

THE TECHNICAL UNIVERSITY OF CLUJ-NAPOCA
Faculty of Civil Engineering and Building Services

Eng.Mizgan Paraschiva

**BEHAVIOR AND DESIGN OF LIGHTWEIGHT
REINFORCED CONCRETE MEMBERS SUBJECTED TO
SHEAR**

Ph.D. Thesis Summary

Supervisor
Prof.dr.ing.Traian Onet
M.C.Acad.STR
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CHAPTER 1 . INTRODUCTION

The use of lightweight concrete for building high strength members and structures requires an in-depth knowledge of its behavior to various actions and stresses and improved design standards related to the knowledge mentioned.

The main objective of the Ph.D. thesis consists in pointing out the behavior of the lightweight reinforced concrete mainly subjected to shear, at increasing loads up to failure as well as in the conception of a design methodology related to the ultimate limit strength of inclined sections.

The lightweight concrete has become a valuable building material due to its many-sided uses and fields of application everywhere in the world.

One of the earliest uses of the lightweight concrete is found in the building of the ships and barges in the year 1918.

Many multistory structures have been designed then, since 1950, starting with the foundations made of lightweight concrete, as this material does not exhibit a normal weight.

In Romania, the first preoccupations to use lightweight concrete are met in the years 1966-1967, when research on the main properties of the lightweight concrete and their variations in time were carried out, together with experiments in view of establishing the needed technologies to develop types of prefabricated members and elements and to make experimental studies.

The chapter also includes:

- the principles on which lightweight concrete is made, i.e. aggregates, cement and additives used in its composition;

- the advantages of the lightweight concrete: apparent density smaller by 20 ...30 % (an average of 25 %), improved behavior to seismic actions, improved thermal insulation, better resistance to fire etc

- the presentation of the main fields of application: reinforced and prestressed concrete flat roof members, reinforced and prestressed concrete beams, wall panels, buildings sited in seismic areas etc [9].

CHAPTER 2. PARTICULAR BEHAVIORAL ASPECTS OF THE LIGHTWEIGHT CONCRETE TO ENVIRONMENTAL ACTIONS AND CONDITIONS

The main aspects presented in this chapter are:

a. the physical and mechanical properties of the lightweight concrete

- apparent density: it can be a quarter smaller than that of the normal weight concrete made from sand, gravel or crushed stone aggregates;
- thermal and physical properties; conductivity and water absorption;
- resistance to compression: The experimental research have shown that, in general, the behavior to compression of the lightweight concrete is similar to that of the normal weight concrete in identical service conditions. Consequently, STAS 10107/0-90, prescribes the same resistance to compression for the lightweight concrete as for the normal weight concrete;
- tensile strength: The experimental research have highlighted the fact that the tensile strength of the lightweight concrete exhibits a larger variation than that of the normal weight concrete, with similar resistance to compression. It is for this reason that, together with its higher brittleness features, the detailings in STAS 10107/0-90 for a smaller tensile strength are valid in the case of the lightweight concrete than normal weight one, having the same resistance grade [2].

b.strains under loads

- the characteristic curve: the stress-strain ratio, according to STAS 10107/0-90 and the stress-strain ratios according to EUROCODE 2;
- the deformation modulus: the longitudinal modulus of elasticity E_b , usually half of the modulus in the normal weight concrete; modulus of elasticity-plasticity and the plasticity coefficient 40% smaller than the one of the normal weight concrete; modulus of elasticity in shear;
- slow flow strain: usually higher than for normal weight concrete in equal circumstances, though the slow flow characteristic is smaller than for the normal weight concrete.

c. spontaneous strains (independent of loading)

- contraction: contraction is larger for the lightweight concrete than for the normal weight concrete;
- thermal dilation: approximately 20% lower than of the normal weight concrete;

The thesis presents then a detailed analysis of the behavior of the lightweight reinforced concrete elements to cracking (the cracking bending moment, the average crack opening), to deformations and to failure in normal sections (the deformations of the bent structures and members, their behavior to failure under the bending moment action with or without an axial force included and under a shear force) as the witness member for the comparison with the inclined section case.

CHAPTER 3. SYNTHESIS OF EXPERIMENTAL STUDIES AND RESEARCH CARRIED OUT UPON LIGHTWEIGHT CONCRETE MEMBERS

The chapter describes the influence of the various parameters upon beam cracking and breaking under the action of the shear force.

a. concrete nature (lightweight and normal weight concrete): the lightweight concrete beams crack much easier at smaller loading amounts as compared with the normal weight concrete, the cracks openings are usually larger and the bearing capacity to shear is also smaller, the difference being even more emphasized in the case of beams with small shear span effects and less evident in the case of beams with large shear span effects.

b. longitudinal reinforcement ratio: the larger the beam longitudinal reinforcement ratio, the larger the beam breaking strain and the later the beam inclined cracks appear, with a smaller opening too.

c. transversal reinforcement ratio: the transversal reinforcement ratio affects the beam breaking strain to shear and the occurrence and opening of the inclined cracks in a similar manner to the one of the longitudinal reinforcement ratio.

d. beam shear span effect (a/h_0): with respect to the experiments made with the experimental members, the author has noticed that in the case of beams with a smaller shear span effect the failure occurred by opening the inclined crack (which joins the bearing with the force application point) after the reinforcement flow, while in the case of beams with a larger shear span effect, the failure occurred to shear force, sometimes to the bending moment by crushing the concrete compressed area and the inclined cracks did not go on opening more.

The value of the shear force for the failure of the beams has decreased with the increase of the shear span effect.

This chapter ends with some remarks concerning the degree of applicability of the Romanian (STAS 10107/0-90) and European (EUROCODE 2) standards in the field.

