ARCHITECTURAL AND STRUCTURAL DESIGN REQUIREMENTS FOR CONSTRUCTIBILITY IN STRUCTURAL MASONRY

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ABSTRACT

The use of structural masonry has to some extent been hampered by its long history as a craft based material and its disappearance for structural use was being predicted. The fact that this has not happened is a result of the inherent advantages of brickwork. However, to use structural brickwork effectively, the architectural conception and design must contribute to improve constructibility and reduce costs of buildings providing, at the same time, better technical solutions. Wall-layout for a particular building evolve from functional requirements and site conditions. A balance on functional requirements and structural behaviour should be found by architects and engineers. 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. It is shown that a clear understanding of the constructive system together with the flexibility offered by the material in terms of building layout can contribute to a better use of structural masonry.

Key words: structural masonry, architectural design, brickwork, structural design, constructive system, constructibility.

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INTRODUCTION

In spite of the great influence that efforts acting over walls have in the design of masonry structures, the construction under modern structural principles are quite recent. By the end of the nineteenth century and the early part of the twentieth century, some tests on piers and walls had been carried out in several countries in order to support a more rationalised structural design. The knowledge was under an empirical basis leading to the design of thick walls, loss of space and high consumption of time and workmanship during the building process. Masonry buildings were designed and built by the rule of thumb without structural calculations. This approach could not be applied to multi-storey structures without using very thick walls, and led to the demise of masonry till 1950. As a consequence, new materials, such as concrete and steel, took the place of a significant portion of structural masonry constructions.

Since the 1950's results of several investigations in different countries led to the preparation of codes of practice taking into account the results of these investigations and pushing the design of masonry structures to a more competitive approach. In spite of representing a great advance, these codes were limited in their scopes and, in some way, still based on builder's experience. (HENDRY *et al.*, 1997).

Due to the change in design concept, development of rational codes of practice, extensive research and testing and adoption of adequate theoretical methods, masonry has emerged as a structural material and can compete with steel and concrete in the construction of office buildings and flats, hotels and hospitals (ABRAMS, 1996). However, to use structural brickwork effectively, the architectural conception and design must contribute to improve constructibility and reduce costs of buildings providing, at the same time, better technical solutions. Masonry can further be exploited in heavy civil engineering constructions provided its tensile weakness is overcame by reinforcing or prestressing.

CHARACTERISTICS OF MASONRY DESIGN AND CONSTRUCTION

Since the 1960's, the use of masonry as structural material has intensified. During this time considerable advances can be observed especially in developing countries such as Brazil and Malaysia.

Particularly in Brazil the improvement of both construction process and materials considerably contributed to the development of the structural masonry technology. This is reflected by the large-scale production of clay and concrete blocks, and mortars. 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 one

(FRANCO,1992).

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 such as partition and insulation. Material used has a low cost and the initial investment is low. Small size of units (bricks and blocks) also offers a great design flexibility, besides attractive finished surfaces under aesthetically and plastic views.

One of the most important characteristics of masonry construction is the simple method of construction by laying brick over brick joined by mortar. This possibly explains why the technique has been used since ancient times together with other important characteristics like solidity, durability, low maintenance costs, good acoustic and thermal insulation, and fire protection.

To profit from its 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 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. It is also important to detail the special elements and their connections, allowing relative movements, settlement of foundation and earthquakes, where applicable.

For horizontal load the interaction slab-wall is of particular interest, mainly for tall buildings where those loads are considerably higher. The first approaches neglected this consideration and wind loads were distributed proportionally to wall rigidity. Later, effects of torsion were considered and recently more accurate methods for the analysis of concrete shear walls were validated through full-scale tests for masonry walls (HENDRY, 1998).

The recent development of the structural use of masonry has allowed the consideration of shear wall effect to support lateral loads, and, thereby, the strength and deformation characteristics of brickwork have become more significant. This has increased the interest on non-framed multi-storey construction and on infilled walls in concrete and steel frames.

STRUCTURAL MASONRY DESIGN AND ARCHITECTURE

Architectural conception and design in structural masonry are closely linked. Their interaction are essential to achieve a better constructibility, making the constructive process more rational (PEDRESCHI *et al.*, 1996). The architectural design should clearly express the constructive process. For that, when taking into account the formal and symbolic character of architecture, the design should focus on aspects like dimension of units (blocks and bricks) and modular planning, which are similar to the idea of *design of product*.

