COMPARISON OF FRP-RETROFITTING STRATEGIES IN CHINESE AND ITALIAN CODES

J. W. DAI[1], Y.R. WANG[2], B. JIN[1, 3], D.F.ZU[4], Silvia Alessandri[5], Giorgio Monti[5], Nicola Nisticò[5]

[1] *Professor, Institute of Engineering Mechanics, Harbin. China*
[2] *Ph.D Student, Institute of Engineering Mechanics, Harbin. China*
[3] *Professor, Harbin Institute of Technology, Harbin China*
[4] *Master Student, Institute of Engineering Mechanics, Harbin. China*
[5]*Professor,Dipartimento di Ingegneria Strutturale e Geotecnica, SAPIENZA Università di Roma, Via A. Gramsci 53, 00197, Italy*
Email: jwdai@iem.net.cn

ABSTRACT:
In recent years, FRP (fiber-reinforced polymer/plastic) has been widely used in retrofitting of R/C structures due to its high tensile property. Many research works and actual applications about FRP retrofitting for civil structures were carried out by both domestic and international organizations. However, different technical specifications are used in FRP retrofitting practice for R/C structures in different countries. As an example, related specifications about FRP-retrofitting strategies in Chinese and Italian codes are compared in this paper. The strategies of the both codes for FRP-retrofitting concrete structures are consistence in essence from principle point of view, nevertheless, the calculation methods of the bonded length, flexural strengthening, and shear strengthening are different from each other. The reasons leading to distinctness and sameness are also interpreted concretely. The differences would illuminate the designer to pay attention to the related issues during calculation.

KEYWORDS:
FRP-retrofitting, R/C structure, Chinese and Italian codes

1. INTRODUCTION

In recent years, FRP, a kind of new material applied in retrofitting field of civil engineering, has been paid close extensive attention for its advantages such as high strength, high elastic modulus, corrosion resistance, fatigue resistance, and easy processing. At home and abroad, many researchers have already done massive research work on the performance of FRP; what's more, they conclude reinforcing function of FRP from three aspects: theoretical analysis, experiments, practical engineering; and then they compile their own national specification. Different countries have different opinions on the applications of FRP. Based on the difference, this paper is going to compare the FRP-strengthening strategies in Chinese and Italian codes in detail. The strategies of the both codes for strengthening concrete structures are uniform in essence from principle point of view, nevertheless, the calculation methods of the bonded length, flexural capacity, and shear capacity are different from each other. The differences and sameness would deepen designers' understanding of FRP and illuminate designers to pay attention to the issues during calculation, so that the FRP is effectively and widely applied in the civil structures throughout the world.

2. COMPARISON OF FRP-STRENGTHENING STRATEGIES IN CHINESE AND ITALIAN CODES

2.1 Comparisons on the Bonded Length

2.1.1 The bonded length in Italian codes

The ultimate value of the force transferred to the FRP system prior to debonding depends on the length, l_b, of the bonded area. The optimal bonded length, l_e, is defined as the length that, if exceeded, there would be no increase in the force transferred between concrete and FRP. The length, l_b, should be longer than the optimal bonded length , l_e, as represented in Figure 1. The optimal bonded length, l_e, may be estimated as follows:

$$l_e = \sqrt{\frac{E_f \cdot t_f}{2 \cdot f_{ctm}}} \tag{2.1}$$

Where E_f and t_f are young modulus of elasticity and thickness of FRP, respectively, and f_{ctm} is the average tensile strength of the concrete.

2.1.2The bonded length in Chinese codes

The bonded length (figure 2) should not be less than 200mm and more than the bonding and extending length. Namely:

$$\text{the bond length} \geq \max\left(\frac{E_{cf}\varepsilon_{cf} \cdot A_{cf}}{\tau_{cf} \cdot b_{cf}}, 200\right) \tag{2.2}$$

Where E_{cf} is elastic modulus of FRP; ε_{cf} is tensile strain in full utilization section of FRP, according to the 4.3.2 clause of Technical specification for strengthening concrete structures with carbon fiber reinforced polymer laminate; A_{cf} is the section area on tension face of FRP; τ_{cf} is the design value for bonding strength between FRP and concrete, the value is 0.5MPa and b_{cf} is the width of FRP.

