INTERNATIONAL SCIENTIFIC CONFERENCE
CIBv 2010
12 – 13 November 2010, Braşov

BEHAVIOUR AND SHEAR CALCULATION OF LIGHT REINFORCED ELEMENTS ACCORDING TO SR EN 1992-1 STANDARD

Paraschiva MIZGAN[*], Traian ONEȚ[**]

[*] Transilvania University of Brasov, Faculty of Civil Engineering
[**] Technical University of Cluj-Napoca, Faculty of Engineering and Installation

Corresponding author: Paraschiva MIZGAN, E-mail: paraschiva.mizgan@unitbv.ro

Abstract: In this work is presented the method used for calculating lightweight reinforced concrete elements in oblique sections according to the SR EN 1992-1. There are presented principles and calculus relations for checking the structural resistance of elements that need reinforcement for shearing force, respective vertical reinforced elements. The results of the experimental testing conducted in the Reinforced and Prestressed Concrete Laboratory of The Constructions and Installations University of Cluj-Napoca for 16 beams of lightweight reinforced concrete have permitted the comparative study between the experimental values (Q^e) and the calculated one (Q^c_{cap}), of the shearing force. The idea behind this comparative study was the verification of the module in witch the actual designing norms according to SR EN 1992-1 satisfyingly reflects the observed behavior of the elements during the experimental tests.

Key words: reinforced concrete, experimental testing, shearing force.

1. INTRODUCTION

Choosing the materials for building a construction is an important factor for its quality and requires a technical and economic study involving criteria like strength, stability, function, durability, comfort, economy, etc. Due to its qualities, such as the possibility to fill any geometrical shape, good durability in normal operation, fire resistance, good behavior under external loads, concrete is the material with the widest spread in building construction. However, it can observe few major disadvantages, such as thermal conductivity, high noise and high own weight. These shortcomings can be overcome by using concrete with lightweight aggregates (light concrete) which have some advantages compare to the normal concrete: lightweight, better thermal insulation, improved comfort, better fire and seismic behavior, etc.

Continuous improvement of methods for calculating reinforced concrete elements requires a more thorough knowledge of their reaction to various actions and loads.

Special attention will be given to lightweight concrete reinforced elements behavior at strength limit state in inclined sections and particularly the shear behavior.

2. HYPOTHESIS, PRINCIPLES AND CALCULATION ACCORDING TO SR EN 1992-1

2.1 Strength characteristics used in calculating the elements

Compressive strength of concrete – is defined by its class resistance which means characteristic resistance (with 5% accepted risk) per cylinder (f_{ck}) or cubes ($f_{ck,\ cube}$), determined at 28 days. For concrete made with lightweight aggregate its strength classes are preceded by the symbol "LC" and strength characteristics of concrete are slightly further marked with the symbol "l". Some of them have distinct values and other are obtained by multiplying the normal concrete characteristics, with a normal density, by a coefficient "η_1" ($\eta_1 = 0{,}40 + 0{,}60 \cdot \rho/2200$), that depends on dry density "ρ" of lightweight concrete, corresponding the upper limit.

Resistance value to compression and tension are determined by relations:

$$f_{lcd} = \alpha_{lcc} \cdot f_{lck} / \gamma_C \tag{2.1}$$

$$f_{lctd} = \alpha_{lct} \cdot f_{lctk} / \gamma_C \tag{2.2}$$

where: - f_{lcd}, f_{lctd} – design compressive strength, design tensile strength;
- α_{lcc}, α_{lct} – coefficients with recommended value 0,85;
- f_{lck}, f_{lctk} – characteristic compressive strength, characteristic axial tensile strength;
- γ_C – partial safety factor for concrete, equal 1,5 for permanent and transitory design situations and 1,2 for accidental cases.

2.2 Principles and calculation expressions for inclined sections of light concrete reinforced elements under shear loads

To determine the internal state of loads under the effect of shear force, the static theorem of plasticity theory is used. Real structural element is replaced by a simplified fictive model which provides balance of external loads and internal efforts, to meet plasticizer conditions.

