGTHENING WITH BONDED CARBOSTRESS® SYSTEM**

**Advantages of the Bonded Prestressed CFRP**

Advantages from prestressing CFRP plates prior to their bonding to the concrete substrate can be summarized as follows:

- Cracks in the shear span form at a higher load, and are more finely distributed and narrower in width.
- Existing cracks in the structure are closed.
- Same strengthening magnitude is achieved with smaller areas of CFRP plates compared with the bonded non-prestressed CFRP.
- Internal steel reinforcement yields at a higher load compared with the bonded non-prestressed CFRP.

These advantages result in the improvement of the structure’s serviceability and durability as well as a higher utilization of the CFRP material.

**PRACTICAL APPLICATION OF THE CARBOSTRESS® SYSTEM**

Selected practical application of the CarboStress® System are presented in Table 2.

<table>
<thead>
<tr>
<th>Bridge</th>
<th>Name – Location</th>
<th>Reason for Strengthening</th>
<th>Client</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Xiaofeng Bridge, Hunan Province, China</td>
<td>Insufficient Strength in Longitudinal Direction</td>
<td>Guangzhou Railway Bureau</td>
<td>2007</td>
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<tr>
<td></td>
<td>Stegweid Bridge, Spiez, Switzerland</td>
<td>Insufficient Strength of Pier Head Beams</td>
<td>Canton of Berne Public Works Department</td>
<td>2006</td>
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<tr>
<td></td>
<td>Ländten Bridge, Biel, Switzerland</td>
<td>Increasing of traffic loads from 20 to 40 tons</td>
<td>Civil Engineering Office of the City of Biel</td>
<td>2004</td>
</tr>
<tr>
<td></td>
<td>Clinton &amp; Hopkins Bridges, Ohio, USA</td>
<td>Corrosion of prestressed steel tendons</td>
<td>State of Ohio, Department of Transportation</td>
<td>2003</td>
</tr>
<tr>
<td></td>
<td>Hütten Bridge, Werthenstein, Switzerland</td>
<td>Increasing of traffic loads from 20 to 40 tons</td>
<td>Canton of Lucerne Agriculture Department</td>
<td>2003</td>
</tr>
<tr>
<td></td>
<td>Sung San Bridge, Seoul, Korea</td>
<td>Insufficient existing steel reinforcement</td>
<td>Western Roads &amp; Bridges Maintenance Office, Seoul</td>
<td>2002</td>
</tr>
</tbody>
</table>
**CONCLUSION**

Stress in the existing steel reinforcement is often the limiting factor for the passive-repair technique, such as bonded non-prestressed CFRP plates. Unloading the structure to reduce the existing steel stress prior to strengthening is not always possible, and usually requires the service shut-down. In addition, only the stress due to the live-load portion may be reduced.

By applying the active-repair technique, such as prestressed CFRP plates, both dead-load and live-load induced-stresses can be relieved. In case of deteriorated structures, high tensile stress in the corroded steel can be reduced, and thus, a complete steel replacement may not be required. Serviceability as well as durability of the structure can be improved since existing cracks will be closed or narrower in width.

The CarboStress System is an active-repair system, developed to effectively transfer the prestressing force via load-transfer dowels embedded deeply into the sound concrete. The tensile member is made entirely out of CFRP; thus, corrosion resistant. When compared with the bonded non-prestressed CFRP application, the CarboStress System represents a more effective way of utilizing the CFRP material.

Application of the CarboStress System is simple, and requires minor work, i.e. concrete coring for load-transfer dowels, in addition to the work typically carried out for the bonded non-prestressed CFRP. Depending upon the existing concrete substrate condition and site constraint, bonded- or unbonded-prestressed CFRP may be more feasible. However, both methods are applicable with the CarboStress System.

**REFERENCES**


