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USE OF STEEL FIBER REINFORCED CONCRETE IN THIN SHELL STRUCTURES: EVALUATION OF FIBER PERFORMANCE THROUGH TESTING OF SHELL SPECIMENS

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Abstract. *The following document proposes the use of steel fiber reinforced concrete (SFRC) in the construction of shell structures. SFRC provides bending resistance and improves shell serviceability. One directional bending tests on shell specimens will be carried on, and conclusions on SFRC shell sections performance will be drawn out on the basis of the comparison between theoretical and modeled load – deflection behavior*.

1 Introduction

Structural design of RC shells parting from the results of a shell-type finite-element analysis faces the difficulty of providing the required safety for the ultimate limit states of bending and shear of shell sections.

The addition of steel fibers in the concrete mix allows for the development of tensile stresses along the entire cracked depth of a section. These stresses can provide the required ultimate bending strength. Steel fibers provide also other properties that improve the structural behavior under service loads [1]. For instance:

- Crack width reduction
- More uniform distribution of cracks
- Improvement of structural behavior under cyclic loads
- Increase in structural ductility

The paper focuses on the study of the behavior of steel fiber reinforced concrete (SFRC) as composite material for construction of thin shell structures. The main aims are as follows: On one hand to afford the ultimate design of sections from the results gained in a linear elastic analysis of the shell, considering the bending resistance developed by fibers. On the other hand, to take advantage of the structural qualities which fibers can bring to concrete.

These ideas are being carried into practice in the structural design and construction of a hypar shell roofing structure. This roof is an eight-lobe groined-vault system, spanning 36 m between opposite supports, with a base shell thickness of 6 cm. It will be constructed at the *Parque Oceanográfico Universal* in Valencia (Spain). For this structure we proposed in ref. [2] a design method means an interaction diagram axial force vs. bending moment for concrete shell sections. The diagram is calculated on the basis of a stress – strain ultimate model that considers the effects of central reinforcement mesh and the addition of steel fibers in the mix. The model is based on the one proposed in reference [3] for dimensioning flexural members with or without reinforcement bars. Its main feature is the quantifying of fiber effects as a tensile stress block acting on the entire cracked depth of the section. The amount of stress can be obtained from special tests or from data provided by the fiber manufacturer.

In order to verify the convenience of this model for bending calculations in the case of thin sections, one directional bending tests on 6 cm thick rectangular shell specimens (1,30 x 1,80 m) were carried on in the *Laboratorio de Materiales* of the *Universidad Politécnica de Valencia* (Spain). Each specimen lies horizontally on two linear bearings. Bending forces are introduced through two load lines using one vertical jack. During the testing process values of vertical displacements on several points are measured. Behavior of specimens up to failure will be studied.

Test results will be compared with the results from a load-deflection theoretical model of the specimen. Conclusions are being drawn out on the ability of steel wire fibers to provide the required tensile strength, and to improve shell behavior under service loads.

2 Structural use of steel fiber reinforced concrete (SFRC)

The use of fibers as reinforcement for concrete (especially steel fibers) is a considerably developed technique. Research in this field has token place on the study of the behavior of several fiber types, the properties of the resulting composite, preparation and placing technologies, and the convenient theoretical models – see ref. [1]. Applications of cast-in-place steel fiber reinforced concrete (SFRC) involve in a great extent high requirement floor slabs and pavements, and tunnel and surface linings. Pre-cast SFRC has been applied in thin elements of reduced size, thus with limited structural requirements.

On the other hand, great experience is also available for steel fiber reinforced shotcrete (SFRS), mainly in the field of slope stabilization and tunnel lining. Other applications of SFRS include the construction of reduced size dome-shaped structures, with shotcrete applied to the underside of polyurethane foam moulds to a thickness of about 40 to 100 mm (see ref. [4]).

What concerns the dimensioning of SFRC sections for bending, some available approaches – ref. [1] – are based on conventional design methods supplemented by tensile stress fiber contribution for the bending strength of the section. The main differences lie on the determination of the magnitude of the tensile stress due to the fibers. Other approaches use the fiber tensile contribution to determine the remaining moment capacity in the cracks, considered as plastic hinges.

