A COMPUTING MODULE FOR A QUICK DETERMINATION OF FLEXURAL STRENGTH OF CONCRETE

Nguyen Viet Duc[1]

Abstract: *This paper presents a computing module for a quick determination of flexural strength of fibre-reinforced concrete, plain concrete and hybrid cement composite. The hybrid cement composite consists of two layers of plain concrete and steel fibre-reinforced concrete. Both of these concretes are self-compacting ones. Flexural strength could be defined quickly by a series of codes, which was written in Matlab language. The verification was done by comparing the experimental test results and the one from the code. On the same basis, the deviation between the code and the experiment was less than 5%. This outcome proved the efficiency of the code developed for the study.*

Keywords: Matlab code, hybrid cement composite, flexural strength, elastic modulus.

1. INTRODUCTION

The development of new cement-based composite solutions including high performance concrete, ultra-high performance concrete, self-compacting concrete, ect has made a great contribution to improving the quality of structures and long-term characteristics. On the other hand, an arisen challenge to make them more affordable materials is a stimulating task of concrete science. Aitcin (Aitcin, 2000) recommended once new cement and concrete have been developed; on top of the two questions, that have legitimately to be answered about the economic and acceptance standard consequences of its application.

Economical consideration has been concerned since ancient times, when some applications of straw fibers in a portion of the thickness of the structural member in order to reduce total fiber content have been found (Rahimi & Kesler, 1979). That relates to reducing the cost of construction by material costs. The other way to reduce cost is by using efficient construction techniques. The Roman technique was an original example of it. First, a semi-fluid mixture of lime, pozzolan, and small stones or brickbats was poured in, and then a layer of larger stones, from 3 to 6 inches across, was laid by hand. Then a second layer of fluid cement was poured in, and so on. The pozzolan-lime mortar was compacted around the pieces of aggregate by tamping, which is the only method of removing the voids and closing the molecular structure of the mortar to make lasting concrete. It has been said elsewhere in (Moore, 2004). This kind of technique might have been time-consuming, as illustrated in Figure 1, compared to the present one but it has made Roman concrete last a thousand year with us.

Not like Roman concrete of pozzolan-lime, today concrete mainly contains Portland cement which was invented in the eighteenth century. Better mechanical behaviors and durable concretes like ultra-high performance concrete (UHPC) or reactive powder concrete have been developed by scientists, but sometimes their cost has frightened stakeholders (Aitcin, 2000). It is worth noting about construction of the bridge deck Bourg-lès-Valence (France) (Brandt, 2008), as shown in Figure 2, only precast beams and slabs thickness 20mm of expensive UHPC Ductal® have been used and ordinary concrete was cast in situ to form a bridge deck thickness 200mm. This idea is certainly one of important directions of future UHPC application.

Although the prominence of self-compacting concrete (SCC) has relieved many engineers when

[1] *Thuyloi University.*

they had to deal with the structure of highly congested reinforcement and lack of skilled labour force, the cost of construction using SCC has somehow limited SCC application to general construction.

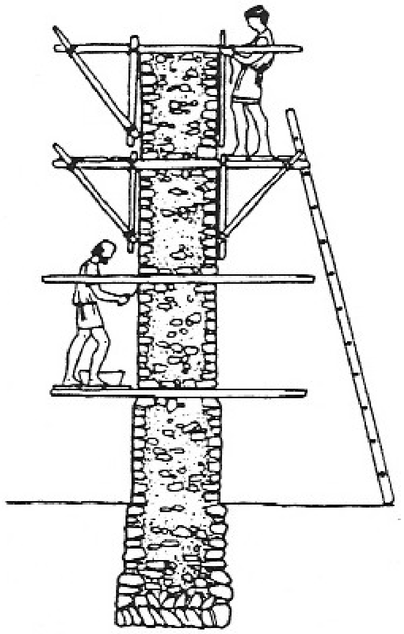

Figure 1. Roman technique (Moore, 2004)

