ARCHITECTURAL CONCEPTION AND DESIGN IN STRUCTURAL MASONRY: SOME PRACTICES TO IMPROVE CONSTRUCTABILITY

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ABSTRACT

This work attempts to consider some basic principles of structural design and material properties of bricks and brickwork to carry out the architectural design of a complete building in structural masonry. The paper deals with the architectural conception itself, including design requirements, walls layout, and the simplification of the design. Design and detailing including modular planning, door and window openings, service design, facade and aesthetics are also discussed. It is shown that a clear understanding of the construction process together with the flexibility offered by the material can contribute to a better use of structural masonry.

Key words: Constructability, Structural masonry, Architectural design, Structural design, Building constructions process, Construction techniques.
Introduction

During the last fifty years, due to the change in design concept, development of codes of practice, extensive research and testing, and adoption of adequate theoretical methods, the use of masonry as a structural material has intensified with clear improvements of construction techniques, especially in developing countries (1). Besides scientific developments, environmental concerns and social considerations created an opportunity for the resurgence of the masonry industry (2).

Structural masonry has several advantages widely discussed in the literature (2, 3, 4, 5, 6, 7, 8, 9). One of the advantages is the possibility of using the same element to perform a variety of functions providing simultaneously structure, subdivision of space, thermal and acoustic insulation as well as fire and weather protection (1). Another advantage is the simple method of construction, laying brick over brick on mortar joints, a technique used since ancient times. Brickwork can further be exploited in heavy civil engineering constructions provided its low tensile strength is overcame by reinforcing or pre-stressing.

However, to use brickwork effectively, the architectural conception and design must contribute to achieve a better constructability and a more rational construction process, reducing costs of buildings and leading to better technical solutions. It is necessary to have a closer understanding of essential properties of the materials used, and structural characteristics of masonry, expressing the construction process throughout planning, detailing and specifications. The architectural design process must recognize the application of technical codes and recommendations to ensure the adequacy of structural masonry in terms of design modulation, rationalization, simplicity of construction, reduction of construction costs avoiding potential failures. It is important to note that architectural concept has to be considered in terms of the construction system. This means that for a multi-storey building the layout of walls cannot be thought as a substitute for an equivalent planar frame. In this sense, load bearing walls may require a different plan compared to those most suitable for concrete and steel framed structures (10).

The first part of this paper reviews some research studies into structural basic design forms and conceptions, analyzing the evolution of brickwork construction. The second part looks into some architectural design requirements that increase the efficiency of structural masonry focusing on simplicity, creativity, rationality, and constructability coming out with situations where masonry has constructional advantages over other materials, even the concrete.
Advantages and Prospects of Structural Masonry

The growing number of research programs carried out together with the improvement of both material and construction process considerably contributed to the development of the structural masonry technology in developing countries such as Brazil. This is reflected by the large-scale production of required materials. As a result, structural masonry became a more efficient process with lower time consumption, lower final cost and better final quality compared to the traditional ones.

The increasing amount of structural masonry constructions particularly in Brazil, at the beginning of the 90’s, is also due to the adoption and the improvement of the system by a well known private company and, mainly by the development of the so-called Poli-Encol system. Since then, several of technological innovations are in use by various companies of the civil construction sector (2, 7, 11). The cost reduction in masonry construction is, however, not only due to the development of structural design but also due to the use of multiple possibilities that walls can offer like partition and insulation. Material used has a low cost, and a high initial investment is not required. Other important characteristics are solidity, durability, low maintenance requirement, good acoustic and thermal insulation, and fire protection. Several programs have been developed by associations and local authorities for unfamiliar and multifamily residences adopting the structural masonry process in Brazil. The advantages offered by this system lead to the effectiveness, the quickness and the economy desired. These constructions also explore the different texture, shape, and colors of the units.

Architectural Aspects of Structural Masonry Design

Architectural options adopted during the design process are decisive to exploit the maximum potential of structural masonry constructions. There are several variables to be considered during the design process, to develop and to reach a higher competitiveness level and technological efficiency by a construction system. A good understanding of the design process, the aspects related to the features and behavior of the material, the solution of technical and construction methods, should be well known and analyzed in details as well as the specific characteristics of masonry. Usual procedures of traditional construction in Brazil, mainly the disconnection of the various designs such as architectural, structural and facility ones should be avoided. The design process may be considered as a key factor in the adoption of a construction system with satisfactory technical and architectural results.

