A COMPARISON BETWEEN SOME CHARACTERISTICS FOR REHABILITATION OF TWO METHANE TANKS

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ABSTRACT
The paper aims to compare the characteristics of confined concrete calculated according with FIB Bulletin 14/2001 and ACI 440.2R-02 (2002), in the case of partial wrapping of two methane tanks with CFRP and GFRP fabrics. The reason for strengthening these tanks is primarily lack of compliance with new code requirements. The results reveal that the rehabilitation with Carbon Fiber wraps is better than the rehabilitation with Glass Fiber wraps.

Keywords: rehabilitation, CFRP, GFRP, confinement, methane tanks

INTRODUCTION
An efficient technique used to increase the compressive strength and ductility of reinforced concrete members is the confinement of concrete. The main objectives of the confinement are: to enhance concrete strength and deformation capacities, to provide lateral support to the longitudinal reinforcement and to prevent the concrete cover from spalling. In the case of circular cross sections, these objectives can be achieved by applying external FRP wraps continuously all over the surface or discontinuously as strips. The paper deals with the rehabilitation solution for two methane tanks by partial wrapping with CFRP and GFRP fabrics. The characteristics of confined concrete are calculated according with FIB Bulletin 14/2001 and ACI 440.2R-02 (2002) code and then the results are compared.

MATERIALS AND METHODS
1. Degradations and their causes
There are two prestressed concrete methane tanks in Wastewater Treatment Plants Oradea that need rehabilitation because of their degradations and lack of compliance with new code requirements (low concrete strength 11.69 N/mm², C18/22.5). These tanks are cylindrical structures 10.75 m in height and 19 m in diameter (fig. 1).
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Fig. 1. Methane tanks from Wastewater Treatment Plants Oradea

The main deficiencies revealed in the survey of prestressed concrete tanks are as follow:

- reinforced concrete cracking,
- concrete degradation,
- leakage.

The main causes of these deficiencies that decreased the sustainability of these types of structures were:

- the action of temperature variation,
- inefficient use of insulating materials,
- an inefficient fluoride silicatization of the inner surface of the tanks.

The tanks are protected from the outside with AAC masonry blocks that are damaged about 50% in case of a tank and 45% in case of the other one (fig. 2).

Fig. 2. Degradations of AAC masonry blocks

2. Rehabilitation solution

The use of fiber reinforced polymer (FRP) composites in strengthening solutions has become an efficient alternative to traditional methods due to some advantages such their features in terms of strength,
corrosion resistance, lightness and ease of application. There is nowadays a wide range of available types of FRP composites (with epoxy, polyester or vinyl-ester matrices) reinforced with carbon, glass and aramid fibers. These composites can be manufactured in many shapes and forms such as flexible sheets or fabrics (wraps) with fibres in one or at least two different directions.

CFRP fabrics consist of two components, epoxy based impregnating resin and carbon fiber fabric and can be used to strengthen reinforced concrete structures or to confine concrete. The main advantages of these fabrics are [1]:
  - low in weight,
  - available in any length,
  - flexible, fit around any given structural element,
  - excellent chemical and weathering resistance,
  - low overall thickness,
  - economical application.

Confinement of concrete using CFRP strips is an efficient method to improve strength of concrete [2].

GFRP wrap is an unidirectional woven glass fiber fabric for structural strengthening. GFRP wrap can be used for every kind of strengthening requirement; it has an excellent cost performance and it is non conductive.

The rehabilitation solution proposed for these tanks is partial wrapping with CFRP and GFRP fabrics.

The CFRP and GFRP dimensions required to provide confinement strengthening and calculated according with FIB Bulletin 14/2001 and ACI 440.2R-02 (2002) are as follow.

**FIB Bulletin 14/2001**
  - SikaWrap Hex 100C: thickness 0.76 mm, width 150 mm, centre-to-centre distance 450 mm,
  - SikaWrap Hex 100G: thickness 1.44 mm, width 150 mm, centre-to-centre distance 450 mm.

**ACI 440.2R-02**
  - SikaWrap Hex 100C: thickness 1.14 mm, width 150 mm, centre-to-centre distance 450 mm,
  - SikaWrap Hex 100G: thickness 1.8 mm, width 150 mm, centre-to-centre distance 300 mm.

### 3. The calculus of confined concrete characteristics

The characteristics of confined concrete are calculated according with **FIB Bulletin 14/2001** and **ACI 440.2R-02 (2002) code**.
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Current international design guidelines provide predictive design equations for the strengthening of reinforced concrete members by means of fiber-reinforced polymer (FRP) confinement [3].

FIB Bulletin 14 gives detailed design guidelines on the use of externally bonded fibre reinforced polymer reinforcement for reinforced concrete structures in accordance with the design format of the CEP-FIB Model Code and Eurocode 2, the practical execution and the quality control. This bulletin is today’s state-of-art in the area of strengthening of concrete structures by means of externally bonded FRP reinforcement [4].