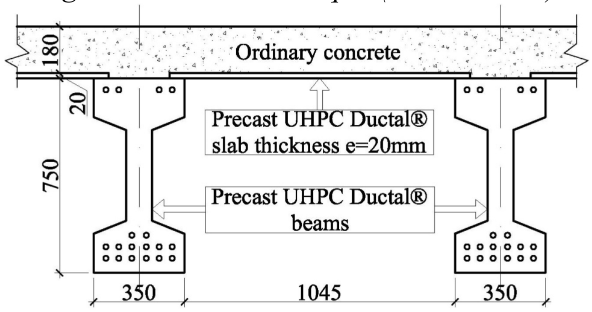

Figure 2. Description of composite solution (Brandt, 2008)

Ho and his co-workers (Ho et al., 2001) introduced the multi-layer "sandwich" concept of construction in order to solve the issue of cost reduction of SCC. It involves the casting of SCC, where with dense reinforcement, and conventional concrete, where with less dense one, in layers within the same member, as can be seen in Figure 3. In addition to cost, the sandwich system could offer other benefits as well. In addition, Tam and his colleagues (Tam et al., 2002) have reported the sandwich concept for incorporating SCC and ordinary one enables to achieve the limit of maximum temperature and satisfactory temperature differential. Those factors have been arisen from the concern for early thermal cracking, potential danger of delayed ettringite formation also known as internal sulfate attack, particularly in ordinary Portland cement.

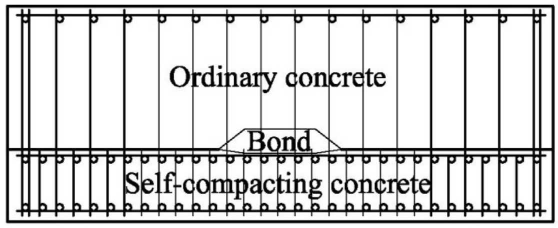

Figure 3. The idea of "sandwich" concept (Ho et al., 2001)

A hybrid solution has been mentioned in the patent of Gudovich (Gudovich, 2002). In this, the hybrid definition implies the sandwich panel with embedded thermal insulation layer which has been used broadly in countries of cold climate and long winter. The sandwich panel is made in form of two external layers of normal weight concrete (NWC) and the internal thermal layer is heat-insulating material (HIM) attached to thin transition layers of foam concrete, as it can be observed in Figure 4. The advantage of this multilayer material is a shortening time of construction and reduction involving construction expenses significantly. Nevertheless due to the core of sandwich panel is made of non-durable material, its estimated durability is just mid-term referred to building construction such as dwelling, office building, etc.

The hybrid cement composite in this study is a combination of steel fibre-reinforced concrete and plain concrete. Both of these concretes are self-compacting ones. Up to the present moment, in the literature, a few studies have been reported in terms of this type of composite that have attempted to test elements of a hybrid of concrete with and without fibres by taking advantages of SCC properties. The hybrid cement composite can meet the sustainable use of material thanks to the efficient use of the costly fibre. Experimental tests on this type of material have been conducted thoroughly in the literature elsewhere in Refs.

(Nguyen et al., 2014; Nguyen, 2015). However, there is a need to have a method of determining flexural strength of this material in a quick manner, rather than by means of the experimental tests on standard samples. Therefore, this is an objective of the present paper.

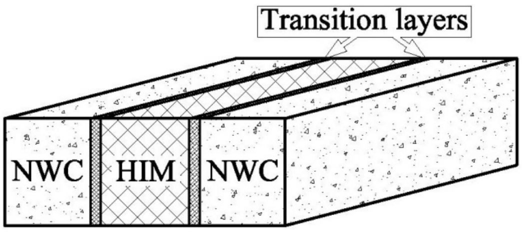

Figure 4. Multilayer building material

2. METHODOLOGY

In order to determine flexural strength of material, in this study, the author uses the limit-state method of design. As it is well-known, the addition of steel fibre improves crucially tensile strength, but hardly enhances compressive strength of concrete. In other words, in comparison with plain concrete, fibre-reinforced concrete has a higher tensile strength and similar compressive strength (Neville, 2002). Hence, it is assumed that under bending load the beam made of fibre-reinforced concrete and hybrid-cement composite has a similar cross-section of the plain concrete with steel bar reinforcement at the tensile layer, as it is shown in Figure 5. In this figure, the stress-strain distribution of this type of beam under bending load is also provided.