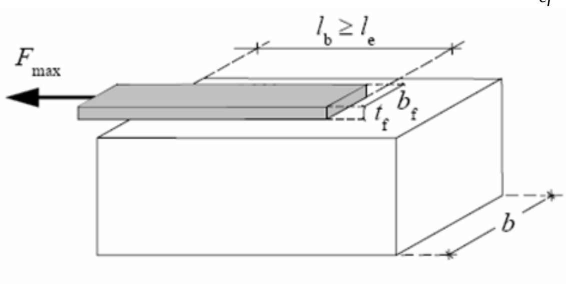

Figure 1 the bonded length in Italia code

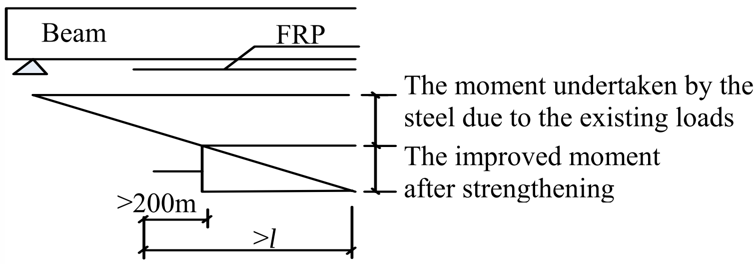

Figure 2 the bonded length in Chinese code

2.1.3 Differences and sameness on the bonded length

From Italian and Chinese codes, the calculation method of the bond length is quite different from each other. The formula of the bond length in Italian code is based on the experimental results. It is related with the average tensile strength of the concrete, young modulus of elasticity and thickness of FRP. The formula of the bond length in Chinese code connects with elastic modulus of FRP, tensile strain in full utilization section of FRP, the design value for bonding strength between FRP and concrete, and thickness of FRP. Comparing two codes, the bond length in Chinese code depends on the forced state and the formula is consistent from a dimensional point of view; but the bond length in Italian code is a fixed value once the material of FRP is determined and the formula is inconsistent from a dimensional point of view.

2.2 Comparison on Flexural Strengthening

2.2.1 The flexural strengthening in Italian codes

1) Fundamental hypotheses

ULS analysis of RC members strengthened with FRP relies on the following fundamental hypotheses:

- Cross-beam sections, perpendicular to the beam axis prior to deflection, remain still plane and perpendicular to the beam axis after deflection.
- Perfect bond exists between FRP and concrete, and steel and concrete.
- Concrete does not react in tension.
- Constitutive laws for concrete and steel are accounted for according to the current building code.
- FRP is considered a linear-elastic material up to failure.

2) Calculation

Flexural design at ULS of FRP strengthened members requires that both flexural capacity, M_{Rd}, and factored ultimate moment, M_{Sd}, satisfy the following inequation:

$$M_{Sd} \le M_{Rd} \tag{2.3}$$

For both failure modes, the position x of the neutral axis is computed by means of the translational equilibrium equation along the beam axis as follows:

$$0 = \psi \cdot b \cdot x \cdot \overline{f}_{cd} + A_{s2} \cdot \sigma_{s2} - A_{s2} \cdot f_{yd} - A_f \cdot \sigma_f \tag{2.4}$$

Where $\overline{f}_{cd}$ is equal to the design concrete compressive strength, f_{cd}, suitably reduced if it is necessary.
The flexural capacity, M_{Rd}, of the strengthened member can be calculated using the rotational equilibrium equation as follows:

$$M_{Rd} = \frac{1}{\gamma_{Rd}} \left[\psi \cdot b \cdot x \cdot \overline{f}_{cd} \left(d - \lambda \cdot x \right) + A_{s2} \cdot \sigma_{s2} \cdot \left(d - d_2 \right) + A_f \cdot \sigma_f \cdot d_1 \right] \tag{2.5}$$

Where the partial factor, γ_{Rd}, should be assumed equal to 1.00.
In Equations (2.4) and (2.5), the non-dimensional coefficients ψ and λ represent the resultant of the compression stresses and its distance from the extreme compression fiber, respectively, divided by $b \cdot x \cdot \overline{f}_{cd}$ and by x, respectively.

