A RAPID REPAIR AND RETROFITTING INTERVENTION FOR SEISMIC DAMAGED CHINESE BRIDGE USING FIBER REINFORCED CONCRETE SHAPED REBAR AND EXTERNAL CFRP OR STEEL WRAPPING

Davide Lavorato1(*), Alessandro Vittorio Bergami1, Camillo Nuti1,4, Bruno Briseghella2, Angelo Marcello Tarantino3, Silvia Santini1

1Department of Architecture, Roma Tre University, Italy
2College of Civil Engineering of Fuzhou University, Fuzhou, China
3Department of Engineering, University of Modena and Reggio, Italy
4Visiting Professor, University of Fuzhou, College of Civil Engineering, Fuzhou (China)
1(*) Email: davide.lavorato@uniroma3.it

ABSTRACT

A rapid repair and retrofitting technique applied on reinforced concrete (rc) bridges damaged after a strong earthquake, can be a very effective solution to guarantee the use of the bridge for the emergency response in short time. This repair intervention makes possible a proper plastic dissipation distribution on the rebars in plastic hinge only and increases the original insufficient shear strength minimizing the intervention time and cost.

In this paper, the technique was applied on the most damaged pier of an irregular rc bridge designed according to Chinese codes (JTG D60-2004, JTG D62-2004 and JTG/T B02-01-2008) but with insufficient transversal steel reinforcement. The rc pier repair operations consist in: substitution of the original damaged rebar parts by shaped rebar; restoration of the damaged concrete parts by concrete with fibers in plastic hinge only. In particular, this research focuses on the use of fiber concrete to increase the insufficient original shear strength and ductility of the pier.

Compression and flexural tests on fiber concrete specimens were performed to determine the variation of the concrete mechanical properties with different fiber contents. Furthermore, the shear strength of the repaired pier specimen was evaluated by CNR-DT 204/2006 formulations considering the contribution of the new and of the original concrete parts. Finally, some pier specimens (scale 1:6) were repaired using different concrete mixture with different fiber contents to prove the feasibility of the intervention in situ.

Keywords: Fiber reinforced concrete, shaped rebar, CFRP, steel wrapping, repair, retrofitting.

INTRODUCTION

The retrofitting of a rc bridge pier can be done using different techniques as concrete jacketing (Sabnis 1996, Teran 1992, Vandoros 2008), steel jacketing (Georgopoulos 1994, Priestley 1994) or wrapping with FRP (fiber reinforced polymer composite; Triantafillou 2001, Cheng 2006 ) or steel tissue sheet.

Furthermore, some rapid repair interventions for rc columns, which permit a quick opening of the bridge for the emergency response, were presented in literature (Sun 2011, He 2013, Cheng 2003).
Finally, different research studies demonstrated how concrete with fibers can give an important contribution to the ductility and shear strength capacity of rc beam and columns (Mansur 1986, Foster 2001, Lihua Xu 2015).

In this paper, a new repair and retrofitting intervention was proposed to repair seriously seismic damaged rc bridge piers in short time. This technique improves the repair and retrofitting interventions proposed and tested successfully by means of PSD (pseudo-dynamic) tests on seismic damaged Italian bridges piers with insufficient seismic details at Roma Tre University by some of the authors (Lavorato 2015a).

The interventions focused on the damaged parts of the rc pier only (plastic hinge, Fig. ) and consisted of: the substitution of damaged rebar parts, the construction of a concrete jacket without modifying the pier dimension (Fig. b) to restore the damaged concrete and the retrofitting by an external C-FRP wrapping to increase the pier shear strength and ductility. The substitution of the damaged stirrups was limited to the use of a minimum stirrups content to permit a simpler new concrete casting.

However, this research campaign shown that some technique improvements were necessary as a great local plastic demand on the side welding connections between the original anchorages and the new rebar parts (Lavorato 2015a) was evident in some pier specimen during the PSD tests. It is important to underline that the realization of welding on vertical rebars in modest space (removed concrete) in situ is difficult and critical.

