Innovative Techniques
for
Seismic Retrofit of Reinforced Concrete Joints

I. Bedirhanoglu    A. Ilki    N. Kumbasar
Istanbul Technical University
Contents

Introduction
Retrofit of Joints with CFRP sheets
Retrofit of Joints with prefabricated HPFRCC panels
Conclusions
Introduction

1999
Kocaeli Earthquake
Introduction

Low quality of concrete \( \sim 10 \) MPa

Plain round bars \( \sim 220 \) MPa

Poor detailing

(no transverse bars)

(insufficient anchorage lengths)
Introduction

Purpose and scope

To improve the behavior of rc joints against earthquake excitations with applicable and realistic details.

<table>
<thead>
<tr>
<th>Improvement</th>
<th>Joints</th>
<th>Retrofit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strength</td>
<td>Exterior</td>
<td>CFRP sheets</td>
</tr>
<tr>
<td>Ductility</td>
<td>Low strength concrete</td>
<td>Prefabricated HPFRCC panels</td>
</tr>
<tr>
<td>Energy dissipation</td>
<td>No hoops</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Plain bars</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Full scale</td>
<td></td>
</tr>
</tbody>
</table>
Specimens
ACES Workshop: Innovative Materials and Techniques in Concrete Construction
October 10-12, Corfu, Greece

Specimens

Note: Dimensions are in mm, 1mm = 0.0394 in.
Materials - Concrete

Mix-proportion (kg/m³)

<table>
<thead>
<tr>
<th>Water</th>
<th>Cement</th>
<th>Sand</th>
<th>Stone powder</th>
<th>#1 Aggregate</th>
<th>Admixture</th>
</tr>
</thead>
<tbody>
<tr>
<td>239</td>
<td>170</td>
<td>698</td>
<td>414</td>
<td>747</td>
<td>1.8</td>
</tr>
</tbody>
</table>

Compression characteristics

\[ E_{c180\text{days}} = 13500 \text{ MPa} \]
Materials – Reinforcing bars (plain round)

<table>
<thead>
<tr>
<th>Diameter (mm)</th>
<th>Yield strength (MPa)</th>
<th>Yield strain</th>
<th>Maximum strength (MPa)</th>
<th>Strain corresponding to maximum strength</th>
<th>Ultimate strength (MPa)</th>
<th>Ultimate elongation</th>
</tr>
</thead>
<tbody>
<tr>
<td>16.05</td>
<td>325</td>
<td>0.0018</td>
<td>457</td>
<td>0.21</td>
<td>320</td>
<td>0.34</td>
</tr>
<tr>
<td>8.55</td>
<td>308</td>
<td>0.0016</td>
<td>411</td>
<td>0.20</td>
<td>265</td>
<td>0.44</td>
</tr>
</tbody>
</table>
Testing setup

Column axial load: 0 – 12.5 – 25 – 50 - 62.5% of axial capacity
Testing setup

![Diagram of testing setup with labels](image-url)
Behavior of reference specimens

Pseudo-ductile behavior
No strength degradation upto 4% drift
Strength is below shear capacity of joint and flexural capacity of beam
Measure for prevention of concrete crushing in front of hooks
Behavior of specimens rehabilitated in terms of prevention of slip

Calculated capacity corresponding to beam flexural failure
ACES Workshop: Innovative Materials and Techniques in Concrete Construction
October 10-12, Corfu, Greece

CFRP retrofit of joints

CFRP: 3800 MPa, 240 GPa, 1.55%, 0.176 mm and 330 g/m²
CFRP retrofit of joints

For specimens; JC-F-3 and JWC-F-3
CFRP retrofit of joints

For specimens:

- JWC-D-2    2 Pliés
- JWC-D-5    5 Pliés
- JWCP-D-(1+1) 1 Ply (for each face)

one 2700x200-mm piece for each ply in each diagonal direction
Retrofit application
Test results

Shear force (kN) vs. Drift ratio

- Contribution of FRP
- Contribution of welding and repair mortar
Test results

* FRP strains varied between 0.1% and 0.4% at peak load levels. FRP strains increased with increasing drift ratios and strains on FRP sheets in diagonal directions reached approximately 1.5%.

* It was seen that effective FRP strain can be considered as 0.4% in force based design of FRP retrofitted joints (approximately 25-30% of the ultimate FRP strain for this case)

* However, if displacement based design is carried out, FRP strains exceeding 0.4% can be considered, provided that FRP retrofit design is sufficient to obtain ductile behavior
Test results

* Joint shear strengths of reference specimens were between 0.42 and 0.52 $\sqrt{f'_c}$.  

* The failures of retrofitted specimens were basically due to shear failure of joint after FRP sheets were cut because of diagonal tension stresses in the joint core.

• Joint shear strengths of retrofitted specimens were around 0.70 $\sqrt{f'_c}$.  