2.2.2The flexural strengthening in Chinese codes

1) Fundamental hypotheses

• when members reach the bending ultimate limit state, tensile strain of FRP is determined based on the plane section assumption and is no more than ultimate strain of FRP in tension, $\left[\varepsilon_{cf} \right]$.

• when considering the effect of secondary load, initial strain, ε_i, on the extreme tension fiber of concrete is calculated according to the plane section assumption before strengthening.

• tensile stress, σ_{cf}, of FRP is equal to products of elastic modulus, E_{cf}, and tensile strain, ε_{cf}, of FRP.

• Perfect bond exists between FRP and concrete, and steel and concrete.

2) Calculation

In Chinese codes, flexural strengthening calculation of rectangular section is classified into three types:

• when concrete compression height, x, is between $\xi_{cfb} h$ and $\xi_b h_0$ (Figure 3a), calculation formula is as follows.

$$M \le f_c b x \left(h_0 - \frac{x}{2} \right) + f_y' A_a' \left(h_0 - a' \right) + E_{cf} \varepsilon_{cf} A_{cf} \left(h - h_0 \right) \tag{2.6}$$

Concrete compression height, x, and tensile strain, ε_{cf}, of FRP are determined by the formula(2.7).

$$\begin{cases} f_c b x = f_y A_s - f_y' A_s' + E_{cf} \varepsilon_{cf} A_{cf} \\ x = \dfrac{0.8 \varepsilon_{cu}}{\varepsilon_{cu} + \varepsilon_{cf} + \varepsilon_i} \cdot h \end{cases} \tag{2.7}$$

• when concrete compression height, x, is less than $\xi_{cfb} h$ (Figure 3b), calculation formula is as follows.

$$M \le f_y A_s \left(h_0 - 0.5 \xi_{cfb} h \right) + E_{cf} \left[\varepsilon_{cf} \right] A_{cf} h \left(1 - 0.5 \xi_{cfb} \right) \tag{2.8}$$

• when concrete compression height, x, is less than $2a'$, calculation formula is as follows.

$$M \le f_y A_s \left(h_0 - a' \right) + E_{cf} \left[\varepsilon_{cf} \right] A_{cf} \left(h - a' \right) \tag{2.9}$$

Where M is the design moment including initial moment; A_s and A_s' are the area of steel reinforcement subjected to tension and the area of steel reinforcement subjected to compression respectively; A_{cf} is area of FRP reinforcement; f_y and f_y' are design yield strength of tensile reinforcement and design compressive strength of compressive reinforcement respectively; f_c is design concrete compressive strength; E_{cf} is elastic modulus of FRP; x is concrete compression height; ξ_{cfb} is relative limit height of compression region when ultimate strain of FRP in tension and concrete compression failure simultaneously reach the value, $\dfrac{0.8\varepsilon_{cu}}{\varepsilon_{cu}+\left[\varepsilon_{cf}\right]+\varepsilon_i}$; ε_i is bending moment acting before FRP strengthening; $\left[\varepsilon_{cf}\right]$ is ultimate strain of FRP in tension; ε_{cf} is strain of FRP.

2.2.3 Differences and sameness on the flexural strengthening

The strategies on flexural strengthening of the both codes for strengthening concrete structures are uniform in essence from principle point of view. The flexural capacity in both codes comes from three parts: concrete, steel bar, and FRP; however, details of calculation are different from each other: (1) Partial coefficient of two codes. In Chinese code, partial coefficients of steel bar and concrete are 1.12 and 1.4 respectively; in Italian code, partial coefficients of steel bar and concrete are 1.15 and 1.6 respectively. From the partial coefficient, flexural strengthening calculation in Italian code is more conservative than in Chinese code. That will be demonstrated in the following example. (2) Failure mechanism could be classified into different types: failure due to the rupture of the FRP system or failure due to concrete crushing with yielding of steel in traction, while FRP strain has not reached its ultimate value. Failure of structure belongs to which type according different criteria in different codes: in Chinese code, criteria is concrete compression height; in Italian code, criteria is CFRP maximum tensile strain.