In this way, comparing architectural design to *product design*, it should be taken into account the restrictions of resolution and solution. Restrictions of resolution are those related to the available knowledge, to time consumption and to existing technologies. Restrictions of solution include those like costs, availability of materials and equipment's, qualified staff, workmanship, use and maintenance.
The architectural conception, the preliminary design, the design itself and the detailing should also consider information related to other aspects of life cycle such as recycling and disposal.

Three dimensions can be related to the construction: the physical aspects, the accessibility and the occupation, which are universal needs to be put in a balance of priorities. The result of the identification and quantification of these attributes are used for decision making in the design. In this way, architectural design should focus on methods and tools adapted for the quality control, to identify the needs and the user's explicit or implicit desires, such as privacy, space, safety, illumination and ventilation, basic infrastructure and location related to the dwelling, the work, the leisure and the items of public infrastructure at accessible and adequate price. These different aspects should be integrated and optimised, adapted to the available technologies and provide an interaction between the constructive system and the design solution. The optimisation of factors as time, cost and quality improves the economic competitiveness, determining the acceptance of the structural masonry in the market.

THE CONCEPTION IN ARCHITECTURAL DESIGN OF MASONRY

The choice of a constructive system depends on the entrepreneur's experience and/or on the customer's will, starting from the analysis and evaluation of the requirements, the elements that should be considered in the design production process and organised according to guarantee the desired quality.

Definition of the design requirements

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

- the number of possible storeys to be designed with materials available in the market;
- the arrangement and distribution of walls;
- the limitations and the relationship to the transition of structures existing in the ground floor and basement;
- 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, rationalisation 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 loadbearing 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 constructibility 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 constructibility (TAYLOR, 1993). For that it is recommended:

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

DESIGN AND DETAILING

Modular Planning

Modular planning is a method of co-ordinating dimensions of various building components to simplify work and reduce construction costs. The traditional proportions of bricks (approximately 3:4) was given up as a result of standardisation system and forms, which prioritised the proportion 2:1 (ADELL-ARGILÉS, 1994).

The great difference of the technology introduced in the nineteenth century was that the new characteristics allowed the use of the bricks as structural element besides formal and aesthetic character of the architecture (ABRAMS, 1996).

The modulation is the basis of the dimensional co-ordination 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. An example of modulation is given in Figure 1.

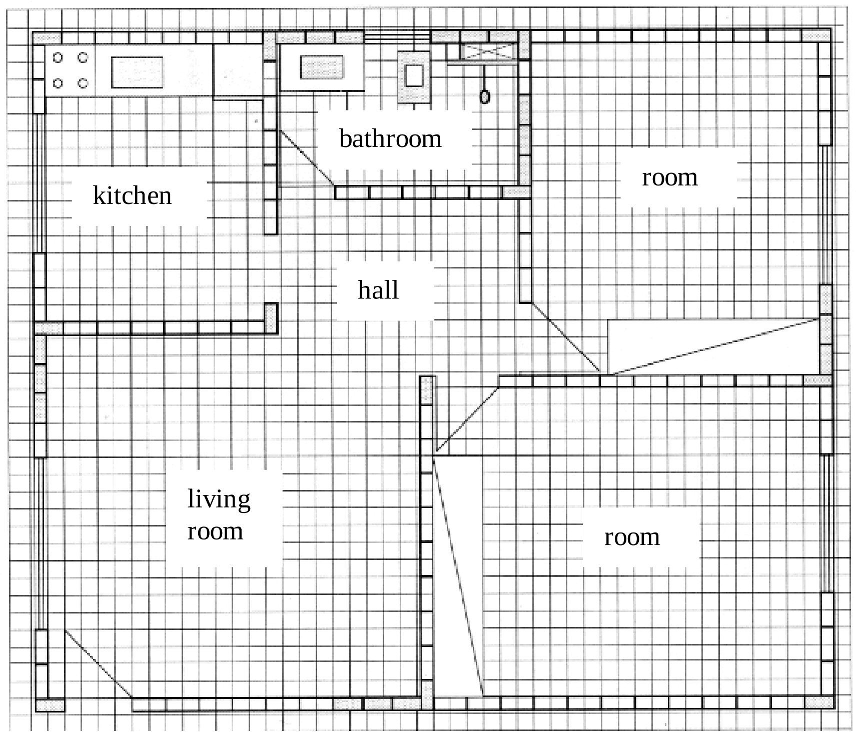

Figure 1 – Mesh used in a modular planning of masonry using blocks of 340 mm and 390 mm length.