The model can be an isostatic truss made by compressed concrete and tensed still bars (Fig. 1).

Calculation of braced girder model assumes that rupture may occur either by failure of tensed transverse reinforcing bars, or by crushing the concrete from compressed diagonals.

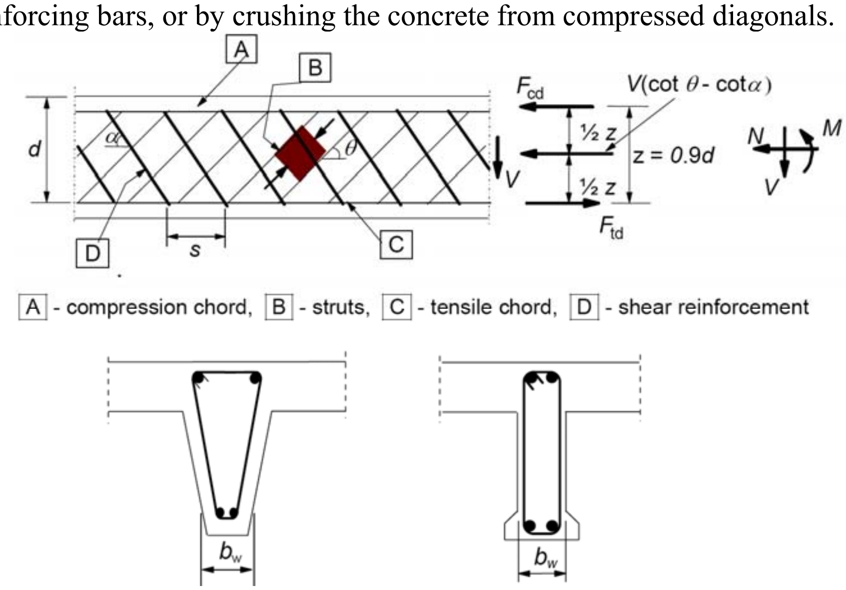

Fig. 1 Truss calculation model

Notations used in figure 1 means:
- α – the angle between shear reinforcement and the tensile chord;

- θ – the angle between the concrete compression strut and the tensile chord;
- F_{td} – the design value of the tensile force in the longitudinal reinforcement;
- F_{cd} – the design value of the concrete compression force in the direction of the longitudinal member axis;
- b_w – the minimum width between tension and compression chords;
- d – effective depth of a cross-section;
- z – lever arm of internal forces; its value can be approximated to $0{,}9 \cdot d$.

The value of "θ" angle is limited according to relation:

$$1 \leq \cot\theta \leq 2{,}5 \tag{2.3}$$

Method of calculating the shear action is based on three values of bearing capacity of the element:

- $V_{lRd,c}$ – the design value of the shear resistance of a lightweight concrete member without shear reinforcement (light concrete contribution to take up shear force;
- $V_{lRd,max}$ – the design value of the maximum shear force which can be sustained by the member, limited by crushing of the compression struts;
- $V_{lRd,s}$ – the design value of the shear force which can be sustained by the yielding shear reinforcement.

In regions of the member where the design value of the applied shear force "V_{Ed}" confirm 2.4 condition, no calculated shear reinforcement is necessary.

$$V_{Ed} \leq V_{lRd,c} \tag{2.4}$$

However, in those regions minimum shear reinforcement should be provided and must be according to standard recommendations.