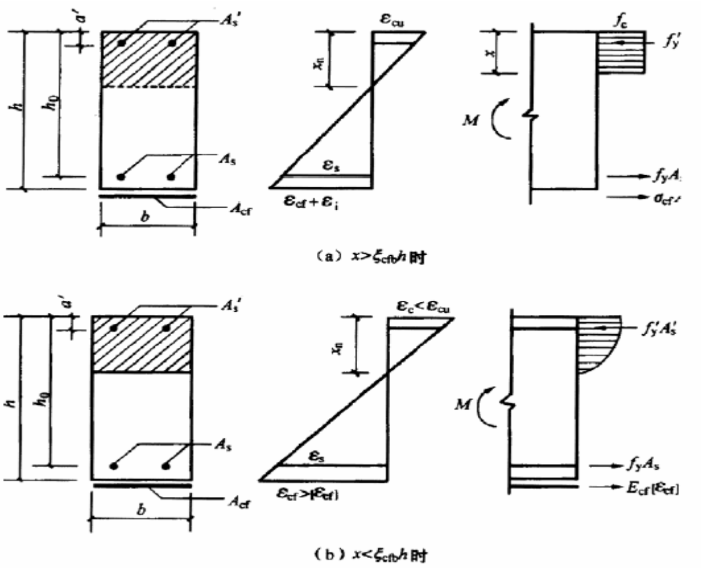

Figure 3 flexural strengthening calculations in Chinese code

2.3 Comparison on Shear Strengthening

2.3.1The shear strengthening in Italian code

Shear capacity of FRP strengthened members can be evaluated as follows:

$$V_{Rd}=\min\left\{V_{Rd,ct}+V_{Rd,s}+V_{Rd,f},V_{Rd,\max}\right\} \tag{2.10}$$

Where $V_{Rd,ct}$ and $V_{Rd,s}$ represent concrete and steel contribution to the shear capacity according to the current building code, and $V_{Rd,f}$ is the FRP contribution to the shear capacity to be evaluated as CNR-DT 200/2004 58 indicated in the following. Shear strength shall not be taken greater than $V_{Rd,\max}$. This last value denotes the ultimate strength of the concrete strut, to be evaluated according to the current building code.

In the case of a RC member with a rectangular cross-section and FRP side bonding configuration, the FRP contribution to the shear capacity, $V_{Rd,f}$, shall be calculated as follows:

$$V_{Rd,f}=\frac{1}{\gamma_{Rd}}\cdot\min\left\{0.9\cdot d,h_w\right\}\cdot f_{fed}\cdot 2\cdot t_f\cdot\frac{\sin\beta}{\sin\theta}\cdot\frac{w_f}{p_f} \tag{2.11}$$

where the partial factor γ_{Rd} shall be assumed equal to 1.20; d is the member effective depth, h_w is the stem depth, f_{fed} is the effective FRP design strength to be evaluated as indicated in Section 4.3.3.2 of Guide for the Design and Construction of Externally Bonded FRP Systems for Strengthening Existing Structures; t_f is the thickness of the adopted FRP system, β is the fibers angle with respect to the member longitudinal axis, θ represents the angle of shear cracks (to be assumed equal to 45° unless a more detailed calculation is made), and w_f and p_f are FRP width and spacing, respectively, measured orthogonally to the fiber direction

(Figure 4). For FRP strips installed one next to each other the ratio w_f / p_f shall be set equal to 1.0.

In the same case of a RC member with a rectangular cross-section and U-wrapped or completely wrapped configurations, the FRP contribution to the shear capacity shall be calculated according to the Moersch truss mechanism as follows:

$$V_{Rd,f} = \frac{1}{\gamma_{Rd}} \cdot 0.9 \cdot d \cdot f_{fed} \cdot 2 \cdot t_f \cdot (\cot\theta + \cot\beta) \cdot \frac{w_f}{p_f} \quad (2.12)$$

Where all symbols have the meaning highlighted in item above.