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 a concrete block plus mortar thickness. Vertically the dimensions are given in multiples of the full nominal height of the block, considering the joint thickness. Figure 2 shows a horizontal and vertical modulation.

This co-ordination allows the control of joint thickness in the site construction. Workmanship should be qualified to adequate the joint thickness according to dimensions of units and to the tolerance of modulations.

In practice, however, some constructive elements force to accommodate some dimensions. The slab, for example, have its thickness determined by economics and rarely coincides with the modulation. In those conditions the concern of vertical modulation will be limited by the height from floor to slab.

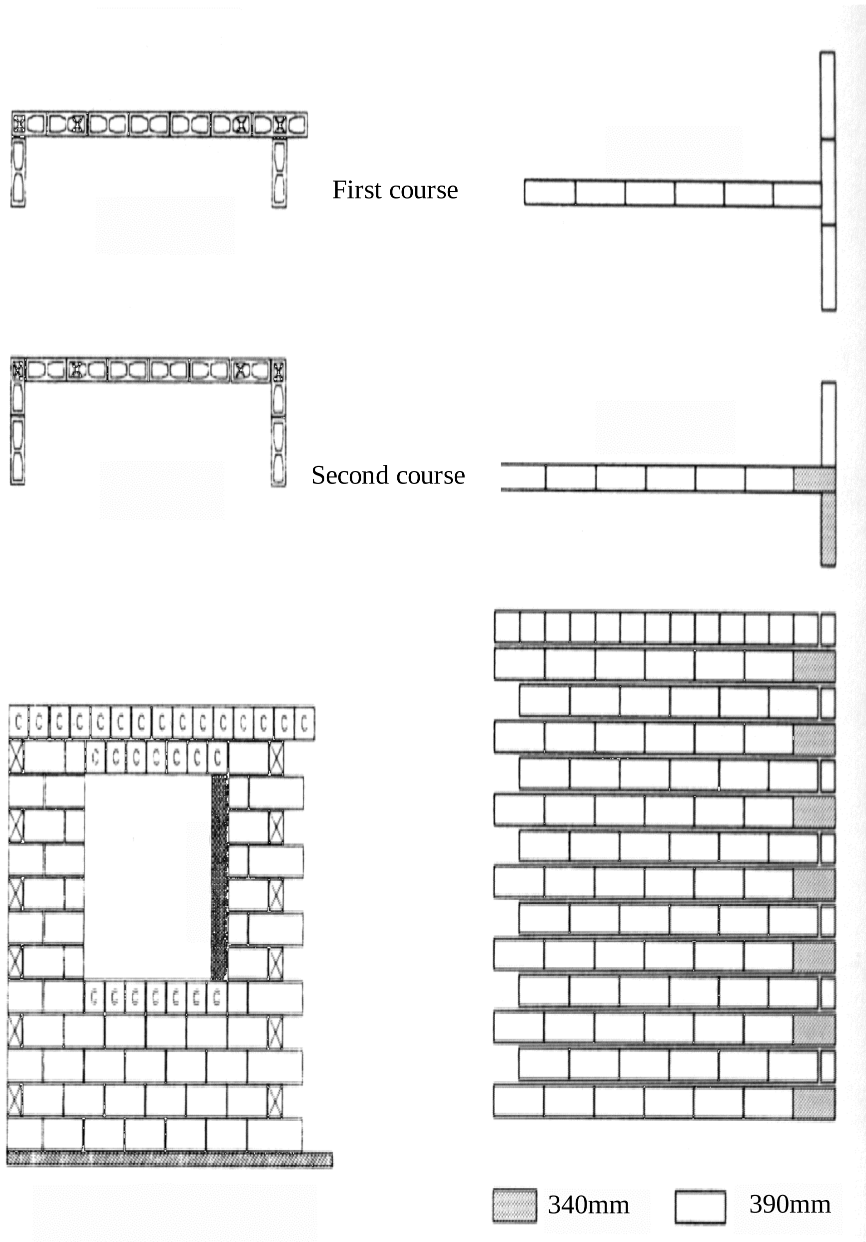

Figure 2 – Horizontal and vertical modulation of units

If there are different thickness of walls, the layout in plan may require special units such as the corner layout shown in Figure 3.