For that reason, a new research campaign in collaboration with the College of Civil Engineering of the Fuzhou University and the Sustainable and Innovative Bridges Engineering Research Center of the Fujian Province University (SIBERC) started (Lavorato 2015b). This research focused on the use of shaped rebar for the damaged rebar substitution. The effectiveness of these shaped rebar was tested successfully on pier specimens (scale 1:6) by cyclic test at Fuzhou University lab (Lavorato 2015b). The shaped rebar permitted a proper plastic distribution along the new rebar parts only without local plastic concentration. The rc pier specimens were representative of the seismic damaged piers of an irregular rc bridge designed according to Chinese code but with insufficient shear reinforcement (Fig. ).

In this paper, some new technique improvements are presented about the rebar substitution, the concrete restoration and the shear and ductility improvements to simplify the interventions reducing time and cost. In particular, the shaped rebar connection with the original rebar was realized by means of stronger steel coupler system using symmetric side welding connections. This system is simple to perform in situ on vertical longitudinal rebar in modest space (removed concrete), guarantees a connection of the rebars along the same axis avoiding local bending action on the connection and it results much strong as two symmetric side welding chords are used.

Finally, the use of a fiber concrete jacket to restore the removed concrete without modify the pier dimension, was designed to guarantee also the shear strength enhancement without the substitution of the transversal steel reinforcement and application of external C-FRP wrapping for intervention time and cost saving. Ultra-High Performance Concrete (UHPC) with steel fibers were designed properly at Fuzhou University considering different fiber content (1 %, 2 % and 3%) and tested by compression and flexural tests.

Some pier specimens in scale 1:6 were repaired with and without new steel stirrups and external wrapping in plastic hinge only using fiber concrete to evaluate the feasibility of the intervention. The use of steel tissue was considered as alternative to the C-FRP wrapping to increase shear strength and ductility of the pier specimen with external wrapping.
The shear strength due to the UHPC concrete jacket was evaluated by CNR-DT 204/2006 model using the concrete experimental test results in case of specimens without transversal reinforcement and external wrapping.

THE STUDIED RC BRIDGE

An irregular rc bridge (Figure 1) already studied in Lavorato 2015a was designed according the Chinese codes (JTG D60-2004, JTG/T B02-01-2008, JTG D62-2004) in Lavorato 2015b. The transversal pier reinforcement was defined to reproduce the one of existing bridges with insufficient shear reinforcement. In this way, it was possible to consider the problem of the shear and ductility retrofitting during the repair operations (a problem for many existing rc bridges). The rc bridge geometries are shown in Figure 1 whereas the design details for the steel reinforcement of the bridge piers are described in Lavorato 2015b.

In this study, the center pier of this bridge, the most stressed pier during seismic action application, was severely damaged at the pier base in plastic hinge (Lavorato 2015b). The pier damage consisted in: concrete spalling and crushing, transversal stirrups rupture, longitudinal rebar buckling and ruptures and evident shear cracking.

PROPOSED RAPID REPAIR AND RETROFITTING INTERVENTION ON RC BRIDGE PIERS

A rapid repair and retrofitting solution was proposed in Lavorato 2015a and applied on the most stressed and damaged rc bridge pier in plastic hinge only where the damage was more relevant. This technique consisted of: damaged concrete and rebar parts removal along the entire pier surface in plastic hinge (Figure 2a), substitution of the damaged rebar parts by new rebar parts, damaged concrete restoration by self-compacting concrete (Figure 2b) and shear strength and ductility improvements by the application of an external C-FRP wrapping (Figure 2c).
The good experimental results of the previous research campaign on Italian and Eurocode EC8 bridges assure the feasibility and the effectiveness of the interventions to restore the pier strength (Lavorato 2015a).

However, high local plastic deformation was observed in some rebar welding connections between the original undamaged rebar and the new rebar parts.

For that reason, some technique improvements were proposed during a new research campaign in collaboration with the Fuzhou University (Lavorato 2015b). In particular, shaped rebar were used to replace the damaged rebar parts. The shape of this new rebar permitted a proper plastic distribution along the new rebar parts only and it was tested successfully on Chinese repaired pier specimens (scale 1:6) by cyclic tests at Fuzhou University (Lavorato 2015b).

The ongoing research study focuses on new improvements of rebar substitution and concrete restoration. In particular, the problem of the connection in situ between new and original rebar parts during the rebar substitution is analyzed. Strong welding connection systems by steel coupler were designed to connect the new shaped rebar parts with the original undamaged rebar parts in the pier. Furthermore, a concrete with fiber was studied to restore the removed concrete parts and increase the insufficient original shear strength and ductility without using new stirrups and/or external wrapping reducing time and cost of the interventions.