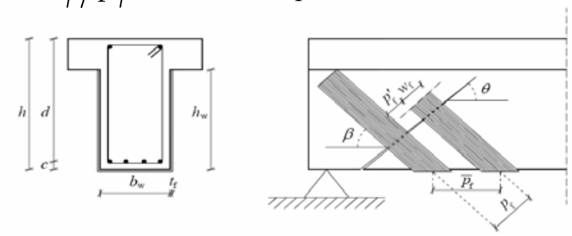
Figure 4 Notation for shear strengthening using FRP strips

For completely wrapped members having circular cross-sections of diameter D when fibers are placed orthogonal to the axis of the member ($\beta = 90^\circ$), the FRP contribution to the shear capacity, $V_{Rd,f}$, shall be calculated as follows:

$$V_{Rd,f} = \frac{1}{\gamma_{Rd}} \cdot D \cdot f_{fed} \cdot \frac{\pi}{2} \cdot t_f \cdot \cot\theta \quad (2.13)$$

In all Equations (2.11) to (2.13), it is allowed to replace the term p_f with the term $\overline{p}_f$ measured along the member longitudinal axis, where $p_f = \overline{p}_f \sin\beta$.

2.3.2The shear strengthening in Chinese code

In Chinese code, shear strengthening of concrete beam should be calculated according to the following formula:

$$V_b \le V_{brc} + V_{bcf} \quad (2.14)$$

$$V_{bcf} = \varphi \frac{2n_{cf}\omega_{cf}t_{cf}}{(s_{cf} + \omega_{cf})} \varepsilon_{cfv} E_{cf} h_{cf} \quad (2.15)$$

$$\varepsilon_{cfv} = \frac{2}{3}(0.2 + 0.12\lambda_b)\varepsilon_{cfu} \quad (2.16)$$

Where, V_b, represents shearing force design value; V_{brc} is shear capacity of concrete before FRP strengthening; V_{bcf} is shear undertaken by FRP; ε_{cfv} is strain of FRP when members reaching ultimate limit states of shear capacity; ε_{cfu} is ultimate strain of FRP; φ is FRP strengthening formal coefficient, completely wrapped: φ=1.0, U-wrapped: φ=0.85, side bonding: φ=0.7; λ_b is shear span ratio, when load is uniform load $\lambda_b = 3.0$; when load is concentrated load, $\lambda_b = a/h$, if $\lambda_b > 3.0$ then $\lambda_b = 3.0$, if $\lambda_b < 1.5$, then $\lambda_b = 1.5$; n_{cf} is bonded layer numbers of FRP; h_{cf} is side bonding height of FRP; s_{cf} is spacing of FRP; t_{cf} is thickness of FRP; ω_{cf} is width of FRP.

2.3.3 Differences and sameness on the shear strengthening

The shear capacity in both codes comes from three parts: concrete, steel bar, and FRP; however, details of calculation are different from each other: (1) Partial coefficient of two codes. In Chinese code, partial coefficients of steel bar and concrete are 1.12 and 1.4 respectively; in Italian code, partial coefficients of steel bar and concrete are 1.15 and 1.6 respectively. From the partial coefficient, flexural strengthening calculation in Italian code is more conservative than in Chinese code. That will be demonstrated in the following example. (2)In both codes, FRP strengthening configuration is classified into three types: side bonding, U-wrapped, and completely wrapped beams. In Chinese code, three FRP strengthening configurations are realized by three coefficients; in Italian code, three FRP strengthening configurations are realized by three different formulas.

3. AN EXAMPLE

The example, which comes from Italian code, shows differences between Chinese code and Italian code. It is part of examples of FRP strengthening design in Italian code to compare the bonded length, flexural strengthening and shear strengthening.

