COORDINATION AND TRANSFER INTO PRACTICE OF RESEARCH ON MASONRY: THE ROLE OF CIB COMMITTEE W23 WALL STRUCTURES

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1. ABSTRACT

The role and activity of the Working Commission W23 Wall Structures of the International Council For Building Research Studies And Documentation (CIB) in promoting international coordination and transfer into practice of research on masonry wall structures is briefly presented. The main contributions of CIB W23 in this field consists in preparing and issuing prenormative documents, which are used by international standard bodies for both drafting new and maintaining existing codes.

2. INTRODUCTORY REMARKS

Internationally agreed normative documents based on the expertise and research originating in different countries constitute powerful practical tools for promoting progress in industry and commerce at a global level. The achievement of international consensus on such documents and on their multi-aspect (scientific, technical, economical, commercial) implications is however a very long, complex and difficult process.

One unavoidable step of the process is in any case the establishment of the best updated scientific knowledge on any specific topic to be dealt with in a code. In this respect an essential role is played by international scientific bodies, and specifically by CIB Working Commission W23 in the case of masonry structures.

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The Commission has in fact since its inception in 1964 been the very international scientific forum which ensured continuous and direct contacts and discussions, some time the confrontation, between worldwide experts and researchers on structural and other aspects of masonry.

As a result of that activity, CIB W 23 Recommendations on masonry structures were available at the end of the seventies and finally published in 1980 [1]. The revised and final version of the Recommendations, including all types of masonry (unreinforced, confined and reinforced) and the design specifications for seismic zones was published in 1987 [2].

That documents gave a strong impulse to the code making process at the international level in the field of masonry. First of all, they constituted the real basis on which special drafting panels established by the Commission of the European Communities (CEC), and since few years special committees (sub-committees of the Technical Committee TC 250) of the European standardisation body (CEN), have been developing in the recent years the relevant so called EUROCODES. As it is stated in their preface, "These codes are intended to establish a set of common rules as an alternative to the differing rules in force in the various Member States and also to serve as a guide for the development of national rules".

In this context, the EUROCODE 6 - Common Unified Rules for masonry Structures [3] and the chapter of EUROCODE 8 - Earthquake Resistant Design of Structures [4] - dedicated to specific rules for masonry buildings have been in that period developed and issued and subsequently up-dated until the final version has been recently agreed to be prepared for the formal adoption according to the CEN rules.

At a more wide international level, it is enough to remember the very strong cultural impact which the CEN activity in the field of the Structural Eurocodes is exerting outside the European Community (EC). This happens both un-formally, through the traditional technical and scientific information channels, and formally, through the participation of the EFTA countries and of observers representing some eastem Europe countries in the CEN committees, and through the coordination of CEN (TC 250) and ISO (TC 179) activities in the field of masonry.

This is mainly for newly constructed buildings, for which only few themes are not yet covered both in CIB Recommendations and in EC6 and EC8. Among them, the most important are related to such problems as the design rules for simple buildings, simplified calculation methods, robustness, serviceability and durability of wall structures. On such themes, besides the maintenance of the already issued codes, working groups of CIB W23 are preparing proposals, also in order to identify specific research needs and then to promote coordinated pre-normative research projects.

More recent, but in tune with the increasing demand coming from many countries, is the interest of the commission for the very complex problems regarding assessment and redesign for maintenance, repair and strengthening of existing masonry structures. CIB W23 promoted the publication of a prenormative document on this subject [5], but is convinced that most of its efforts in the near future for promoting and coordinating research activities and drafting pre-normative documentation on masonry structures should be concentrated on this field.
3. GENERAL PROFILE OF THE COMMISSION

The Working Commission W23 "Wall Structures" is part of CIB - International Council For Building Research Studies and Documentation - a network of hundreds of organisations and individuals who are interested in every aspect (technical, economic and social) of buildings and constructions. The CIB Full Members include nearly all the National Building Research Institutes of the world and among the Associates Members are many specialised research institutes, standard organisations, and large construction organisations, particularly those who both design and build.