**IMPROVEMENT OF THE REBAR SUBSTITUTION**

Shaped rebar parts used to substitute the original damaged ones can guarantee and improve the plastic dissipation in plastic hinge only (Lavorato 2015b). This shaped rebar was obtained starting from a steel rebar with diameter and mechanical properties very similar to the original ones. The original rebar is shaped reducing the rebar diameter to guarantee that the plastic dissipation develops along this part only. The shaped rebar length was assumed equal to the theoretical plastic hinge length. Firstly, these parts plasticize according the design and protects the original rebar parts (i.e. anchorages) and the rebar connections avoiding local high plastic demand. The rc pier section resisting moment was reduced but this reduction is controlled so that the real pier plastic dissipation guarantees a proper reduction of the design actions.

The connection of the new rebar parts with the original ones was realized using strong steel coupler element and two symmetric strong side welding chords. This connection system is simple to perform in situ on vertical longitudinal rebar in modest space (removed concrete). The new and original rebar parts are connected along the same longitudinal axis avoiding local rotation and plastic deformation as observed in Lavorato 2015a.

**IMPROVEMENT OF THE CONCRETE RESTORATION**

A concrete jacket (CJ) realized by means of an UHFRC (Ultra High Fiber Reinforced Concrete) can be built to restore the removed concrete cover and the external parts of the core. The pier geometries are not modified as the CJ substitutes the removed concrete parts only. In this way, the volume of the pier does not change and there are not interaction problems among the repaired elements and the other bridge structural or nonstructural elements. Furthermore, the pier appearance does not change after the repair (no esthetic impact). The UHFRC was designed:
To guarantee that the concrete with fibers can flow between and around reinforcement during the casting in the very modest space (as a fresh Self compacting concrete)

To exhibit the maximum compressive strength after a few days for a rapid opening of the bridge after the repair

To provide the necessary shear strength by steel fibers contribution without using steel stirrups and external C-FRP wrapping for simplifying the repair intervention and reducing time and cost of the interventions

To assure a durability enhancement without modify the cover dimension by means of the fibers which contrast the crack opening. It is much important in case of rc bridge piers in contact with water and moisture.

In particular, three different UHFRC mix designs were considered (Table 1). Each mix design includes: a super-plasticizer, silica fume and fine sand to guarantee high mobility and pass ability similar to the ones of a self-compacting concrete (SCC). In this way, the casting results simple, rapid and uniform also in modest space (cover and external part of pier core).

<table>
<thead>
<tr>
<th>Fiber content</th>
<th>water/cement (W/B)</th>
<th>Cement (C)</th>
<th>Silica fume/cement (SF/C)</th>
<th>Sand/cement (S/C)</th>
<th>Superplasticizer/cement (Su/C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 %</td>
<td>0.26</td>
<td>1</td>
<td>0.3</td>
<td>1.20</td>
<td>0.025</td>
</tr>
<tr>
<td>2 %</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 %</td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

Steel fibers were added to the UHFRC mix design to increase the durability and guarantee the necessary shear strength of the CJ without steel stirrups and external C-FRP wrapping. These fibers have an ultimate tensile strength of 2000 MPa and modulus of Elasticity of 200 GPa. The mechanical performance of the UHFRC depends on the aspect ratio and the volume fraction of the fibers. The selected fibers are straight and smooth with length $l_f = 13$ mm and equivalent diameter $d_f = 0.20$ mm. Different percentage of fibers ($V_f$) were considered 1 %, 2 % and 3 % (volume of steel fibers to the volume of concrete) to evaluate the corresponding shear strength contribution and the fresh state properties to permit the casting of the concrete in modest space.

Compression and flexion tests were performed on UHFRC specimens at Fuzhou University. In particular, the compression tests were executed on three UHFRC cube specimens (100 x 100 x 100 mm) for each fiber percentage after 6 days to evaluate the cylindrical compression strength ($f_{c_{m6}}$) developed by the specimens in short time (Table 2). The mean value of the cylindrical compressive strength after 28 ($f_{c_{m28}}$) days was also calculated according to Fib model code 2010 (Table 2). The comparison between cylindrical compressive strength after 6 or 28 days shows that almost the maximum strength value was exhibited after 6 days. This result confirms that the UHFRC is a good material for a rapid concrete restoration.