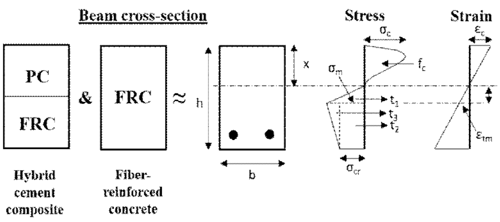

Figure 5. Beam cross-section and stress-strain distribution

According to the abovementioned stress-strain distribution for the beam under bending load, in order to define flexural strength with the limit-state method of design, for fibre-reinforced concrete beam, we have the following expressions:

$$\varepsilon_c = \frac{x*\varepsilon_{tm}}{h-x} \quad (1)$$

Where, ε_c is compressive strain; x is depth of neutral axis, ε_{tm} is tensile strain, and h is height of beam. At the upper compressive layer, compressive stress σ_c is defined as shown in equation (2)

$$\sigma_c = \varepsilon_c * E * 10^3 \quad (2)$$

Where, E is elastic modulus of fibre-reinforced concrete. Next, compressive force f_c at the upper layer is defined as follows:

$$f_c = 0.5 * x * \sigma_c * b \quad (3)$$

Regarding the lower layer, which is exposed to tensile loading, the tensile load is combination of t_1, t_2, t_3, which are determined in equations (4), (5), (6), respectively.

$$t_1 = 0.5 * y * \sigma_c * b \quad (4)$$

$$t_2 = (\text{h} - \text{x} - \text{y}) * \sigma_{tcr} * b \quad (5)$$

$$t_3 = 0.5 * (\text{h} - \text{x} - \text{y}) * (\sigma_{tm} - \sigma_{tcr}) * b \quad (6)$$

Where, y is the distance the neutral axis and the location where the maximum stress is attained. According to the limit-state design, we have the following equation:

$$f = x * \varepsilon_{tcr} - y * \varepsilon_c \quad (7)$$

For the ultimate limit-state design, the data of which is used for determination of flexural strength, we need to solve the system of equations, in which there is an equilibrium of tensile and compressive force on beam cross-section and f equals to nill. This system of equations is expressed below.

$$\begin{cases} f_c - t_1 - t_2 - t_3 = 0 \\ f = 0 \end{cases} \quad (8)$$

By solving this system, the variables x and y will be defined for the further determination of flexural strength of fibre-reinforced concrete beam.

With respect to the beam made of hybrid cement composite. The procedure is almost the same, except the variable y in this case depending on x, as presented in equation (9).

$$y = (1 - a) * h - x \quad (9)$$

Where, a is ratio of depth of fibre-reinforced concrete and the total beam depth.

By solving the system of equations (8), the variables x and ε_c will be defined for the further determination of flexural strength of hybrid cement composite beam.

The loading scheme and moment distribution of the beam under third-point loading is shown in Figure 6. For the beams made of fibre-reinforced concrete and hybrid cement composite, the loading moment M is defined as followed:

$$M = 2 * f_c * \frac{x}{3} + 2 * t_1 * \frac{y}{3} + t_2 * (y + \frac{h - x - y}{2}) + t_3 * (y + 2 * \frac{h - x - y}{3}) \quad (10)$$

On the other have, for plain concrete, it is determined by the equation (11)

$$M = \frac{E * \varepsilon_{tc} * b * h^2}{6} \quad (11)$$

Where, ε_{tc} is tensile strain of plain concrete.