Through its many Working Commissions and task Groups, some fifty in total, CIB, offer the best network for exchanging research findings and interdisciplinary links, and is then in a strong position to spread the results of research around the world and thus to serve all countries and all sectors of the building community worldwide in providing better housing and buildings for all the people. In recognition of that, CIB has had a cooperation agreement with ISO, the International Standard Organisation, and has been accorded an official liaison status by CEN, the European Committee for Standardisation. CIB has in fact a permanent seat on the ISO Coordination Committee for standards in building and construction and is invited to the meetings of BTS1 of CEN, supervising building standardisation.

Important rights and obligations derive from these agreements. CIB Commissions may request participation on those ISO and CEN Technical Committees that are active in their respective fields. CIB Commissions may inform ISO and CEN of their Meetings at which matters relevant to international standardisation are being discussed. CIB papers and reports which may be of potential interest for ISO and CEN should be brought to the attention of these organisation [6].

As far as the safety aspects of building structures are concerned, CIB acts in cooperation with CEB (Comite Europeen du Beton), CECM (Convention Europeene de la Construction Metallique), FIP (Federation International de la Precontreinte), IABSE (International Association for Bridges and Structural Engineering) and RILEM (Reunion Internationale des Laboratoires d'Essais des Materiaux). All such organisations established in fact the Joint Committee for Structural Safety (JCSS), whose plenum is formed by representatives of each member body, which serves as their general coordination group in this field of activity.

In this context, the Working Commission W 23 "Wall Structures" has been established in 1964 in the specific areas of interest of the structures of load bearing walls, prefabricated panels, in-situ cast concrete and masonry of both new and existing buildings. The main objectives of the commission are:

• provide scientific basis and international consensus for the preparation and maintenance of building codes and recommendations;
• exchange research experiences and ideas in order to coordinate the research efforts in the field of interest throughout the world;
• single out pre-normative research needs and possibly promote internationally coordinated new researches and give guidance for application for funding to international agencies.
A general and synthetic overview of the activity of the commission during its first twenty years of existence in the above cited broad field of wall structures is given by the proceedings of the international symposium on wall structures organised by the commission in 1984 [7]. CIB W23 has been however principally concerned with masonry structures after the project was undertaken under the general coordination of the Joint Committee on Structural Safety to produce International Recommendations:

- based on general principle for the Safety and the control of structures, independent of the basic materials (concrete, steel, masonry or timber), that means harmonisation across materials;
- capable of furnishing "a common basis for the designer and builders of structure and to allow different countries to draw them in drafting national standards", that means harmonisation across the countries.

Such an ambitious program required of course that the work should be shared among the organisations according to their prevailing specific field of interest and specialisation, and CIB W23 appeared to be the most suitable one to deal with masonry.

The Commission holds a general meeting once in a year, but ad-hoc groups prepare state of the art reports and pre-normative documents on the above topics, which are discussed and finalised during the meetings. The final documents contribute to the activity of ISO and CEN. The effectiveness of the links with these organisations is ensured by the fact that many of the W23 active members are also official members of the relevant ISO (TC 179) and CEN (particularly CEN TC 125, CEN TC 250/SC6 and /SC8) committees.

4. MAIN ASPECTS OF CIB W23 CONTRIBUTION TO THE STANDARDISATION OF STRUCTURAL DESIGN OF MASONRY

What makes particularly appreciable the work done within CIB W23 for standardising the design procedures of masonry structures are the uncommon, and for many aspects surprisingly successful efforts made to overcome what could be called the "schizophrenia" which marks the entire matter.

One the one hand, masonry is in fact traditionally intended to be the typical material for not engineered structures. Most of the existing inventory of structures all over the world are in fact masonry, and still at the time when CIW W23 started is work in this field, most of them were built by small contractors, if not directly by the owners, on the basis of their own expertise and of traditional construction rules. This situation is responsible for having frequently poor quality constructions, as demonstrated by the dramatic consequences of earthquakes on this type of structures, both in developing and in highly industrialised countries.

On the other hand, masonry presents tremendous difficulties in dealing with it in an appropriate scientific way. First, the material offers in any case inhomogeneous, anisotropic and highly non linear behaviours. Second, an enormous variety of types of units, of bonding and of materials (normalweight and lightweight clay and concrete, aerated concrete, calcium silicate, different types of natural stones) exists to which different mechanical (deformability, strength, ductility) and physical (e.g. thermal conductivity) properties correspond.
When appropriately treated with engineered approaches, however, masonry structures can furnish excellent performances, certainly the best in terms of comfortability of houses, and, within the limits of the material properties, among the best in terms of structural behaviour. In this respect, it is enough to note that their stiffness provides very good conditions as far as the serviceability aspects are concerned, while their natural redundancy and robustness, and the box type behaviour create very fair condition as far as the load bearing capacity and the seismic response are concerned.