The flexion tests were carried out on three prismatic specimens for each steel fiber percentage (100 x 100 x 400 mm prismatic specimen bended under four flexion points) with a notch size of 30 mm. The concrete equivalent flexural strength ($f_{eq2}$) corresponding to crack opening of 1.8 mm was obtained according to CNR-DT 204/2006 in Table 2. The characteristic value of the ultimate tensile residual strength ($f_{F_tuk}$) was also obtained according to CNR-DT 204/2006.
PIER SPECIMENS

The research program considers different repair interventions applied on nine rc pier specimens in scale 1:6, which are representative of the center pier of the Chinese irregular rc bridge in Figure 1. This pier is the most stressed during the seismic action application as it described in Lavorato 2015b.

The pier specimen geometries and reinforcement details were obtained considering the geometries and steel reinforcements of the real scale pier and applying some scale factors which guarantee similitude criteria between pier model and pier prototype in terms of global quantities (flexural and shear strength and confinement effect; Lavorato 2015a, b). The perfect geometrical scaling of materials is not necessary allowing the use of ordinary concrete mixing and commercial steel rebars simplifying the construction of the pier specimens and the tests on concrete and steel rebars specimens.

Each pier specimen has diameter equal to 420 mm and height 1170 mm. The pier specimen geometries and steel reinforcement are given in Table 1. The longitudinal reinforcement consists of 14 rebar with diameter of 18 mm. The transversal reinforcement out of the plastic hinge has a space of 60 mm and diameter of 4 mm.

The pier specimens present different types of repair and retrofitting interventions in plastic hinge (Table 1). In particular, pier specimens with and without stirrups and external wrapping to increase the shear strength and the ductility were built. The new rebar parts, which were used for damaged rebar substitution, had the same length ($L_s$) and diameter reduction ($\Phi_{SR}$) of the shaped part with the exception of the control specimen 9.

Different concrete mix designs were developed to restore the specimen damaged concrete: an UHFRC with steel fiber developed and tested at Fuzhou University (it was described above) and a High Fiber Reinforced Concrete (HFRC-I) developed at Roma Tre University Lab (Italy). The HFRC-I was realized using 2 or 3 % of polymeric fibers (by ISTRICE) and a commercial repair mortar (commercial name Geolite MAGMA by Kerakoll) very fluid at fresh state with optimum compressive strength after 6 days. The HFRC-I will be not described here in details.

The pier specimens (5, 7 and 8) without stirrups and external confinement will be tested to evaluate the shear strength contribution of the fiber concrete jacket CJ.

The pier specimens with stirrups and external confinement (1, 2, 3, 4, 6 and 9) will be tested to compare their responses with the ones of the specimens without stirrups and external confinement. An external C-FRP wrapping with one layer only ($n_e=1$) was selected for this first part of the research campaign. The external wrapping provides ductility and shear strength enhancements. The C-FRP mechanical properties are: thickness of 0.167mm, elastic...
modulus 242GPa and maximum deformation of 0.005 in accordance with CNR DT 200/2013 Italian guideline.

External steel sheet wrapping (by Kerakoll) will be used as alternative to the C-FRP wrapping during the second part of the ongoing research campaign to increase the shear strength and the ductility. This reinforcement is extremely easy to handle and shape, and combines excellent mechanical and installation properties with high durability thanks to galvanization of the individual wires. Furthermore, the steel sheet can be anchored and fastened on concrete elements with metal plates without having to take particular precautions and can be also tensioned.

Table 3 - Repair and retrofitting details for Chinese pier specimens (scaled 1:6): type of concrete jacket (CJ), length of the new shaped rebar (Ls), diameter of the new shaped rebar (ΦSR), diameter of the stirrups (Φs), spacing of the stirrups (s), number of the external C-FRP wrapping layers (ne). [mm]