The conservative point of view is to analyze the section with reinforcement bars resisting the total tensile load, and is based on the fact that variability of fiber distribution can lead to dangerous reductions in strength. On the opposite side lie recent proposals such as the one in ref. [3] (Belgium), or the methods described in ACI Report 544.4R-10 (ref. [7]) to standardize the ultimate design methods for concrete sections with conventional and steel fiber reinforcement. These proposals include design methods for bending and longitudinal forces, for shear and calculation of crack width.

Reference [7] describes the method developed by Henager and Doherty in 1976 for static flexural analysis of beams containing bars and fibers, which is similar to the ACI ultimate strength design method. This method proposes the use of:

a) a rectangular compression block with a stress value of 0,85 fc (concrete compressive strength) and a depth of 0,8 x (neutral axis depth).

b) a rectangular tensile block with a stress value calculated from the length, diameter, percent by volume and bond efficiency factor of fibers, developed at a certain strain under the neutral axis.

The flexural analysis method of ref. [3] is based on a more sophisticated method for the stress – strain diagram for steel wire fiber reinforced concrete:

1. For concrete in compression a parabolic-rectangular behavior until maximum concrete strain (0,0035) is assumed

2. For concrete in tension a linear behavior is assumed up to the concrete axial tensile strength. After cracking stress is assumed to decrease to 0,37 $f_{ct,eq,300}$ (equivalent flexural tensile strength of SFRC – obtained in the standard bending test with controlled strain corresponding to a deflection of L/300) at a strain value of 0,001. From this strain value to the SFRC limit strain 0,01, stress decreases linearly to 0,37 $f_{ct,eq,150}$ (equivalent flexural tensile strength of SFRC corresponding to a deflection of L/150).

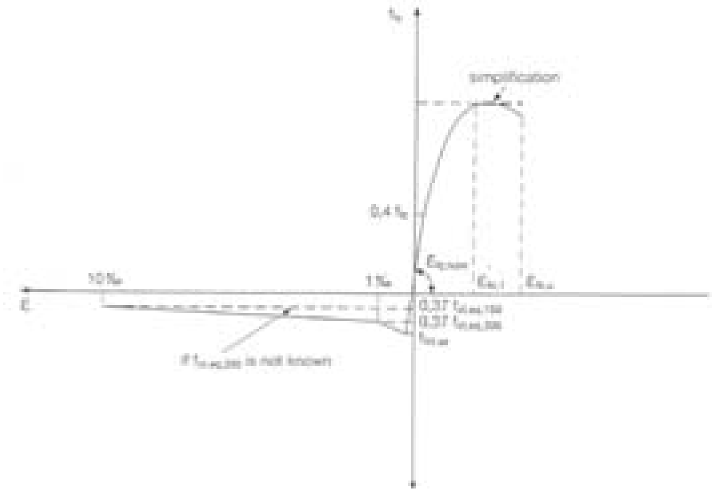

Figure 1. SFRC stress – strain diagram (source: ref. [3])

Based upon this stress-strain diagram a plastic design or a conventional design with a tensile stress block with the described form, with flexural tensile stress values gained from standard bending tests, can be carried on.

Reference [3] includes guaranteed mean values for the equivalent flexural tensile strength for different types and weight ratios of Dramix-type fibers and the corresponding analytical expressions to evaluate this parameter. These values could be used in case of absence of standard tests.

3 Target of this research

The structural design and dimensioning of thin shell elements, faces an important question: the ability of the shell section to resist bending forces. Generally thin shell structures are designed to resist mainly membrane forces, without consideration of bending forces. This hypothesis, traditionally accompanied by theoretical models and calculations based on the membrane theory, leads to thin shells reinforced approximately along the mean surface with bars oriented in two perpendicular directions. Considering this principles fascinating reinforced concrete shell structures, only a few centimeter thick, were built in the sixties (see ref. [10]).

The development of the FE method allows for easily carrying on linear analysis of shells with complicated geometry. When using shell type elements, values of bending and torsional forces in the shell are obtained. If the shape of the shell is adequate, the values of the bending moments will be generally little. But in some load cases, and also near stiff zones of the shell, higher moments will appear, for which the necessary structural safety must be guaranteed. Only the mechanical capacity of the section accounts for this purpose.

The flexural strength of a shallow reinforced concrete section is especially sensible to the depth of the reinforcement bars. The resisting moment depends on the distance between re-bars and the centroid of the compression block. Thus, a little change of the re-bar position (few mm) can cause an important relative reduction of the lever arm, hence a decrease of the resisting moment. In this kind of thin shell reinforcement is placed along the middle surface, therefore it is probable that the real re-bar position lies in the upper half of the section and the lever arm reduces to 20% of the total section depth. For such cases, the addition of steel fibers to the concrete mix, and its tensile contribution in the hardened concrete can mean an important increase of the security resisting bending forces.