CIB W23 accomplished the above mentioned task undertaken under the general coordination of the Joint Committee on Structural Safety to produce harmonised and engineered Recommendations through the documents [1, 2]. Further contributions, more informal but not less effective, came from the commission's meetings, where the discussions on the most relevant topics of the standardisation process continued even after the publication of the above documents. From this work, new proposal derived for upgrading and improving that documents, based on the updated results of ongoing or new studies and investigations, as it can be seen for example in [8].

The first step of the harmonisation was of course the adoption of the same safety verification method which was being adopted internationally in producing Recommendations for steel, concrete and timber structures, i.e. the so called Level 1 - Semi-probabilistic method. To make it appropriately work however, a huge work was necessary mainly in dealing with the following problems:

- classification and determination of the relevant mechanical parameters of the materials;
- definition of the essential design rules, in both seismic and not seismic situation, trying to meet the requirements of simplicity which are appropriate for the design methods of the smaller constructions.

On these aspects some details are furnished in the following. It is worth mentioning the efforts were made to keep the best inputs from the traditional expertise in preparing the documents. They are evident in the parts dedicated to the structural detailing and to construction, which are not dealt with here. They were however essential also in the adoption of the concept of simple building, and in the definition of its characteristics, for which a minimum design effort is required.

4.1 Evaluation of the relevant mechanical properties of the materials

One particularly important contribution of CIB W23 consists in the proposal of a unique way to evaluate the relevant mechanical parameters of masonry through appropriate correlations with the compressive strength of the component materials, units and mortars, as an alternative to expensive standard tests on wallets. This was done in particular for the characteristic value ( the value having a 95% probability of being attained) of the compressive ($f_{mk}$) and of the shear ($f_{yk}$) strength of masonry.

In the first case, a table was proposed giving the values of $f_{mk}$ in function of the class of mortar and of the characteristic compressive strength of units. More refined proposal followed in preparing the EC6, which led to the introduction of: the shape factor correcting the apparent strength of the units obtained experimentally; analytical correlations taking into account the influence of the geometrical characteristics of the
units, particularly the type and percentage of perforation. CIB contributed on this subject mainly by calibrating the proposed formulas (e.g. in [8]) on the basis of data available in different nations.

In the second case, the task was even more difficult as to shear actions a number of different possible failure mechanisms of the masonry correspond, depending on the characteristics of the component materials and on their possible combinations. For the sake of simplicity, the following unique formula was proposed, $f_{vk} = f_{vko} + 0.4 \sigma_n$ (where $f_{vko}$ is the masonry shear strength under zero compressive stresses, and $\sigma_n$ is the mean compressive stress acting on the compressed zone of the wall section), which evidently represent the mode of failure due to the sliding of units along the mortar joints. This is however the typical failure of masonry made with units relatively strong in comparison with the mortar. In the case of highly perforated units, for example, which are very popular in many countries, tensile and lateral compression failure of the units are more frequent. In this respect, the basic assumption was made that the verification against such modes of failures can be covered by introducing limitations to the maximum value of $f_{vk}$.

For the materials properties defined in this way, the complete set of partial safety coefficients, taking into account different levels of control of the production of units and of the construction, was also provided.

4.2 Design of masonry

The basic issue is in this case the evaluation of the ultimate load of walls bent out of plane. The design procedure proposed for masonry, which is used for concrete as well, consists in several independent steps. First, the eccentricity of forces is estimated: if statical indeterminate schemes are used, it is reduced for the joint flexibility. The design eccentricity is increased for accidental eccentricity and lateral loads. The following steps are the reduction of mean stress for eccentricity, the adjustment of the effective height for end restraints, and the reduction of mean stress for slenderness.

The capability of the entire procedure to check the true failure mode and the way each steps should be carried out in order to meet such scope avoiding too complex calculations but also excessive conservatism, have been the centre of long discussions and specific studies of the commission's members. A summary of this activity can be found for example in some of the papers presented in [8].