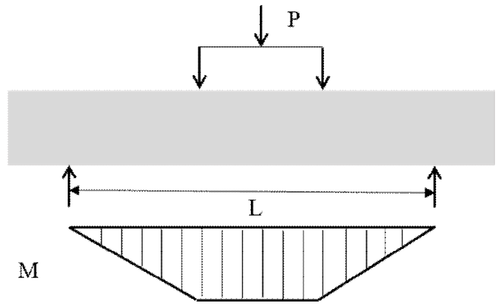

Figure 6. Loading scheme and moment distribution of the beam under third-point loading

As soon as moment is defined, the applied load P can be determined by the equation (12).

$$P = \frac{6 * M}{L * 1000} \quad (12)$$

Finally, flexural strength of the material from third-point loading test is defined by the equation (13) below.

$$R = \frac{P * L}{b * h^2} \quad (13)$$

3. RESULTS AND VERIFICATION

The computing module for a quick determination of flexural strength of fiber-reinforced concrete, plain concrete, and hybrid cement composite was written in Matlab Language. The code description in detail can be found in the Appendix below.

Regarding the code details, the determination of flexural strength for fibre-reinforced concrete is carried out as follows: first, it needs to introduce the parameter of the sample, such as breadth, depth and span, used for strength determination; then elastic modulus of concrete, cracking tensile stress concrete, cracking tensile strain concrete, maximum tensile stress of concrete and maximum tensile strain of concrete are introduced. After this procedure, the compilation process of Matlab is taken into account to yield flexural strength for fibre-reinforced concrete. In the case of plain concrete, the procedure occurs as same as the previous one with the introduction of sample parameter. Afterward, as soon as the input of' maximum tensile strain of concrete is done, the compilation process of Matlab will bring out the outcome.

With respect to the determination of flexural strength for hybrid cement composite, the process is carried out as same as it is done for fibre-reinfored concrete above-mentioned.

The verification of the obtained outcome from the Matlab code and the experimental results was performed by mean of a series of test samples. The prismatic sample is with dimension of 100x100x400 mm^3. The span in the third-point loading test is 300 mm. For each type including plain concrete, fibre-reinforced concrete and hybrid cement composite, three samples were employed and the average result was used to compare with the outcome from the Matlab code. All of material data that need to be introduced into the computing module are described in detail in Ref. (Nguyen, 2015). Besides, for the deliberate comparative study, the experimental flexural strength of plain concrete, fibre-reinforced concrete and hybrid cement composite was defined by using the material, data of which was afterwards introduced into the computing module for determination of flexural strength by the Matlab code. The comparison of the outcome from the code and the experiment is provided in Table 1 below.

Table 1. Comparison of the outcome from the code and the experiment

	Illustration	Flexural strength in MPa					Deviation
		Experiment				Code	
		Sample 1	Sample 2	Sample 3	Mean		
Plain concrete	SCC	6.8	7.1	7	7.0	7.2	3.35%
Fibre-reinforced concrete	FSCC	9.8	9.4	9.5	9.6	10	4.53%
Hybrid cement composite	SCC FSCC	8.3	8.1	8.5	8.3	8.7	4.82%

Looking into Table 1, it is seen that the deviation between the outcome from the code and the experimental results is 3.35% for plain concrete. Besides, the deviations for fibre-reinforced concrete and hybrid cement composite are 4.53% and 4.82% respectively. Since the deviation between the code and the experiment is less than 5%, this effect proves the efficiency of using the code for a quick determination of flexural strength.

4. CONCLUSION

A computing module for a quick determination of flexural strength of fiber-reinforced concrete, plain concrete, and hybrid cement composite was developed in this study. The hybrid cement composite consists of two layers of plain concrete and steel fibre-reinforced concrete. Both of these concretes are self-compacting ones. The following conclusions can be withdrawn:

- The code for a quick determination of flexural strength of not only hybrid cement composite, but also plain concrete and fibre-reinforced concrete was successfully written in the Matlab language.
- On the same basis, the deviation between the code and the experiment was less than 5%. This outcome proved the efficiency of the code developed for the study.