The final target of this research is to test the applicability of a flexural analysis method considering tensile contribution of SFRC for shell structures with shallow sections. For this purpose we propose the comparison of the load-deflection behavior of shell specimens, with and without steel wire fibers, tested for one-directional bending, and the theoretical behavior of these specimens based on the model which will be explain in the next paragraph. A value of 6 cm for shell specimens' thickness was chosen, considering that a lower thickness could imply a violation of the requirements for covering in the applicable standards.

4 Theoretical model of SFRC behavior for bending

The analytical model to predict the load-deflection behavior is based on the method of curvature integration proposed in the European standard EC-2 [9], deduced from the Maxwell-Mohr theorem. The integration is carried on with the mean curvature function along the piece:

$$w = \int_L C_{II} \, \overline{M} \, dx \qquad (1)$$

where $\overline{M}$ is the bending moment function caused by a fictitious unity load applied on the point where deflection w is going to be evaluated. The mean curvature C_{II} is evaluated for each section from the curvature of the uncracked section C_I and the curvature of the cracked section without contribution of concrete in tension C_{IIo}, with the following relation:

$$C_{II} = (1 - \zeta) \, C_I + \zeta \, C_{IIo} \qquad (2)$$

where ζ is the interpolation coefficient for each section, varying between 0 and 1 depending on the magnitude of the bending moment (equals 0 in uncracked sections). The calculation of the curvature follows the lines described in ref. [9] and is based on the hypothesis of plane section and on a simplified trapezoidal stress-strain behavior of concrete (linear behavior with secant elasticity modulus until 0,85 fc -concrete compressive strength- is reached.

Uncracked section

Assuming the strain ε_c in the upper concrete fiber to be known, the corresponding stress and the compressive force D_c of the stress block, depending on the neutral axis depth *x*, can be evaluated as follows:

stress $$\sigma_c = E_c \; \varepsilon_c \tag{3}$$

compressive force of concrete $$D_c = \alpha \; \sigma_c \; b \, x \tag{4}$$

where *b* is the section width, and α is a coefficient describing the form of the compression block (with a value of 0,5 in the pre-cracking stress – triangular block). Strain in steel and at the lower concrete fiber is calculated from the plane section hypothesis.

reinforcement $$\varepsilon_s = -\frac{d-x}{x} \varepsilon_c \tag{5}$$

lower concrete fiber $$\varepsilon_{cb} = -\frac{h-x}{x} \varepsilon_c \tag{6}$$

force of bar reinforcement $$T_s = E_s \; \varepsilon_s \; A_s \tag{7}$$

tensile force of concrete $$T_c = \alpha \; E_c \; \varepsilon_{cb} \; b \, (h-x) \tag{8}$$

where *Ec* is the secant concrete elasticity modulus, *Es* is the reinforcement steel elasticity modulus, *d* is the reinforcement depth and *h* is the total depth of the section. Beginning with a given value of the concrete upper fiber strain, the neutral axis depth *x* can be calculated considering equilibrium of internal forces acting on the section:

$$D_c + T_s + T_c = 0 \tag{9}$$

Once the value of x is known, the uncracked curvature can be evaluated from the strains in reinforcement and in concrete. The corresponding bending moment can be obtained by taking moments on the reinforcement position:

pre-cracking curvature $$C_I = \frac{\varepsilon_c - \varepsilon_s}{d} \tag{10}$$

pre-cracking moment $$M = D_c\ (d - \gamma x) + T_c\ \left[(d-h) + \gamma\ (h-x)\right] \qquad (11)$$

where the coefficient γ describes the position of the centroid of the compression block, with a value of 1/3 before concrete has reached its limit stress (0,85 fcd).