In regions where 2.4 condition is not satisfied, sufficient shear reinforcement should be provided in order that:

$$V_{Ed} \leq V_{Rd} \tag{2.5}$$

Anywhere in the member, the design shear force should not exceed the permitted maximum value $V_{Rd,max}$, which means:

$$V_{Ed} \leq V_{lRd,max} \tag{2.6}$$

For members with vertical shear reinforcement, the shear resistance, V_{Rd} is the smaller value between those bellow:

$$V_{lRd,s} = \frac{A_{sw}}{s}\left(z \cdot f_{ywd} \cdot cot\,\theta\right), where 1 \leq cot\,\theta \leq 2{,}5, and \tag{2.7}$$

$$V_{lRd,max} = \alpha_{cw} \cdot b_w \cdot z \cdot v_1 \cdot f_{lcd} / (\cot\theta + tg\theta), \tag{2.8}$$

with ductility condition consideration:

$$(A_{sw,max} \cdot f_{ywd}) / b_w \cdot s \leq 0{,}5 \cdot \alpha_{cw} \cdot v_1 \cdot f_{lcd} \tag{2.9}$$

where:
- A_{sw} – the cross-sectional area of the shear reinforcement;
- s – the spacing of the stirrups;
- f_{ywd} – the design yield strength of the shear reinforcement;
- α_{cw} – a coefficient taking account of the state of the stress in the compression chord;
- v_1 – a strength reduction factor for concrete cracked in shear;
- f_{lcd} – design compressive strength of light concrete.

The recommended value for "α_{cw}" is 1, for structures without prestressed elements.

The recommended value for "v_1" is:

$$v_1 = 0{,}5 \cdot \eta_1 \cdot (1 - f_{lck} / 250) \tag{2.10}$$

$$\text{where } \eta_1 = 0{,}40 + 0{,}60 \cdot \rho / 2200 \tag{2.11}$$

and: - ρ – the oven-dry density of lightweight aggregate concrete;
- f_{lck} – light concrete characteristic compressive strength.

3. DESIGN METHOD VALIDATION BY TESTING

Experimental tests on the behavior of light concrete elements under shear action with particular reference to the bearing capacity in inclined sections were performed for a total of 16 beams of reinforced light concrete with 15 x 30 cm cross section and 3,00 m span. The total length of the beams was 3,40 meters, in order to ensure a sufficient extension of reinforcing bars over the beams bearings.

Longitudinal and transverse reinforcement of beams was made with PC 52 steel in the form of welded enclosures. They used two frames of the same type for each beam, with cross bars (reinforcing cross) of the same diameter (Ø 6 mm for all elements) and the same distance along its length.

At the ends of the beams have taken additional measures to ensure proper anchorage of the reinforcing bars in concrete (PC 52 steel coupons with Ø 12 mm diameter was welded between the frames). From place to place (at about 80 cm) carcasses was interlocked with reinforcement of cross bars Ø 4 ... 5 mm horizontally.

Experimental elements were performed in laboratory conditions, using metal formwork, and preparing and compacting concrete being done mechanically.

The static model was that for a pinned beam, loaded with two concentrated forces of equal size, symmetrically, in order to obtain shear beams openings (a_v / d) value 1.0, 1.5 and 2.5. This scheme assured shear testing of the beams in the areas between forces and supports. Test beams were made by applying loads with a pace of 1/10 from presumptive breaking load.

In making the elements concrete samples was collected to determine their physical and mechanical characteristics, namely: 3 cubes each side having 14.1 cm, 3 prisms with dimensions 10 x10 x 55 cm and 3 cylinders each having base area 200 cm^2 and a height of 32 cm.

The test results obtained from tested samples (at the same age when tested with the beam) represents physical and mechanical characteristics which are considered in calculations formulas for determining the bearing capacity in shear action (Q^c_{cap}).

Comparative analysis of the experimental values of shear force bearing capacity (Q^e) and values determined by calculation (Q^c_{cap}) highlighted the elements behavior at shear force, by considering all parameters (a different kind of reinforcing, different shear openings, etc.) as well as the way in which the design rules accurately reflect the actual behavior of elements in different states limit under shear action.

Comparative analysis of the shear bearing capacity determined experimentally (Q^e) and by calculation (Q^c_{cap}), based on reports Q^e / Q^c_{cap} from Table 1, the following conclusions:

- Bearing capacity set by breaking beams is higher than that calculated in ultimate state limit with design resistance of materials determined by tests on samples.

- Reports Q_e / Q^c_{cap} range 0.74 ... 2.04 (average 1.34) and is actually the partial safety factor related to materials properties.