In particular, it has been pointed out (S. Sahlin, [8]) that:

- "since the steps are inherently coupled there is a risk that the true failure mode will be missed";
- "the possible failure of a joint is often neglected. Most joints do have an upper limit for the moment it can carry as well for its rotation capacity. This failure mode may warrant more attention so that it can be included in the future revision of the code (EUROCODE 6) in a rational way".

As far as the evaluation of the eccentricity of forces is concerned, the three-dimensional box behaviour of masonry structures offers the possibility to use very simple theoretical. The simplest, and very popular one, based on the assumption that the wall
to floor joints behave as hinges, which allows any single wall to be calculated independently from the remaining structure, was included. In this case, simple but conservative rules are given to evaluate the eccentricity of the normal action at each section. For example, in [2] the eccentricity of the resultant normal action is assumed to simply derive from the separately evaluated eccentricities of loading from wall above the joint and of reaction from left and right slabs. Several methods have been also discussed and proposed in order to take into account indeterminacy in a simplified way [2, 8].

Very debated is also the point regarding the values of the factors (\( \phi \)) taking into account eccentricity and slenderness. Substantial discrepancies are found in different national codes, according to its evaluation is based on theoretical analyses or on experimental results. Second order effects are very sensitive to the hypotheses assumed for the material properties (tensile strength and deformability) and end restraints. In spite of the huge work done worldwide both theoretically and experimentally, a real general agreement has not yet been found.

4.3 Seismic design

CIB W23 Recommendations for the seismic design of masonry structures [2] incorporated very interesting and innovative approaches, particularly as regards the following two major issues:
- reinforced masonry made with highly perforated units;
- simplified verifications of "simple buildings".

Highly perforated units (mostly units having vertical holes, whose total section can represent up to 55% of the gross units' section) are very popular in many countries for the construction of low rise buildings. The perforation, and now the use of lightweight clay too, allows in fact for an appropriate selection of the apparent density of the units in order to optimise their physical characteristics (in particular thermal insulation capacity) for given minimum strength requirements. One very important consequence of the reduction of the apparent density of the units is the possibility of increasing their dimensions, which reduces the construction costs and improves both the mechanical and the physical characteristics of walls.

As far as the use in seismic zones of such type of units is concerned, the most crucial aspect is the low compressive strength in the direction perpendicular to the direction of the holes. This practically makes not usable the so called "capacity design" approach adopted for masonry structures in seismic zones in such countries as the United States and New Zealand. According to such codes the masonry wall should be provided with enough shear reinforcement to avoid the shear failure, so that the very ductile flexural failure is induced by seismic actions.

This criterion can be evidently applied only when the shear reinforcement is capable to prevent every possible shear failure mode. In the case of the units under consideration, shear reinforcement could not inhibit the very brittle shear failure mode due to the crushing of units under the horizontal compressive stresses induced by the shear actions. For this reason, while the "capacity design" approach is of course applicable according to the CIB W23 Recommendations [2], a warning exists regarding the
minimum amount of steel reinforcement, which should be limited in order to avoid the above mentioned brittle mode of failure. Consequently, a very low minimum percentage of reinforcement is prescribed (0.05 %) which is intended not to serve for increasing the shear strength but for ensuring enough ductility when the shear mode of failure occurs. The actual energy dissipation capacity of walls which fail under shear must be however experimentally demonstrated. The behaviour factor, which synthetically represents the capacity of the structure to reduce dynamic response due to its ductility, is in fact given in function of the results of cyclic shear tests specifically conducted on masonry wallets.

Finally, the concept of simple building is adopted and kept for any type of masonry, for which the safety verification consists in comparing the design shear strength to the mean shear stress calculated dividing the total horizontal seismic action by the total gross area of the cross sections of the resisting walls. Besides prescribing minimum construction detailing and some geometrical limitations to the plan configuration, the definition of "simple building" requires that the number of storeys must not be greater than two. In spite of such severe limitation, the initiative has a very significant economical and social impact, as it allows for the adoption of engineered solutions for a very wide class of buildings whose construction still now is very frequently competence of a not engineered environment.

5. REFERENCES


6. CIB Information, NR 4/92, July-August 1992