The innovations on the structural masonry construction brought by the Poli-Encol system were based on the development of residential building design. Initially four-storey buildings were built over a ground floor on reinforced concrete with standardized architectural typography, generally of I or H shape for lower income population.
As the system was developed, taller buildings were built, including buildings those of up to 23 storey in some Brazilian States such as São Paulo, Minas Gerais, Mato Grosso do Sul and Santa Catarina (2).

Architectural flexibility is provided by the construction system due to the physical features of the blocks. Small size of units (bricks and blocks) also offers attractive finished surfaces under aesthetically and plastic points of view. Ecological advantages provided by materials, design and construction should be considered as well (12). Figure 1 shows some concrete units available in the Brazilian’s ordinary market. Similar ceramic ones are also used, mainly in the south area of the country.

![Concrete samples used in structural masonry](image)

**Figure 1.** Concrete samples used in structural masonry

To profit from structural masonry advantages, adequate structural arrangements are necessary, preferably avoiding large spans, especially for non-reinforced or pre-stressed masonry. A repetitive layout of walls from the foundation to the top floor of the building is also recommended for multi-stories buildings. For situations in which large spans are necessary in the ground and/or first floor, a rigid concrete or steel structure may be required. Concentrated loads should also be avoided. Although buildings of different shapes and heights have been constructed, structural masonry continues to be used mainly for standard typology in residential buildings, which do not show any kind of innovation regarding the architectural shape. The potential of the block as a construction element is still under exploitation, regarding plastic and aesthetic aspects, strength and structural efficiency. In spite of that, most of the structural masonry constructions have a planar geometry and a lack of architectural expressiveness that can be described as repetitive in a formal point of view (7).
Management Aspects of Masonry Construction

Test methods have evolved in various countries and have been standardized. It would be desirable however if they were standardized on an international basis so that information on material properties, design data and research results could be understood irrespective of their country of origin or use. In a general way, masonry tests are developed for different functions such as development of products and production control, derivation of physical and mechanical properties for design purposes, site quality control and manufacturing and for structural research in engineering.

New concepts looking for rationalization and compatibility of design were developed by the Poli-Encol system, including layers modular planning, vertical modulation of walls as well as the rationalization and improvement of productivity. Among them, is included a better control of verticality allowing the use of thinner layer of plaster, prefabricated elements in addition to the use of suitable equipments and tools.

The overall considerations about the construction system include procedures modifications such as planning, control and productiveness. The management process should ensure the adequacy of the building site organization and workmanship training programs as well as the use of adequate equipments and tools in order to provide the economy desired. The architectural design of masonry depends on the analysis and evaluation of the requirements that should be considered and organized in the design production process, including conception, design and detailing phases, so as to guarantee the desired quality. Some of these recommendations can be summarized as follow (13).

Definition of the design requirements

For structural masonry, some restrictions are imposed to the architectural and structural designs, and they should be taken into account. It can be pointed out:

i. the number of possible storeys to be designed with materials available in the local market;

ii. the arrangement and distribution of walls;

iii. the limitations and the relationship to the transition of structures existing in the ground floor and basement;

iv. the possibility of removal of walls.

The restriction of removing walls limits the functional flexibility; however this matter can be solved satisfactorily, if the structural design is conducted in such a way that some walls are previously designed as non-structural. Other requirements such as architectural arrangement, dimensional and modular co-ordination, rationalization of the project and production, costs (including use and maintenance), safety aspects and reliability are also important.
Layout of walls

The designer should find a balance to avoid the stress concentration in specific areas of the building taking into account the distribution of the load bearing walls in the whole area of the plan. If this balance is found, it is possible to use materials with the same strength for the walls of the pavement. If not, grouting or reinforcement of certain walls may be required, which is not recommended under cost and constructability aspects.

The designer should also distribute the structural walls in both directions to guarantee the stability of the building due to the horizontal forces, being important the symmetry in plan to avoid torsion as a consequence of non-coincidence of shear and mass centre.

Simplification of the design

The simplification of the design is one of the main tasks for improvement of the constructability (13). For that it is recommended:

i. to minimise the numbers of different components, elements or pieces;
ii. to use materials easily available in the market, with usual size and configuration;
iii. to use materials and simple components that can be connected without requiring highly qualified professionals, with limited need of care during storage and use;
iv. attention to connections between components and construction elements.