3.1 Geometrical, Mechanical, and Loading Data

The building considered for design is shown in Figure 5 and Figure 6. Structural elements are defined as follows: Main rectangular beams with cross-section of 30 cm x 50 cm (concrete cover $d1$=$d2$=3 cm). Secondary rectangular beams with cross-section of 30 cm x 40 cm (concrete cover $d1$=$d2$=3cm). Rectangular columns with cross-section of 20 cm x 30 cm (concrete cover $d1$=$d2$=3 cm).

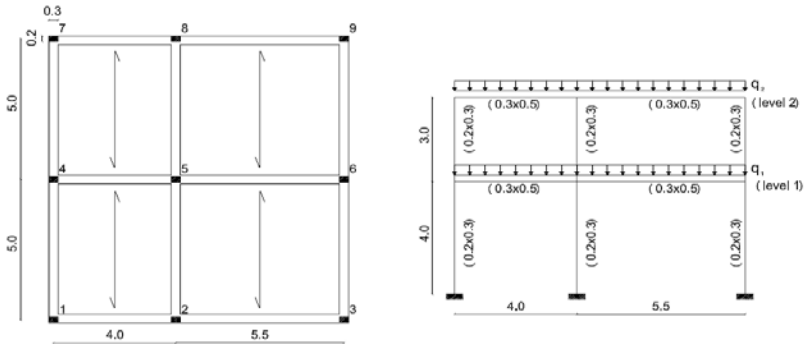

Figure 5 – Building geometry (dimensions in m).

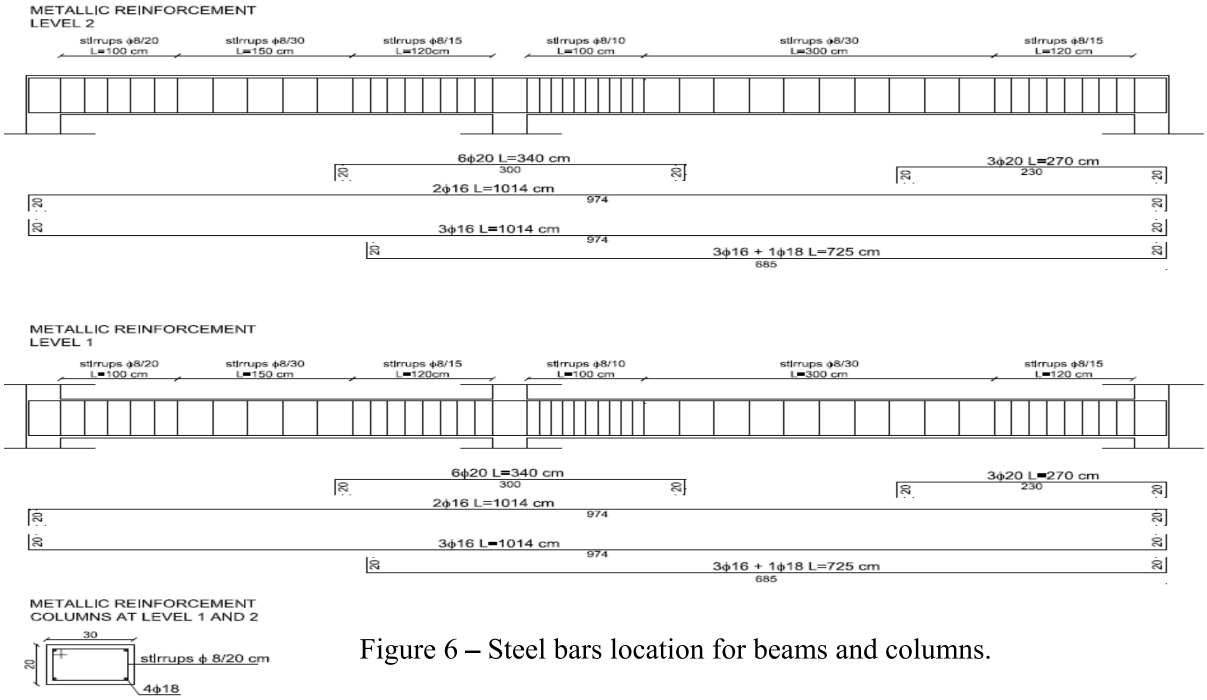

Figure 6 – Steel bars location for beams and columns.