Taking into account partial safety factor associated with loads, with an average value of 1.4, reaching a global safety of 1.8, which can be considered satisfactory, being generally used as a global safety factor in design.

Table 1 presents a comparative analysis between experimental and calculated values of the shear bearing capacity (Q^e / Q^c_{cap}) for the light concrete elements.

Table 1

No.	**Indicative**	**Concrete type**	**Q^e, [N]**	**Q^c_{cap} EC 2, [N]**	**Q^e / Q^c_{cap}**
0	1	2	3	4	5
1	G 1-1	light	150 000	71 612	2.04
2	G 1-2	light	120 000	79 963	1.50
3	G 1-3	light	150 000	78 451	1.91
4	G 1-4	light	165 000	88 260	1.86
5	G 1-5	light	195 000	132 297	1.47
6	G 2-1	light	135 000	82 012	1.64
7	G 2-2	light	150 000	98 687	1.52
8	G 2-3	light	150 000	178 638	0.84
9	G 2-4	light	150 000	86 872	1.72
10	G 2-5	light	150 000	99 528	1.50
11	G 3-1	light	90 000	98 009	0.92
12	G 3-2	light	90 000	121 361	0.74
13	G 3-3	light	100 000	99 743	1.00
14	G 3-4	light	100 000	123 413	0.81
15	G 3-5	light	120 000	99 474	1.20
Average					1.34

4. CONCLUSIONS

Outcome studies and research conducted indicates that the light concrete elements behaves and can be easily calculated in inclined sections at shear action in the same way as normal concrete elements, but pressures to take into account particularities of the material (tensile strength lower than that of normal concrete, x / d ratio less significantly for light concrete reinforced elements and therefore the maximum percentages slightly lower for longitudinal reinforcement, lower adhesion between concrete and reinforcing bars, as well and the following provisions:

- Relations of calculation presented in Chapter 2 apply to all enclosed concrete structure consists of lightweight mineral aggregates, natural or artificial. These not apply to aerated concrete or lightweight aggregate concrete with open structure.

- Coefficient of thermal expansion of concrete with lightweight aggregates depends mainly on the type of aggregates used and varies between $4\cdot10^{-6}$ and $14\cdot10^{-6}$ / K. For those relations in whom thermal expansion has a minor importance, thermal expansion coefficient value may be equal to $8\cdot10^{-6}$ / K.

- Secant modulus E_{lcm} average values for concrete with lightweight aggregates can be obtained by multiplying the corresponding values of normal concrete densities, with the following coefficient:, where ρ is the density after drying in the oven.

- Slow flow coefficient “φ” can be assessed by multiplying the amount corresponding to the normal density concrete with two factors:

$\eta_E = (\rho / 2200)^2$ and

$\eta_2 = 1.3$ for $f_{lck} \leq LC16/18$;

$= 1.0$ for $f_{lck} \geq LC20/22$.

- Final values of drying shrinkage can be obtained by multiplying the values for concrete with normal densities by factor:

$\eta_3 = 1.5$ for $f_{lck} \leq LC16/18$

$= 1.2$ for $f_{lck} \geq LC20/22$.

- Concrete cover must be 5 mm greater than required for normal volume mass concrete;

- Lower adhesion between concrete and reinforcing bars, requires that the anchorage length of round bars are 50 % higher than provided for normal density concrete elements;

- Diameter of bars embedded in concrete with lightweight aggregates is limited to 32 mm. In addition, the package is not used in more than two bars and is limited to 45 mm equivalent diameter.

Comparative analysis of the shear bearing capacity determined experimentally (Q^e) and by calculation (Q^c_{cap}) in the ratio Q^e / Q^c_{cap} of Table 1 emphasize the fidelity for which design rules according to SR EN 1992-1 reflects real behavior of reinforced light concrete on shear loads, respectively that by applying these rules of calculation a 1.8 overall level of safety is reached and can be considered as satisfactory, generally being used as a global safety factor in design.

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Received September 20, 2010