Cracked section – no fibers

Cracking occurs when SFRC tensile strength is reached. With no fiber addition the force of compressive stress block should internally equate the tensile force of bar reinforcement. The same procedure as in the uncracked section will be used, with some considerations. When the strain at the upper concrete fiber overcomes ε_{c0} (strain corresponding to a stress equal to 0,85 fc), the form of the compression block becomes trapezoidal and the values of α y γ are described with this equations:

$$\alpha = \frac{\varepsilon_c - 0.5\varepsilon_{c0}}{\varepsilon_c} \qquad (12)$$

$$\gamma = 0,5\ \frac{\left[(\varepsilon_c - \varepsilon_{c0})^2 + \varepsilon_{c0}\ (\varepsilon_c - 2/3\ \varepsilon_{c0})\right]}{\alpha\ \varepsilon_c^{\ 2}} \qquad (13)$$

These values allow the evaluation of the neutral axis depth with the following equation (9b):

$$D_c + T_s = 0 \qquad (9b)$$

The tensile force of bar reinforcement *Ts* will be limited to the yield strength *fy* of the reinforcing bar once the steel strain ε_{s0} is reached. Curvature and bending moment can be calculated with the following expressions:

curvature of the cracked section $$C_{IIo} = \frac{\varepsilon_c - \varepsilon_s}{d} \qquad (14)$$

moment $$M = D_c\ (d - \gamma x) \qquad (11b)$$

Cracked section – with fibers

In this case the development of a rectangular tensile stress block in the fibrous concrete is assumed, with a stress value of 0,37 $f_{ct,eq,150}$ (equivalent flexural tensile strength for the fibrous concrete – obtained from a standard bending test with controlled deflection – corresponding to a deflection of L/150). Tensile force of SFRC is evaluated as follows:

SFRC in tension $$T_c = -\ f_{ct,eq,150}\ b\ (h-x) \qquad (8b)$$

The neutral axis depth will be calculated from eq. (9), curvature is obtained from eq. (14) and the equation for the bending moment is:

moment $$M = D_c\ (d - \gamma x) + T_c\ \left[(d-h) + 0,5\ (h-x)\right] \qquad (11c)$$

These equations allow for plotting the moment – curvature diagrams, with or without fibers, as shown in the next figure:

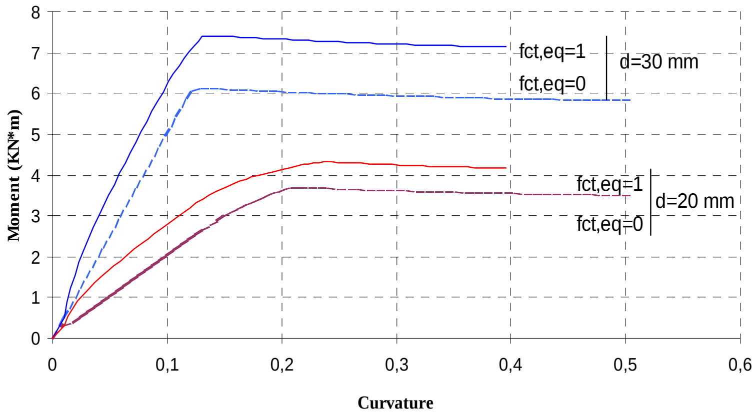

Figure 2. Moment – Curvature diagrams. Analytical model

In order to interpolate curvatures constant values for C_I (uncracked state) and for the interpolation coefficient ζ have been considered. The latter is computed with the bilinear method – proposed in Eurocode EC-2:

$$C_I = \frac{M}{E_c I} \tag{15}$$

$$\zeta = 1 - \left(\frac{M_r}{M}\right)^2 \tag{16}$$

The results of the curvature integration are shown in the following load-deflection diagrams:

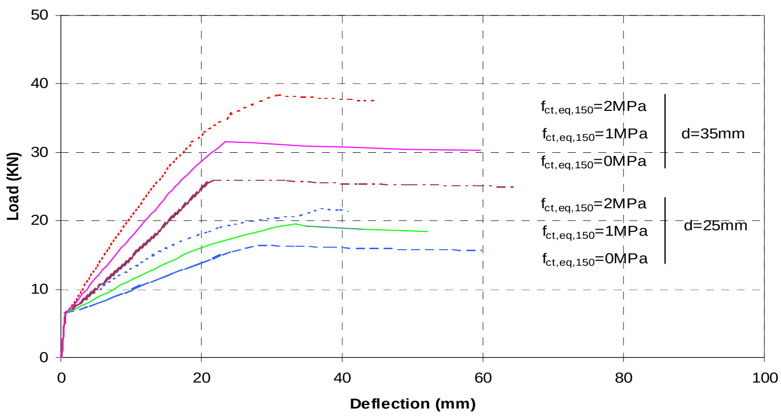

Figure 3. Load – deflection curves – Analytical model

5 Laboratory tests

5.1 Objectives of the tests.

The experimental program was carried on in the *Laboratorio de Materiales (Universidad Politécnica de Valencia)*, and had the following objectives:

- Check the adequacy of the proposed numeric model, comparing the theoretical results with the ones obtained by tests on rectangular shell specimens.