Material mechanical properties are as follows:

- Concrete: R_{ck} = 20 N/mm^2. • Steel: FeB32k (f_{yk}=31.5 N/mm^2).

Loading conditions are defined as follows:

- Live load at level 1: a_1 = 2.00 kN/m^2. • Live load at level 2: a_2 = 0.50 kN/m^2.
- Snow (zone III, height a_s < 200 m): b = 0.75 kN/m^2.
- Dead load due to flooring (for each level): g = 6.00 kN/m^2.

Factored loads acting at ULS can be evaluated as follows:

- Level 1: q_1 = 62.25 KN/m. • Level 2: q_2 = 55.00 KN/m.

3.2 Increase of Applied Load

New loads are defined as follows:

- Level 1: a_1 = 6.00 KN/m2. • Level 2: a_2 = 4.00 KN/m2.

New factored loads acting at ULS can be evaluated as follows:

- Level 1: q_1 = 92.25 KN/m. • Level 2: q_2 = 81.20 KN/m.

3.3 Design of Flexural Reinforcement

The flexural strengthening calculation of a beam with 5.5m span is used to explain the differences between Chinese code and Italian code in flexural strengthening.

3.3.1 Flexural strengthening calculation parameters with Italian code

Design material properties are determined as follows:

・ Concrete (f_{ck} =16.6N/mm^2, γ_c=1.60, f_{cd}=10.38 N/mm^2, f_{ctm}=1.95 N/mm^2, f_{ctd}=0.7·f_{ctm}· γ_c=0.85 N/mm^2)

・ Steel (f_{yk} = 315.00 N/mm^2, γ_s = 1.15, f_{yd} = 274.00 N/mm^2)

FRP flexural strengthening is performed by installing carbon fiber reinforcement using the wet-lay-up method with the following geometrical and mechanical characteristics (0: α_{fE}= α_{ff}=0.9):

・ CFRP thickness: $t_{f,1}$= 0.167 mm. ・ CFRP width: b_f = 240.0 mm.

・ CFRP Young modulus of elasticity in fibers direction (beam axis):
α_{fE}·E_f = 0.9·300000 N/mm^2 = 270000 N/mm^2.

・ CFRP characteristic strength: α_{ff}·f_{fk} = 0.9·3000 N/mm^2 = 2700 N/mm^2.

3.3.2 Flexural strengthening calculation parameters with Chinese code

Design material properties are determined as follows:

・ Concrete (f_{ck} =16.6N/mm^2, γ_c=1.40, f_c=11.86 N/mm^2, f_{ctm} = 1.95 N/mm^2, f_t= 1.39 N/mm^2)

・ Steel (f_{yk} = 315.00 N/mm^2, γ_s = 1.12, f_y = 281.25 N/mm^2)

FRP flexural strengthening is performed by installing carbon fiber reinforcement using the wet-lay-up method with the following geometrical and mechanical characteristics:

・ CFRP thickness: $t_{f,1}$= 0.167 mm. ・ CFRP width: b_f = 240.0 mm.

・ CFRP Young modulus of elasticity in fibers direction (beam axis): E_f = 300000 N/mm^2

・ CFRP characteristic strength: f_{fk} = 3000 N/mm^2.

3.3.3 Flexural strengthening calculation results

According to Chinese code and Italian code, flexural capacity of FRP-strengthened member and the bonded length are as follows:

Table 3.1 comparison on flexural strengthening results

Code	level	Span[m]	n_f	flexural capacity [KN m]	bonded length[m]
Chinese code	1	5.5	1	213.8	0.85
	2	5.5	1	213.8	0.85
Italian code	1	5.5	1	195	0.11
	2	5.5	1	195	0.11

Table 3.1 shows comparison on flexural strengthening results. With the same materials and different codes, the results are quite different from each other. Flexural capacity and bonded length are 213.8 KN/m and 0.85m respectively when Chinese code is utilized; however, Flexural capacity and bonded length are 195KN/m and 0.11m respectively when Italian code is utilized. The calculation method of the bonded length in Chinese code is found to be conservative and the calculation method of flexural capacity in Italian code is found to be conservative. The differences between the two codes are mainly caused by the calculation methods and partial coefficient.