APPENDIX

Fibre reinforced concrete

```
%%%%%%%%%%%%%%%
function CF4b
clc
disp('Ult. load of fibre reinforced concrete beam under 4point bending');
disp('                To exit press button Ctrl+C                  ');
disp(' ');
b = input('Breadth of beam in mm: ');
h = input('Depth of beam in mm: ');
l = input('Span of beam in mm: ');
e = input('Elastic modulus of concrete used in GPa: ');
sigtc = input('Cracking tensile stress of FRC in MPa: ');
eptc = input('Cracking tensile strain of FRC: ');
sigtm = input('Maximum tensile stress of FRC in MPa: ');
eptm = input('Maximum tensile strain of FRC: ');
syms x y
%b=100;
%h=100;
```

```
%sigtc=4.01;
%sigtm=4.99;
%e=38.7e3;
%eptc=121e-6;
%eptm=3600e-6;
epc=x*eptm/(h-x);
sigc=epc*e*1000;
fc=0.5*x*sigc*b;
t1=0.5*y*sigtc*b;
t2=(h-x-y)*sigtc*b;
t3=0.5*(h-x-y)*(sigtm-sigtc)*b;
f=x*eptc-y*epc;
[x y]=solve(fc-t1-t2-t3,f);
x=double(x(2))
y=double(y(2));
epc=x*eptm/(h-x);
sigc=epc*e*1000;
fc=0.5*x*sigc*b;
t1=0.5*y*sigtc*b;
t2=(h-x-y)*sigtc*b;
t3=0.5*(h-x-y)*(sigtm-sigtc)*b;
m = 2*fc*x/3+2*t1*y/3+t2*(y+(h-x-y)/2)+t3*(y+2*(h-x-y)/3);
P = m*6/l/1000;
disp('Ult. load of fibre-reinforced concrete beam under 4point bending in KN is: ');
disp(f)
end
```

Plain concrete

```
%%%%%%%
function SF4b
clc
disp('Ult. load of plain concrete beam under 4point bending');
disp('            To exit press button Ctrl+C            ');
disp(' ');
b = input('Breadth of beam in mm: ');
h = input('Depth of beam in mm: ');
l = input('Span of beam in mm: ');
e = input('Elastic modulus of concrete used in GPa: ');
ept = input('Maximum tensile strain of concrete: ');
m = e*ept*h^2*b/2/3;
P = m*6/l;
disp('Ult. load of plain concrete beam under 4point bending in KN is: ');
disp(f)
end
```

Hybrid cement composite

```
%%%%%%%%%%%%%%
function CF4b
clc
disp('Ult. load of fibre reinforced concrete beam under 4point bending');
disp('                   To exit press button Ctrl+C                    ');
disp(' ');
b = input('Breadth of beam in mm: ');
h = input('Depth of beam in mm: ');
l = input('Span of beam in mm: ');
e = input('Elastic modulus of PC used in GPa: ');
a = input('Ratio of depth FRC and total: ');
sigtc = input('Cracking tensile stress of PC in MPa: ');
eptc = input('Cracking tensile strain of PC: ');
sigtm = input('Maximum tensile stress of FRC in MPa: ');
eptm = input('Maximum tensile strain of FRC in microstrain: ');
syms x epc
%b=100;
%h=100;
%sigtc=4.01;
%sigtm=4.99;
%e=38.7e3;
%eptc=121e-6;
%eptm=3600e-6;
y = (1-a)*h-x;
sigc = epc*e*1000;
fc = 0.5*x*sigc*b;
t1 = 0.5*y*sigtc*b;
t2 = a*h*sigtc*b;
t3 = 0.5*a*h*(sigtm-sigtc)*b;
f = x*eptc-y*epc;
[epc x] = solve(fc-t1-t2-t3,f);
x = double(x(1));
epc = double(epc(1));
y = (1-a)*h-x;
sigc = epc*e*1000;
fc = 0.5*x*sigc*b;
t1 = 0.5*y*sigtc*b;
t2 = a*h*sigtc*b;
t3 = 0.5*a*h*(sigtm-sigtc)*b;
m = 2*fc*x/3+2*t1*y/3+t2*(y+(h-x-y)/2)+t3*(y+2*(h-x-y)/3);
P = m*6/l;
disp('Ult. load of hybrid concrete beam under 4point bending in KN is: ');
disp(f)
end
```