- Verify, by means of standard tests, the mechanical characteristics of the concrete with and without fibers, and afterwards compare them with the ones proposed by the fiber producer.

Following variables were analyzed:

- Risks related to the shell reinforcement positioning and the consequences caused by its movement during the construction in the shell mechanical capacity. Due to the fact that reinforcement bars lie in two directions, the bar centroid differs from one direction to another, at least, in the same distance as the bar diameter.

- Advantages in using SFRC. Fibers provide concrete to have flexural tensile strength after cracking. At the same time fiber addition enables to control crack width. Provided that the fiber effectiveness of fibers depends on several variables (mixture proportions, size, slenderness...) we decided to reduce them to the minimum, fixing as the only variable the presence or not of fibers.

- Making process. Possible diferences between cast in place SFRC vs. shotcreted SFRC were testesd.

Figure 4. Shell specimen reinforcement

Figure 5. Fresh SFRC

5.2 Testing program

5.2.1 Tests on shell specimens

Twelve shell-specimens were made, as specified in the following tables:

No. of specimens	Concrete type	Placement	Specimen position	Setting
4	RC	Cast in place	Horizontal	Vibration
4	SFRC	Cast in place	Horizontal	Vibration
2	RC	Shotcreted	60º	---
2	SFRC	Shotcreted	60º	---

Table 1. Shell-specimens

Two different kinds of shell-specimens were made: the first were cast in place in ideal conditions, horizontal position and fit on a shaking table, and the second shotcreted on a 60 degrees inclination surface. Both kinds are rectangular shaped and its dimensions are 1800 mm x 1300 mm x 60 mm. A base reinforcement ϕ 8 to 150 mm was placed in both main directions (figure 4). Materials had the following features:

Concrete type	Shotcreted	Shaked	
	All	No fibers	With fibers
Cement I-42,5 R	400	290	
Water		180	
Gravel 7/12	600	1040	920
Crushed Sand	1200	450	490
Round Sand		350	440
Superfluidificant (melanine)		(0,8 %) 2,3	(1,2 %) 3,5

Maximum gravel size	12 mm
Fibers (when placed)	50 Kgr/m^3
Fiber Type	Dramix fibers with the following features were used:

Steel class	Length (l – mm)	Diameter (ϕ - mm)	Slendern. (l / ϕ)	Type
Low carbon	35	0,45	78	80/35

Table 2. Concrete mixture and properties of materials

The following fabrication process was followed:

Shell specimens in ideal conditions

These eight shell-specimens were fabricated in the pre-casting firm PREVALESA. Two concrete mixes were made; one with fibers and another without them. Concrete was prepared in a vertical axis mixer, and the specimens were made on a shaking table. Figure 6 shows the second four specimens. Specimens were unmoulded and stocked after 24 h.

Shotcreted shell specimens

These shell-specimens were prepared in the firm HORMIGONES PROYECTADOS S.A. Concrete was prepared in dry way (water addition occurred in the projection gun). Figure 7 shows the shotcreting process. The shell-specimens were left for seven days in the work-site and afterwards they were moved (unmoulded) to the laboratory

Figure 6. Making in a shaking table

Figure 7. Shotcreting

5.2.2 Complementary tests.

In order to establish the concrete characteristics of the shell-specimens, two prismatic test moulds for each mixture were prepared. From each of them, by sawing or by extraction, we obtained the following specimens to examine:

a) 1 prismatic specimen 500x500x140 mm

- 4 specimens ϕ70x140 mm, for compression tests.
- 3 specimens 100x100x500 mm, for bending tests.

b) 1 prismatic specimen 500x500x60 mm.

- 4 specimens 60x60x120 mm, for compression tests.
- 3 specimens 100x60x500 mm, for bending tests.

Axial loading tests to specimens ϕ70x140 mm and 60x60x120 mm were made according to the Spanish standard UNE 83.508-“SFC tenacity determination to compression”. During each test the complete curve stress/strain was reported, measuring the applied stress with a pressure gauge, and the strain with a gauge that measured the relative displacement between press plates. Loading was controlled for constant speed strain growth. Tests went on until the specimen’s whole crack or until the strain exceeded 0,0075. Figure 8 shows an example of the curves obtained by these tests.