Modular planning

Modular planning is a method of coordinating dimensions of various building components to simplify work and reduce construction costs. The modulation is the basis of the dimensional coordination system used for the design of buildings in structural masonry. The architect, since the early stage of the design, should work on a mesh to modulate according to the component type to be used.

Careful planning minimises cutting and fitting of units on the job, operations that slow up construction. In a modular plan for masonry construction all horizontal dimensions are given in multiples of half the nominal length of the block plus mortar thickness. Vertically the dimensions are given in multiples of the full nominal height of the block, considering the joint thickness. This co-ordination allows the control of joint thickness in the site construction. Figures 2 shows the units distributed on a coordinate mesh, considering the space arrangements with related openings, in the first and the second courses.
In practice, however, some construction elements force to accommodate some dimensions. Considering vertical modulation, the slabs, for example, have their thickness determined by economics and rarely coincide with the modulation. In those conditions the concern of vertical modulation is limited by height from floor to slab.

If there are different thicknesses of walls in plan modulation, the layout may requires special units. Modular design of masonry requires window and door frames to be supplied with adequate dimensions to avoid cutting. In Figure 3 elevations are shown using the available blocks on a non-recommended disposition where cutting units is necessary and also the right modular distribution.
The modular coordination, however, can only be achieved if the units are supplied with standard dimensions without significant variations in their length and height. Workmanship should be qualified to adequate the joint thickness according to dimensions of units and to the tolerance of modulations. Special procedures for the construction of first-course of walls are required in order to assure modulation and levelling. Equipments and tools to ensure the effectiveness of the constructions are also required.

**Joints and openings**

The joints between perpendicular walls require different units in order to achieve a recommended link between alternate courses. The horizontal and vertical dimensions of openings should also follow the modular units’ size. Figure 4 shows a suggested alternative in using ordinary modular units in plan, perspective and elevation.

![Figure 4: Suggested alternative for alternate courses in using ordinary modular units](image)
Facilities design

Architectural, structural and facilities design must be conducted considering their interconnections and mutual requirements. Cutting walls in structural masonry should be avoided under the structural point of view and to reduce waste of material and workmanship. The following can be suggested:

i. location of all the possible facility points on a same wall;
ii. use of non-structural walls for the facilities;
iii. use of shafts and other vertical openings;
iv. use of special blocks to embed horizontal pipes;
v. use of apparent pipes.

Facade and aesthetics

The decision in terms of facades of architectural design is dependent on several aspects such as form, slenderness, possibility of use of in-plane and out-planes elements, verandas, openings and others. These aspects have a close relation with structural behaviour of the masonry and it could be positively exploited using the covering in a aesthetically way. As an example, arches and elements placed over openings can be used as ornaments in apparent masonry.

Conclusion

The improvement of both material and construction process has considerably contributed to the development of the structural masonry technology in developing countries such as Brazil. This is reflected by the large-scale production of required materials. As a result, structural masonry became a more efficient construction process, using both ceramic and concrete blocks, with lower time consumption, lower final cost and better final quality compared to the traditional ones.

The structural masonry is a construction system adequate for several constructions patterns as well different scales with major or minor mechanization. It allows architectural flexibility and offers better security and work conditions. When adequate procedures are adopted in all the phases of the building delivery process is possible to achieve better productiveness, accidents reduction, better work conditions, workmanship qualification, and better construction quality, reduction of construction time, increase the execution velocity and lower cost of facilities installations. From the discussion herein presented the following can be drawn:

1. The conception in the architectural design, as well as its interference with other projects such as structural and services, can contribute to the optimisation of the construction system in masonry.
2. Wall-layout for a particular building evolves from functional requirements and site conditions. A balance on functional requirements and structural behaviour is to be found by architects and engineers.

3. As procedures for the project architectural looking for a better interaction with the construction process it can be suggested:
   i. to use a mesh for modulation looking for the maximum possible symmetry among the structural walls in the plan;
   ii. to dispose the shafts and consider spaces for services and to embed pipes;
   iii. to provide a complete solution with drawings for the first and second course of bricks/blocks;
   iv. to provide a complete solution with drawings for walls with openings and embedded pipes.

4. Architects, engineers and constructors involved in the masonry structures constructions should have the clear understanding of the whole system, considering the construction technology, its advantages and limitations, so that the arrangement respects the functional conditions and technical requirements. Also the construction process can contribute to the final quality of the project.

Finally, and since the architectural conception and structural design are closely linked, their interaction is essential to achieve a better constructability, making the construction process more rational.

References