ACI 440.2R-02 named Guide for the Design and Construction ofExternally Bonded FRP Systems for Strengthening Concrete Structures is reported by American Concrete Institute (ACI) Comitee 440.

The calculus according with FIB Bulletin 14/2001

The volumetric ratio of FRP jacket $\rho_j$ is given in Equation (1):

$$\rho_j = \frac{4 \cdot d_e \cdot t_j \cdot b_f}{(d_e^2 - d_i^2) \cdot s}$$

(1)

where: $t_j$ – FRP jacket thickness,
$d_e$ – outer diameter of the tank,
$d_i$ – inner diameter of the tank,
$b_f$ - width of FRP strip in partial wrapping,
s – pitch in partial wrapping.

The lateral confining pressure $\sigma_l$ can be written as in Equation (2):

$$\sigma_l = k_{conf} \cdot \varepsilon_i = k_{conf} \cdot \varepsilon_{ju}$$

(2)

where: $k_{conf}$ – stiffness of the FRP confinement (see Equation 3),
$\varepsilon_i$ – circumferential strain of the concrete, equal to the strain $\varepsilon_j$ in the FRP jacket; $\varepsilon_j = 0.017$ (CFRP); $\varepsilon_j = 0.028$ (GFRP).

$$k_{conf} = \frac{k_e \cdot \rho_j \cdot E_{fu}}{2}$$

(3)

where: $E_{fu}$ – modulus of the FRP jacket; $E_{fu} = 230000 \text{ N/mm}^2$ (CFRP), $E_{fu} = 76000 \text{ N/mm}^2$ (GFRP),
k_e – the confinement effectiveness coefficient that is given in equation (4) in case that concrete is partially wrapped:
\[ k_c = \left(1 - \frac{s'}{2 \cdot D}\right)^2 \]  \hspace{2cm} (4)

where: \(s'\) – clear spacing between the FRP wraps, 
\(D\) – diameter of the tank.

The confined peak strength \(f_{cc}\) is expressed with an equation (Mander et al. 1988) that has been extensively tested against experimental data [5]:

\[ f_{cc} = f_{co} \cdot \left(2.254 \cdot \sqrt{1 + 7.94 \cdot \frac{\sigma_t}{f_{co}} - 2 \cdot \frac{\sigma_t}{f_{co}} - 1.254}\right) \]  \hspace{2cm} (5)

where: \(f_{co}\) – unconfined concrete strength; \(f_{co}=11.69 \text{ N/mm}^2\) (C18/22.5).

The compressive strain \(\varepsilon_{cc}\) at confined peak strength \(f_{cc}\) is given in equation (6):

\[ \varepsilon_{cc} = \varepsilon_{co} \cdot \left[1 + 5 \cdot \left(\frac{f_{cc}}{f_{co}} - 1\right)\right] \]  \hspace{2cm} (6)

where: \(\varepsilon_{co}\) – compressive strain of unconfined concrete.

\[ \varepsilon_{co} = \frac{f_{co}}{E_c} \]  \hspace{2cm} (7)

where: \(E_c\) – modulus of elasticity of concrete; \(E_c=29000\text{ N/mm}^2\) (C18/22.5).

The formula for ultimate axial compressive strain of confined concrete (Spoelstra and Monti, 1999) [6] is:

\[ \varepsilon_{cu} = \varepsilon_{co} \cdot \left(2 + 1.25 \cdot \frac{E_c}{E_{tu}} \cdot \varepsilon_{tu} \cdot \sqrt{f_t}\right) \]  \hspace{2cm} (8)

where: \(\varepsilon_{cu}\) - ultimate compressive strain of concrete, 
\(E_{tu}\) - concrete tangent modulus:

\[ \frac{E_c}{E_{tu}} = \frac{E_c}{f_{co}} \]  \hspace{2cm} (9)

\(f_t\) - maximum confining stress:
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\[
\tilde{f}_i = \frac{f_i}{f_{co}}
\]

(10)

**The calculus according with ACI 440.2R-02 (2002)**

The design ultimate tensile strength of the FRP material \( f_{fu} \) is determined using the environmental-reduction factor for the appropriate fiber type and exposure condition [7].

\[
f_{fu} = C_E \cdot f_{fu}^*
\]

(11)

where: \( f_{fu}^* \) – ultimate tensile strength of the FRP material as reported by the manufacturer,
\( C_E \) – environmental-reduction factor.

The design rupture strain is given in Equation (12):

\[
\varepsilon_{fu} = C_E \cdot \varepsilon_{fu}^*
\]

(12)

where: \( \varepsilon_{fu}^* \) – ultimate rupture strain of the FRP reinforcement.

The volumetric ratio of FRP jacket is given in Equation (13):

\[
\rho_f = \frac{4 \cdot d_f \cdot n \cdot t_f \cdot b_f}{d_c^2 - d_f^2} \cdot \frac{b_f}{s}
\]

(13)

where: \( t_f \) – FRP jacket thickness,
\( n \) – numbers of plies.