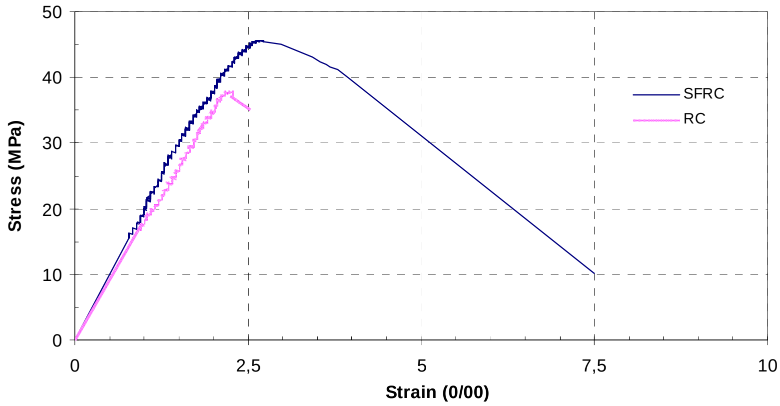

Figure 8. Stress/Strain curves - compression test

Bending tests on prismatic specimens sized 100x100x500 mm and 100x60x500 mm were carried on. Loads were applied at thirds of span with controlled strain speed according to the Spanish Standard UNE 83.508-“SFRC, strength to first crack determination, tenacity and tenacity factor determination on a bending test” o the Belgium Standard NBN B 15-238 “Test on fiber-reinforced concrete – Bending test on prismatic sample”. Figure 9 shows the typical shape of this kind of curve. First crack load and flexural tensile toughness (area below the load curve up to a deflection of L/150) were measured.

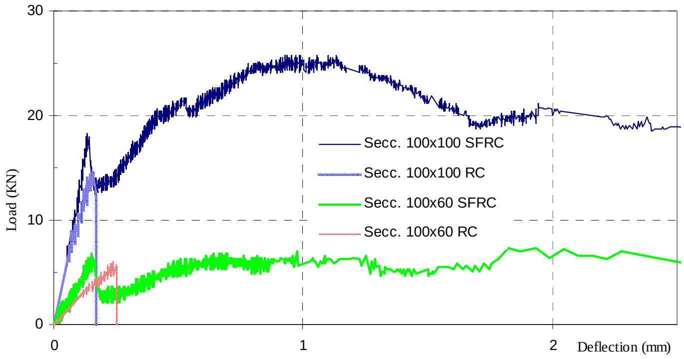

Figure 9. Load/deflection curves - bending test.

Figure 10 shows a specimen in the bending test and figure 11 shows how steel-fibers joins the two pieces of the broken concrete.

Figure 10. Specimen during bending test.

Figure 11. Steel Fibers

Figures 8 and 9 also show that the performance of both concrete types (with and without fibers) is very similar until first crack load is reached. The curve for concrete without fibers finished when the specimen showed the first crack. However, SFRC allows much higher strain and is able to resist increasing loads after the first crack.

Concrete		Compressive strength (MPa)
Concrete	C	37,8
	SFC	33,9
Shotcrete	C	31,7
	SFC	42,1

Table 3. Compressive test values.

CONCRETE		Area	Flexural tensilestrength (MPa)			
			First crack	Maximum strength	0,37 fct,eq, 150	
Concrete	C	100x100		4,22		
		100x60		4,55		
	SFC	100x100	3,78	4,68	1,34	1,17
		100x60	3,67	5,67	2,38	
Shotcrete	C	100x100		2,71		
		100x60		3,35		
	SFC	100x100	2,97	4,73	2,2	1,17
		100x60	3,25	3,25	1,75	

Table 4. Bending test values.