<table>
<thead>
<tr>
<th>label</th>
<th>CJ</th>
<th>Ls</th>
<th>ΦSR</th>
<th>Φs</th>
<th>s</th>
<th>ne</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>SCC</td>
<td>250</td>
<td></td>
<td>4</td>
<td>60</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>SCC</td>
<td>125</td>
<td></td>
<td>4</td>
<td>60</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>SCC</td>
<td>250</td>
<td></td>
<td>4</td>
<td>60</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>HFRC-I</td>
<td>250</td>
<td>15</td>
<td>4</td>
<td>60</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>HFRC-I</td>
<td>250</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>UHFRC</td>
<td>250</td>
<td></td>
<td>4</td>
<td>60</td>
<td>1</td>
</tr>
<tr>
<td>7</td>
<td>UHFRC</td>
<td>250</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>UHFRC</td>
<td>250</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>SCC</td>
<td>250</td>
<td>18</td>
<td>4</td>
<td>60</td>
<td>-</td>
</tr>
</tbody>
</table>

Note: concrete jacket (CJ) types: self compacting concrete (SCC); High performance fiber reinforced concrete developed at Roma Tre Lab (HFRC-I), Ultra High performance fiber reinforced concrete developed at Fuzhou University (UHFRC).

SHEAR STRENGTH OF REPAIRED PIER SPECIMENS WITHOUT STEEL STIRRUPS AND EXTERNAL C-FRP WRAPPING

A fiber reinforced concrete jacket provides the shear strength improvement for the repaired pier specimens without steel stirrups and C-FRP external wrapping in plastic hinge (specimens 5, 7 and 8 in Table 3).

The design of this jacket aims to resist the maximum experimental shear action (Ve equal to about 198 kN, Figure 3) measured on the retrofitted and repaired pier specimens P26 and P36 during the previous cyclic tests at Fuzhou University Lab (Lavorato 2015b). These pier specimens were repaired and retrofitted during the previous research campaign to resist the design shear action according to the capacity design rules. The repair and retrofitting operations on these two pier specimens were very similar. The only difference was about the length (Ls) of the shaped rebar part: the value of Ls for P26 was equal to the plastic hinge length (LH=250mm) whereas the value of Ls for P36 was equal to LH/2. The shear strength and ductility improvements were provided by an external C-FRP wrapping (Lavorato 2015b). A minimum quantity of steel stirrups ø4/100mm were placed in plastic hinge to simplify the casting of new concrete parts.
Fig. 3 - Force (F) VS displacement (D) histories recorded during the cyclic tests on Chinese repaired and retrofitted rc pier specimens P23 and P36 with shaped rebar, stirrups and C-FRP wrapping (scale 1:6). Displacements history obtained by PSD tests (Lavorato 2015a, b) using Tolmezzo (PD1, dot black line) or Tolmezzo scaled to double (PD2, red line) accelerograms.

The shear strength of the specimens repaired by means of a fiber concrete jacket (CJ) without stirrups and external CFRP wrapping, was calculated as the sum of two shear contributions: the shear strength of the CJ and the one of the original concrete pier specimen core.

The concrete jacket (CJ) has a circular crown section. The shear area ($A_{HS}$) of the CJ section was calculated according to Priestley 2000 formulation considering a crown thickness of 100 mm (removed concrete). The CJ shear strength contribution ($V_{Rd,UHFRC}$) was calculated according to CNR-204/2006 formulation (eq. 1) substituting the shear area $A_{HS}$ to $b_w \cdot d$ and considering the UHFRC tensile and compression strengths obtained by the experimental tests on concrete specimens with different mix design (fiber content 1 %, 2 % or 3 %).

\[
V_{Rd,UHFRC} = \frac{0.18}{\gamma_c} \cdot k \cdot (100 \cdot \rho_l \cdot (1 + 7.5 \cdot \frac{f_{Fuk}}{f_{ck}}) \cdot f_{ck})^{1/3} + 0.15 \sigma_p \cdot b_w \cdot d
\]

(1)

where: $\gamma_c$ is the partial safety factor for the concrete without fibers; $\rho_l$ is the reinforcement ratio for longitudinal reinforcement, $f_{ck}$ is the cylindrical characteristic compression strength of the concrete; $k$ is a factor that takes into account the size effect; $\sigma_p$ is the average stress acting on the concrete cross section, $f_{Fuk}$ is the characteristic tensile strength of the concrete matrix and $f_{Fuk}$ is the characteristic value of the ultimate residual tensile strength.

The shear strength contribution of the original specimen concrete core ($V_{Rd,OC}$) was calculated according the equ. 2 proposed by Sezen 2004 for older columns having less transverse reinforcement:

\[
V_{Rd,OC} = \frac{0.5 \sqrt{f_c}}{a/d} \sqrt{1 + \frac{p}{0.5 \sqrt{f_c} A_g}} \cdot 0.8 A_g
\]

(2)
where \( P \) is the axial load, \( A_g \) the gross section area, \( f'_c \) the compressive strength of the concrete and \( a/d \) is the rc element aspect ratio.