REFERENCES

Aitcin P. C. (2000) *Cements of yesterday and today. Concrete of tomorrow.* Cement and Concrete Research. No. 30, pp. 1349-1359.

Rahimi M. M. & Kesler C. E. (1979) *Partially steel-fibre reinforced mortar.* Journal of Structural Division. Proceedings. American Society of Civil Engineers. Vol. 105, No. ST1, proc. Paper 14282, pp. 101-9.

Moore D. (2004). *The Roman Pantheon*-The Triumph of Concrete or website www.romanconcrete.com

Brandt A.M. (2008) *Fibre reinforced cement-based (FRC) composites after over 40 years of development in building and civil engineering*. Composite structures. No 86, pp. 3-9.

Ho D. W. S., Sheinn A. M. M. & Tam C. T. (2001) *The sandwich concept of construction with SCC. Cement and Concrete Research*. Vol. 31, pp 1377-1381.

Tam C. T., Swaddiwudhipong S., Ho D.W.S. & Seow S.S. (2002) *Strategy for casting of raft foundation in tropical climate.* Journal, Institution of Engineer, Singapore, V42, N6, pp 6-11.

Gudovich A. P. (2002) *Multilayer building member and method of its manufacture.* Russian patent, RU 2194133C1.

Neville A.M. (2002). *Concrete Properties 4th edition.* Person Education Limited, Edinburgh.

Nguyen, V. D., Río, O. & Sánchez-Gálvez, V. (2014) *Performance of hybrid cement composite elements under drop-weight impact load.* Materiales de Construcción 34 [314], e017, p. 1-14

Nguyen, V.D. (2015). *Mechanical behavior of laminated functionally graded fibre-reinforced selfcompacting cementitious composites*. Doctoral thesis document, Technical University of Madrid

Tóm tắt:

MÔĐUN TÍNH TOÁN XÁC ĐỊNH NHANH CƯỜNG ĐỘ CHỊU UỐN CỦA BÊ TÔNG

Bài báo này giới thiệu một mô-đun tính toán để xác định nhanh cường độ chịu uốn của bê tông cốt sợi, bê tông không cốt sợi và vật liệu đa chức năng nền xi măng tự lèn cốt sợi. Vật liệu này được tạo ra từ hai lớp của bê tông cốt sợi thép và bê tông không sử dụng cốt sợi thép. Cả hai loại vật liệu sử dụng đều có khả năng tự lèn, không cần đầm rung khi đổ vào ván khuôn. Cường độ chịu uốn của vật liệu được xác định sử dụng phần mềm tính toán Matlab. Việc xác thực đã được thực hiện trên nhiều mẫu thử nhằm đối chứng với kết quả của phần mềm tính toán Matlab. Trên cùng một cơ sở đối chứng, sự sai lệch giữa thực nghiệm và phần mềm đã cho kết quả nhỏ hơn 5%. Điều này chứng tỏ tính khả thi của việc sử dụng phần mềm tính toán cho việc xác định cường độ chịu uốn trong nghiên cứu này.

Từ khóa: Môđun tính toán, vật liệu đa chức năng nền xi măng tự lèn cốt sợi, cường độ chịu uốn, môđun đàn hồi.

Ngày nhận bài: 21/12/2021

Ngày chấp nhận đăng: 31/12/2021