Tables 3 and 4 show the results of the tests. Compressive test results include the mean values of the cylinder and prismatic specimens. Results also include the experimental value of the equivalent flexural tensile strength $f_{ct,eq}$ of SFRC calculated with the bending test with the following equation from reference [3]:

$$f_{ct,eq} = F_m \, l \,/\, b \, h^2 \qquad (17)$$

Where l, b and h are, respectively, span, width and depth of the specimen, F_m is the medium value of the load applied between the deflection values 0 and l/150. Reference [3] shows also an equation for the analytical computation of the equivalent flexural tensile strength $f_{ctm,,eq}$ depending on the following parameters:

$$f_{ct,eq} = (180\, W_f\, \lambda_f\, d_f^{1/3} \,/\, (180\, f_{ck} + W_f\, \lambda_f\, d_f^{1/3}))\, (0{,}3\, f_{ck}^{2/3} \,/\, 0{,}6) \,/100 \qquad (18)$$

Where W_f, d_f and λ_f are, respectively, concrete fiber dosing (Kg/m^3), fiber diameter (mm) and slenderness defined as the quotient between length and diameter. The obtained values have been used in the theoretical model computations.

The values obtained in these tests for $f_{ct,\,eq}$ are superior to the ones grated by the manufacturer. It is also important to be noticed the great tenacity improvement obtained both compression and flexure thanks to the fibers.

5.2.3 Shell-specimens tests.

Bending tests were carried on the shell specimens. Specimens were disposed resting over its extremes leaving 1,5 m span. Load was applied in two transverse lines placed at thirds of span. Figure 12 shows the test plan and figure 13 shows a test picture.

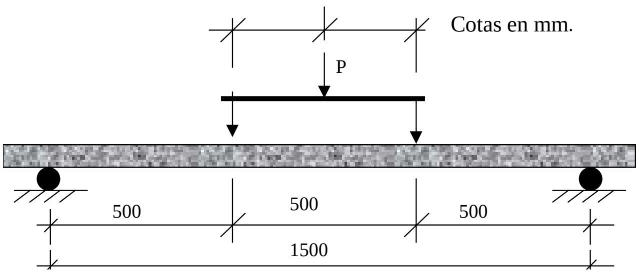

Figure 12. Test draft

Figure 13. Test device

The tests were carried on to failure, with constant speed deflection growth. During the test, 4 displacement power gauges continually recorded load and deflection in the midst of the span.

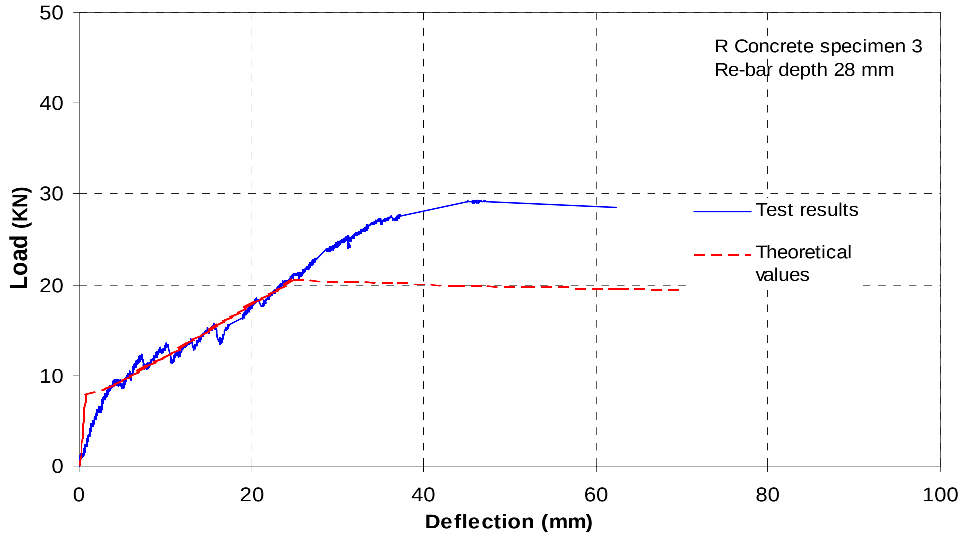

Figure 14. Comparative load/deflection behavior (RC)