Finally, the total shear strength of the repaired specimen \( (V_{Rd,tot}) \) is the sum of \( V_{Rd, UHFRC} \) and \( V_{Rd,OC} \) contributions. The values of the shear contributions for the new fiber concrete jacket, the original core specimen and the total shear strength of the repaired specimens without stirrups and external C-FRP wrapping are shown in Table 4. The comparison between the total shear strength \( (V_{Rd,tot}) \) and the shear action \( (V_e) \) shown that a new fiber concrete jacket built by means of a UHFRC with fiber percentage equal to 2 % or 3 % can provide the necessary shear strength to sustain the shear action considering also the contribution of the original core \( (V_{Rd,OC}) \). These percentages of fiber were used to build the CJ of the specimens (7 and 8) which will be tested in short time at Fuzhou University lab.

<table>
<thead>
<tr>
<th>( V_f )</th>
<th>( V_{Rd, UHFRC} ) [kN]</th>
<th>( V_{Rd, OC} ) [kN]</th>
<th>( V_{Rd,tot} ) [kN]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 %</td>
<td>137.1</td>
<td>49.8</td>
<td>186.9</td>
</tr>
<tr>
<td>2 %</td>
<td>149.3</td>
<td>49.8</td>
<td>205.9</td>
</tr>
<tr>
<td>3 %</td>
<td>156.1</td>
<td>49.8</td>
<td>205.9</td>
</tr>
</tbody>
</table>

**CONCLUSION**

In this paper, a new repair and retrofitting technique for damaged rc bridge pier with insufficient shear strength was presented. This technique was applied on the damaged concrete and steel reinforcement parts of rc pier specimens (scale 1:6) in plastic hinge only. These specimens were representative of the most stressed pier of a Chinese irregular rc bridge (Figure 1). The repair operations consisted in:

- The substitution of the damaged rebar parts by new shaped rebar parts connected with the original undamaged rebar parts by steel coupler system.
- The damaged concrete restoration by concrete jacket built with Ultra-High Performance Concrete (UHPC) with steel fibers to guarantee the necessary shear strength without steel stirrups and external C-FRP or steel tissue wrapping

The new rebar parts used to substitute the original damaged ones in plastic hinge, were shaped properly to guarantee the proper plastic dissipation in plastic hinge only. The connection of these new rebar parts with the original ones was realized using strong steel coupler element and two symmetric strong side welding chords. This connection system is simple to perform in situ on vertical longitudinal rebar in modest space and guarantees the same rebar axis among the connected parts, avoiding local rotation of the connection and so local bending actions. In this way, the great local plastic demand observed in some connection during the previous tests on repaired pier (Lavorato 2015a) can be prevented.
A UHPC was designed and tested by compression and flexion tests on concrete specimens considering different percentage of steel fibers (1 %, 2 % and 3 %). The concrete jacket (CJ) built with this material to restore the damaged concrete parts guarantees:

- The bridge pier can be repaired in short time as this UHPC exhibits almost the maximum compression strength after 6 days
- An improvement of the pier durability without modifying the original cover dimension as the fiber restrains the concrete crack opening
- The improvement of the pier shear strength by means of the shear strength contribution of the concrete jacket with fibers also without stirrups and external wrapping. In this way, time and cost of the repair intervention were reduced.

In particular, the shear strength of the CJ ($V_{Rd,UHFRC}$) was calculated by CNR-DT 204/2006 equations relative to fiber concrete elements without stirrups, and compared with the experimental shear action $V_e$ measured during the previous cyclic tests performed on repaired and retrofitted pier specimens at Fuzhou University lab (Lavorato 2015b). This comparison shows that a CJ built with UHFRC using 2 % or 3% of steel fibers can provide the necessary shear strength to sustain the shear action considering also the contribution of the original core ($V_{Rd,OC}$).

Finally, the feasibility of the proposed repair intervention was proved building some rc pier specimens in scale 1:6 with and without steel stirrups and external wrapping. Cyclic test on these specimens will be performed at Fuzhou University to evaluate the effectiveness of the proposed intervention.

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