3.4 Design of Shear Reinforcement

The shear strengthening calculation of beam with 5.5m span is selected to explain differences between Chinese code and Italian code in shear strengthening.

3.4.1 Flexural strengthening calculation parameters with Italian code

Design material properties are determined as follows:

・ Concrete (f_{ck} =16.6N/mm^2, γ_c=1.60, f_{cd}=10.38 N/mm^2, f_{ctm} = 1.95 N/mm^2, f_{ctd}=0.7·f_{ctm}· γ_c=0.85 N/mm^2)

・ Steel (f_{yk} = 315.00 N/mm^2, γ_s = 1.15, f_{yd} = 274.00 N/mm^2)

FRP shear strengthening is performed by installing U-wrap carbon fiber reinforcement having the following geometrical and mechanical characteristics (mode 1, Section 2.3.3.2: α fE= α ff=0.9):

・ CFRP thickness: $t_{f,1}$= 0.167 mm. ・ CFRP width: b_f = 150.0 mm.

- CFRP Young modulus of elasticity: $\alpha_{fE} \cdot E_f = 0.9 \cdot 300000$ N/mm^2 = 270000 N/mm^2.
- CFRP characteristic strength: $\alpha_{ff} \cdot f_{fk} = 0.9 \cdot 3000$ N/mm^2 = 2700 N/mm^2.

3.4.2 Flexural strengthening calculation parameters with Chinese code

Design material properties are determined as follows:

- Concrete (f_{ck} =16.6N/mm^2, γ_c=1.40, f_c=11.86 N/mm^2, f_{ctm} = 1.95 N/mm^2, f_t= 1.39 N/mm^2)
- Steel (f_{yk} = 315.00 N/mm^2, γ_s = 1.12, f_y = 281.25 N/mm^2)

FRP flexural strengthening is performed by installing carbon fiber reinforcement using the wet-lay-up method with the following geometrical and mechanical characteristics:

- CFRP thickness: $t_{f,1}$= 0.167 mm. · CFRP width: b_f = 150.0 mm.
- CFRP Young modulus of elasticity: E_f = 300000 N/mm^2
- CFRP characteristic strength: f_{fk} = 3000 N/mm^2.

3.4.3 Shear strengthening calculation results

According to Chinese code and Italian code, shear capacity of FRP-strengthened member is as follows:

Table 3.2 comparison on shear strengthening results

Code	level	Span[m]	Section	n_f	shear capacity [KN]
Chinese code	1	5.5	left support	2	459
			right support	1	380
Italian code	1	5.5	left support	2	340
			right support	1	261

Table 3.2 shows comparison on shear strengthening results. With the same materials and different codes, the results are quite different from each other. Shear capacity of left support and right support are 459KN and 380KN respectively when Chinese code is utilized; however, Shear capacity of left support and right support are 340KN and 261KN respectively when Italian code is utilized. The calculation method of shear capacity in Italian code is found to be conservative. The differences between the two codes are mainly caused by calculation methods and partial coefficient.

4. CONCLUSION

This paper compares the strategies of Chinese and Italian codes about FRP-retrofitting practice for R/C structures in detail. The FRP-retrofitting related specifications of both codes are essentially consistence in principle point of view, nevertheless, the calculation methods of the bonded length, flexural strengthening, and shear strengthening are different from each other. The difference mainly comes from two aspects: different partial coefficient and different calculation methods. Case study shows that Chinese code is more conservative in the bounded length; Italian code is more conservative in flexural strengthening and shear strengthening. The differences would illuminate designers to pay attention to the issues during calculation and design.

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REFERENCES

Technical specification for strengthening concrete structures with carbon fiber reinforces polymer laminate. (2002).
Guide for the design and construction of externally bonded FRP systems for strengthening existing structures. (2004).
Code for design of concrete structures. (2002). China building industry press.