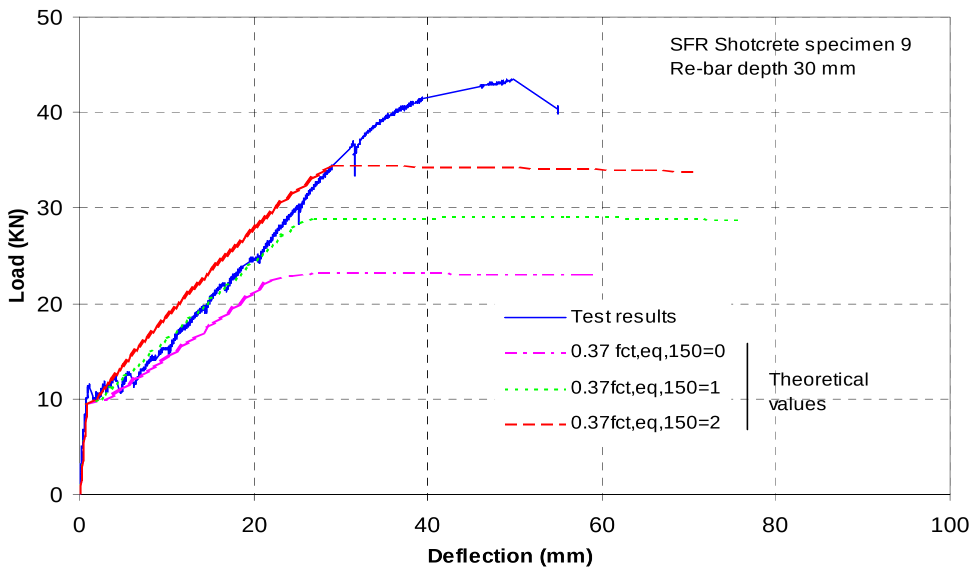

Figure 15. Comparative load/deflection behavior (SFRC)

6 Analysis of results

Figures 14 and 15 show the tested load - deflection curve of shell specimens with and without steel fibers. This curves are compared with the theoretical behavior (described model) with different values of the equivalent flexural tensile strength. Values for this parameter vary from the values given by manufacturers to those obtained on the complementary tests. The theoretical curve is drawn with the real placement of reinforcement bars obtained by measurement in the broken section after the test.

Test curve shapes are quite right up to the theoretical reinforcement yielding value. The analytical load-deflection behavior diverges at this point because yielding stress of reinforcement is considered to be 500 MPa in the analytical model, whereas the actual values of steel yielding stress are higher.

To analyze the coherence between the model and the experimental tests, we tried to relate the areas below the experimental load/deflection curve and the theoretical curve up to a deflection of 150 mm (L/100), so the effect of the reinforcement yielding is obviated. For this purpose, three values of 0,37 $f_{fct,eq}$ in SFRC shell specimens have been considered: 0 (no influence of steel fibers), 1 Mpa (manufacturer's value) and 2 MPa (experimental value).

RC specimens			SFRC specimens				
Specimen No.		**Area relation**	Specimen No.		**Area relation for different 0,37$f_{ct,eq}$**		
					0 MPa	*1 MPa*	*2 MPa*
1	Shaked	0,79	5	Shaked	0,99	0,89	0,85
2		0,81	7		1,04	0,96	0,86
3		0,76	8		1,20	1,15	1,10
4		1,02					
11	Shotcreted	1,27	9	Shotcreted	1,11	1,02	0,90
12		1,38	10		1,55	1,43	1,26
Mean value		**0,99**	*Mean value*		1,18	1,09	**0,99**
Dispersion		**27%**	*Dispersion*		23%	23%	**18%**

Table 5. Area relation below load-deflection curves

Table 5 shows these area relations. The obtained medium value of the area relation (experimental – analytical) is quite good (0,99) for the shell specimens without steel fibers, but values have a very high dispersion (27%). For SFRC shell specimens the best adjustment is provided for a value of 0,37 $f_{fct,eq}$, equal to 2 MPa (experimental value). Moreover, the use of fibers reduces the dispersion down to 18%. The effect of fibers on SFRC seems noticeable and the model sufficiently accurate.

7 Conclusions

1. The flexural behavior of thin reinforced concrete shells, after cracking, is very sensible to the depth of the reinforcement. It is difficult to assure the correct placement of reinforcement even in pre-cast conditions.
2. Steel fiber addition improves RC shells' flexural behavior. Bending tests on SFRC shell specimens show a good adjustment when using the flexural tensile strength (residual tensile strength) values obtained from standard tests. This values are higher than those provided by the manufacturer.
3. Fiber addition improves the results uniformity, because their influence does not depend on the placement.
4. The proposed analytical model adjusts to the experimental results. It includes the effect of fibers as a tensile stress block extended to the lower section edge. Fiber tensile contribution is, thus, considered below reinforcement depth (unlike the model proposed in ref. [3]).
5. Test should be carried on in order to verify the effects of dispersion of results in the necessary security factors. Future tests should consider new variables, as fiber contents, and should analyze the evolution of cracking.

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