The confining pressure \( \sigma_l \) can be written as in Equation (14):

\[
f_j = \frac{k_a \cdot \rho_f \cdot \varepsilon_{fe} \cdot E_f}{2}
\]

(14)

where: \( E_f \) – modulus of the FRP jacket,
\( \varepsilon_{fe} \) – effective strain level in FRP reinforcement, equal to the design rupture strain of FRP reinforcement; \( \varepsilon_{fe} = \varepsilon_{fu} \),
\( k_a \) – efficiency factor; \( k_a = 1 \) for circular sections.

The apparent confined concrete strength \( f'_{cc} \) for a circular concrete member wrapped with an FRP jacket is expressed with equation (15):

\[
f'_{cc} = f'_c \left( 2.25 \cdot \sqrt{1 + 7.9 \cdot \frac{f_l}{f'_c} - 2 \cdot \frac{f_l}{f'_c} - 1.25} \right)
\]

(15)

where: \( f'_c \) – specified compressive strength of concrete; \( f'_c = 11.69 \) N/mm² (C18/22.5).
The maximum usable compressive strain in concrete for FRP-confined reinforced concrete members is given in equation (16):

\[ \varepsilon_{cc}' = \frac{1.71 \cdot (5 \cdot f'_{cc} - 4 \cdot f'_{cc})}{E'_{c}} \]  

(16)

RESULTS AND DISCUSSION

The results for the rehabilitation solution with CFRP and GFRP are presented in Table 1:

<table>
<thead>
<tr>
<th>Rehabilitation solution</th>
<th>( n )</th>
<th>( b_f ) [mm]</th>
<th>( s' ) [mm]</th>
<th>( f_{cc} ) [N/mm^2]</th>
<th>( \varepsilon_{cc} )</th>
<th>( n )</th>
<th>( b_f ) [mm]</th>
<th>( s' ) [mm]</th>
<th>( f'_{cc} ) [N/mm^2]</th>
<th>( \varepsilon'_{cc} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>FIB 14/2001</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rehabilitation with CFRP</td>
<td>2</td>
<td>150</td>
<td>300</td>
<td>19.38</td>
<td>0.00172</td>
<td>3</td>
<td>150</td>
<td>300</td>
<td>21.06</td>
<td>0.00345</td>
</tr>
<tr>
<td>Rehabilitation with GFRP</td>
<td>4</td>
<td>150</td>
<td>300</td>
<td>19.62</td>
<td>0.00176</td>
<td>5</td>
<td>150</td>
<td>150</td>
<td>19.24</td>
<td>0.00291</td>
</tr>
</tbody>
</table>

where: \( n \) – number of FRP plies,

\( b_f \) - width of FRP strip in partial wrapping,

\( s' \) – clear spacing between FRP wraps,

\( f_{cc} \), \( f'_{cc} \) – compressive strength of confined concrete,

\( \varepsilon_{cc} \), \( \varepsilon'_{cc} \) – compressive strain of confined concrete.

Based on the results presented in table 1 the following conclusions are drawn:

- In the case of calculus according with ACI 440.2R-02 (2002), it is required a larger amount of CFRP and GFRP fabrics in order to provide confinement strengthening than in the case of calculus according with FIB Bulletin 14/200. ACI 440.2R-02 (2002) code accounts for environmental degradation and long-term durability by suggesting reduction factors \( C_E \) for various environments. This reduction factor (\( C_E < 1 \)) decreases the design rupture strain.

- The ultimate axial compressive strain of confined concrete obtained from the calculus according with ACI 440.2R-02 is less than the ultimate axial compressive strain calculated according with FIB Bulletin 14/2001 because ACI 440.2R-02 doesn't specify how the confined concrete modulus changes beside the unconfined one. FIB 14 is taking into account this change by calculating a concrete tangent modulus.

- The amount of CFRP wraps required to provide confinement strengthening is less than the amount of GFRP wraps in both cases of calculus.
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The ultimate axial compressive strain of confined concrete calculated according with FIB Bulletin, in the case of wrapping with GFRP wraps is bigger than in the case of wrapping with CFRP wraps. In the case of calculus according with ACI 440.2R-02 the compressive strength and ultimate axial compressive strain of confined concrete wrapped with CFRP are bigger than in the case of wrapping with GFRP.

CONCLUSIONS

The rehabilitation solution for methane tanks by partial wrapping with GFRP fabrics is more effective than the solution with CFRP in terms of confined concrete strength and ductility. ACI 440.2R-02 code is more restrictive than FIB Bulletin 14/2001 because ACI 440.2R-02 accounts for environmental degradation by suggesting reduction factor $C_E$ which values are 0.85 for CFRP and 0.50 for GFRP in the case of aggressive environment (wastewater treatment plants).

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