• Anchorage of sheets on the columns were effective and sufficient.
Theoretical consideration

\[ F_{FRP} = \varepsilon_{fe} \times E_f \times A_f \]
\[ V_{FRP} = F_{FRP} \times \sin 45 \]
\[ V_t = V_c + V_{FRP} \]

\[ \sigma_{1,2} = \frac{\sigma_x + \sigma_y}{2} \pm \sqrt{\left(\frac{\sigma_x - \sigma_y}{2}\right)^2 + \tau_{xy}^2} \]
\[ \tau_{vc} = 0.5 \sqrt{f_c} \sqrt{1 - \frac{N}{0.5 \sqrt{f_c} A_g}} \]
\[ V_c = \tau_{vc} \times b \times d \]

\[ V_{t,drift} = k_{c,drift} \times V_c + k_{FRP,drift} \times V_{FRP} \]
Theoretical consideration

![Graph showing shear stress capacity of concrete vs. drift ratio]
Theoretical consideration
**HPFRCC retrofit of joints**

<table>
<thead>
<tr>
<th>No</th>
<th>Specimen</th>
<th>Explanation</th>
<th>Age (days)</th>
<th>Retrofitting</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>JO</td>
<td>Reference (without weld and repair mortar)</td>
<td>164</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>JW</td>
<td>Reference (with weld and repair mortar)*</td>
<td>230</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>JH</td>
<td>Retrofitted with HPFRCC (without weld and repair mortar)</td>
<td>280</td>
<td>40 mm thick precast HPFRCC panel</td>
</tr>
<tr>
<td>4</td>
<td>JWH</td>
<td>Retrofitted with weld, repair mortar and HPFRCC (with weld and repair mortar)*</td>
<td>283</td>
<td>40 mm thick precast HPFRCC panel</td>
</tr>
</tbody>
</table>
HPFRCC retrofit of joints

ACES Workshop: Innovative Materials and Techniques in Concrete Construction
October 10-12, Corfu, Greece

HPFRCC Plate
500x500x40 mm

all dimensions are in mm

JH and JWH
Materials - HPFRCC mix-proportions (kg/m3)

<table>
<thead>
<tr>
<th></th>
<th>Cement</th>
<th>Water</th>
<th>Microsilica</th>
<th>Silica sand</th>
<th>Sand</th>
<th>Steel fiber</th>
<th>Admixture</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>925</td>
<td>204</td>
<td>186</td>
<td>557</td>
<td>278</td>
<td>314</td>
<td>33.6</td>
</tr>
</tbody>
</table>
ACES Workshop: Innovative Materials and Techniques in Concrete Construction  
October 10-12, Corfu, Greece

**Materials – steel fibers**

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter, d (mm)</td>
<td>0.55</td>
</tr>
<tr>
<td>Length, l (mm)</td>
<td>30</td>
</tr>
<tr>
<td>Aspect ratio (l/d)</td>
<td>55</td>
</tr>
<tr>
<td>Density (kg/dm³)</td>
<td>7.85</td>
</tr>
<tr>
<td>Tensile strength (MPa)</td>
<td>1100</td>
</tr>
<tr>
<td>Cover</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Dramix ZP 30/0.55
ACES Workshop: Innovative Materials and Techniques in Concrete Construction
October 10-12, Corfu, Greece

Retrofit application
Test results
Test results

<table>
<thead>
<tr>
<th>Specimens</th>
<th>Maximum load at the tip of the beam (kN)</th>
<th>Drift ratio at first</th>
<th>Diagonal deformation at 4% drift ratio (measured with LVDT in 480 mm gage length on front face, Fig. 10.a) *</th>
<th>Limiting drift ** (%)</th>
<th>√f_c/√f_c (Slab in tension)</th>
</tr>
</thead>
<tbody>
<tr>
<td>JO</td>
<td>65.8</td>
<td>53.3</td>
<td>1/1000 0.4/100</td>
<td>0.0064</td>
<td>0.0011 0.0012 1.53 6.3 0.19</td>
</tr>
<tr>
<td>JW</td>
<td>87.0</td>
<td>73.0</td>
<td>1/1000 1.0/100</td>
<td>0.0200</td>
<td>0.0017 0.0016 1.97 6.0 0.24</td>
</tr>
<tr>
<td>JHP</td>
<td>73.8</td>
<td>55.2</td>
<td>2/1000 2.0/100</td>
<td>-0.0030</td>
<td>0.0015 0.0014 1.70 10 0.21</td>
</tr>
<tr>
<td>JWH</td>
<td>85.3</td>
<td>84.0</td>
<td>1/1000 2.0/100</td>
<td>-0.0048</td>
<td>0.0017 0.0018 1.97 8.5 0.24</td>
</tr>
</tbody>
</table>
Test results
Theoretical consideration

Joint shear capacity corresponding to flexural moment capacity of the beam

Joint shear force (kN)

Drift ratio

Predicted shear capacity of the joint
Conclusions

Retrofitting the inadequately detailed reinforced concrete joints using FRP sheets or precast HPFRCC panels in an easily applicable manner can significantly increase the strength and drift capacity of joints.
ACES Workshop: Innovative Materials and Techniques in Concrete Construction
October 10-12, Corfu, Greece

Acknowledgments

Financial supports of;
TUBITAK (Project No: 106M054)
ITU BAP (Project No: 31811)
ISTON
BETONSA
YKS-BASF
BEKSA

Assistance of;
Orkun İncecik
Kayhan Kolcu
Cudi Asan
Alican Nart
Süleyman Bedirhanoğlu
and other apprentices

For his valuable contribution in construction of the specimens master Salih Usta who recently passed away is also acknowledged.
THANK YOU