CHAPTER 4. CONSIDERATIONS UPON THE BEHAVIOUR AND DESIGN OF THE LIGHTWEIGHT CONCRETE MEMBERS TO SHEAR

In this chapter, the author presents some general outline concerning the behavior and design in the case of the incline sections of the limit strength state and then describes the design pattern adopted by the Romanian (STAS 10107/0-90) and European (EUROCODE 2) standards and norms.

The chapter continues with the working hypotheses, the design pattern, the characteristics and design algorithm, following the two design norms for the members having or no a transversal, vertical or inclined reinforcements.

The results of the experiments effected in the framework of the research show that lightweight concrete members in inclined sections subjected to shear force behave and can be designed in a similar manner to the normal weight concrete; however, taking into account the special features of this material: a smaller tensile strength, evidently smaller ratios x / d (x / h_0), for the reinforced lightweight concrete members.

CHAPTER 5. EXPERIMENTAL RESEARCH CARRIED OUT

The experimental tests made in the Laboratory of Reinforced and Prestressed Concrete of the Faculty of Civil Engineering and Building Services of Cluj-Napoca have proved the main behavioral patterns of the lightweight reinforced concrete members subjected to bending by shear, mainly with respect to the bearing capacity of the material in inclined sections.

32 members in the form of 15 x 30 cm cross section and 3,00 m span reinforced concrete beams have been tested; out of the 32 beams, 16 were made of (lightweight) expanded clay-based concrete and 16 were made of common aggregates (sand, gravel).

The parameters taken into consideration were the following:

- concrete nature: lightweight or normal;
- longitudinal reinforcement ratio: $p = 1,62\%$; $2,13\%$; $2,43\%$;
- transversal reinforcement ratio: $p_t = 0,19\%$; $0,25\%$; $0,38\%$;
- beam shear span: $a/h_0 = 1,0$; $1,5$; $2,5$;

The beam overall length was 3,40 m, in order to provide enough extension of the reinforcements beyond the beam supports.

Only one member was made from each type.

Table 5.1 presents the main properties and characteristics of the members.

The member building and loading technology is described in detail.

The experimental values of the bearing capacity to the shear force (Q^e) determined for all the members, at each loading level, and the comparison of the experimentally found and the designed values have pointed out the behavior of the members to the action of the shear with respect to all the parameters in question (members made of various materials, different reinforcement manner, various shear spans etc); another aspect highlighted was the way in which the design norms in force reflect the actual behavior of the various members in different limit states under the action of the shear force.

Tables 5.2 and 5.3. present a comparison between the experimental and design values of the bearing capacity to shear (Q^e/Q^c_{cap}) for the lightweight, respectively normal weight concrete.

CHAPTER 6. RELATIONSHIP BETWEEN THE BEHAVIOUR PRESENTED IN THE DESIGN NORMS AND THE ACTUAL BEHAVIOUR OF THE LIGHTWEIGHT REINFORCED CONCRETE SUBJECTED TO SHEAR

The comparative analysis of the bearing capacity to shear established experimentally (Q^e) and calculated (Q^c_{cap}), based on the ratios Q^e/Q^c_{cap} in tables 5.2 and 5.3 leads to the following conclusions:

1. The bearing capacity established for the beam failure is larger than the design one, in limit state, with designed resistance values for the materials, tested on samples, both for the lightweight and normal weight concrete.

2. The European norms show nearer values than the Romanian ones ($Q^e/Q^c_{cap} = 1,34$, respectively $1,24$ compared to $1,14$ respectively $1,09$).

3. Both design norms show nearer values for the lightweight concrete than for the normal weight concrete ($1,14$ vs. $1,09$ respectively $1,34$ vs. $1,24$).

4. The Q^e/Q^c_{cap} ratios represent, in fact, the partial safety coefficient related to the materials properties. If the partial safety coefficient related to the loading is also taken into account, with an average value of $1,4$, the overall safety coefficient according to STAS 10107/0-90 will be $1,14 \times 1,4 = 1,59$ for the lightweight concrete and $1,09 \times 1,4 = 1,52$ for the normal weight concrete. This safety level is under the level of the requirements generally imposed by the design standards. On the other hand, the

European norms lead to an overall safety level of 1,8, that can be appreciated as satisfactory and that is in general used as an overall safety factor for design purposes.

Hence, the Romanian norms should be amended in so far the design for the inclined sections and should be harmonized with the European standards in this domain.

CHAPTER 7. CONCLUSIONS

The results of the studies and research carried out with respect to the personal contributions of the author are the following:

1. A synthesis of documentary evidence concerning the particular behavior of the lightweight concrete with respect to environmental actions and conditions;
2. Conclusions of studies and research carried out on lightweight reinforced concrete members; The presentation of the influence of various parameters upon the beam crack and failure to the shear force enabled the expression of some considerations concerning the design in the limit state of resistance in inclined sections.
3. The processing and valorization of a research program on 32 beams, with a span of 3.0 m and a cross section of 15 x 30 cm. Half of the beams were made of concrete with expanded clay, while the other half of the beams was made from concrete with normal aggregates.
4. Observations and remarks concerning the applicability of the Romanian (STAS 10107/0-90) and European (EC2) norms in the design of the beams in the limit state of resistance in inclined sections

The results of the studies and research carried out during the Ph. D. Work have been published in a book [35] and six scientific articles, written as main author or co-author [41,42,43,44,48,49]. They bring in valuable data for the harmonization of the Romanian standards with the European ones, by writing the National Annex to EUROCODE 2 that pleads in favor of the reuse of the lightweight concrete in the structural members of the buildings erected in Romania.

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Notes: Notations in figures, tables and references belong to the full length paper.