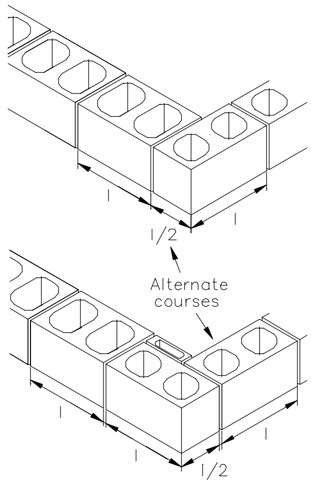

Figure 3 – Corner layout for different wall thickness

The modular co-ordination, however, can only be achieved if the units are supplied with standard dimensions without significant variations in their length and height. Architectural, structural and facilities design must be conducted considering their interconnections and mutual requirements.

Door and Window openings

Modular design of masonry requires window and door frames to be supplied with adequate dimensions to avoid cutting. Some right and wrong examples of modulation of wall openings are shown in Figure 4.

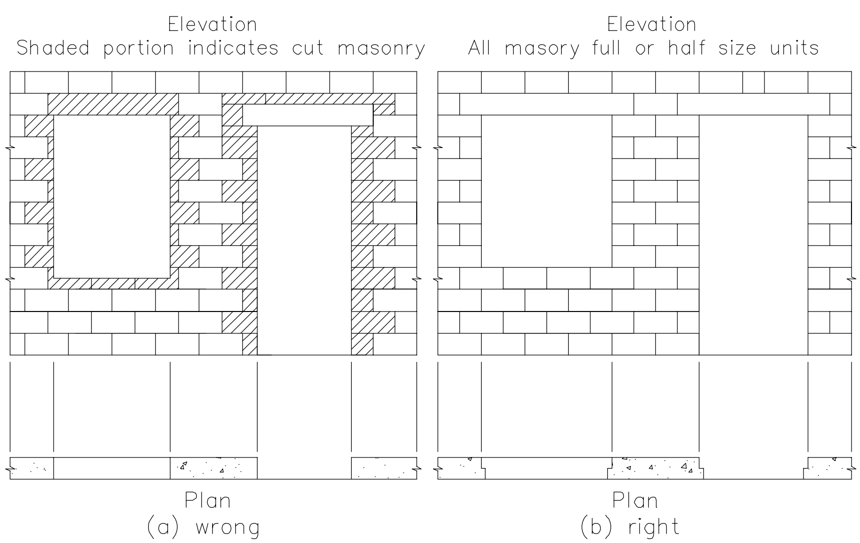

Figure 4 – Examples of wrong and right planning of masonry wall openings.

Service design

Cutting walls in structural masonry should be avoided under the structural point of view and to reduce waste of material and workmanship. The following alternatives can be suggested:

- use of non-structural walls for the services;
- use of shafts and other vertical openings;
- use of special blocks to embed horizontal pipes;
- 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-plane 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

From the discussion herein presented the following can be drawn:

1. Wall-layout for a particular building evolve from functional requirements and site conditions. A balance on functional requirements and structural behaviour is to be found by architects and engineers.

2. A clear understanding of the constructive system together with the flexibility offered by the material in terms of building layout can significantly contribute to a better use of structural masonry. It is necessary to attempt to some basic principles of structural design, to the material properties of bricks and brickwork to carry out the architectural design of a complete building in structural masonry.

3. 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.

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

5. As procedures for the project architectural looking for a better interaction with the constructive process it can be suggested:

- to use a mesh for modulation looking for the maximum possible symmetry among the structural walls;
- to dispose the shafts and consider spaces for services and to embed pipes;
- to provide a complete solution with drawings for the first and second course of bricks/blocks;
- to provide a complete solution with drawings for walls with openings and embedded pipes.

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

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