THE EVOLUTION OF THE DESIGN AND CONSTRUCTION OF MASONRY BUILDINGS IN THE UK

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Abstract

The paper gives a brief history of the use of masonry, mainly clay brickwork and stonework, for historic buildings in the UK. The development of a modern Code of Practice is described, leading to BS 5628: Parts 1, 2 and 3 (BRITISH..., 1978, 1985a, b). The development and use of reinforced masonry is covered, as is the need for sensible rules to ensure that correct materials and workmanship are used. The development of new materials and methods is mentioned. The result of the European Union succeeding in changing National European Codes of Practice into Eurocodes has made a profound difference for designers and the Eurocodes are described. Finally the future use of masonry in the UK is discussed.

Keywords: *clay brickwork, concrete blockwork, stonework, codes of practice, Eurocodes.*

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1. INTRODUCTION

Great Britain, the UK including Ireland, in company with a number of other Countries, has a great tradition of masonry use, historically using fired clay products or natural stone, depending on the material available near to the location. Many fine buildings were built in masonry and a large number still survive today – testimony to the longevity of masonry as a building material. Examples can be found throughout the UK in the form of cathedrals, churches, houses, castles, public buildings, bridges and retaining structures – even lighthouses.

The design of what we now regard as historic buildings was not based on engineering of a very high standard of mechanical understanding; 'design' relied more on experience gained from trial and error and on the accumulated knowledge of the men who did the construction. No-one really knows how much of the masonry in the Babylonian buildings, for example, that has survived until modern times, was erected more than once before the final successful version.

The properties of the materials from which walls were built were themselves not very well known or reliably consistent. The manner of firing clay was 'hit and miss' and the quality of the clay, for example, was variable – usually just dug out of the top metre or so of land as 'brick earth'. Natural stone varied hugely according to the locality from which it was quarried – often from a hill or pit on the relevant landowner's estate or at most only from a few kilometres away – within the range of a 'horse and cart' transport system.

With the onset of the industrial revolution, more 'science' was gradually employed in the production of materials and the knowledge of mechanical behaviour improved dramatically, leading to more understanding of the design of masonry for structural use and eventually to properly 'engineered' masonry.

In the UK there was no Code of Practice that covered any aspect of the design of masonry before 1948, when CP 111 *Structural recommendations for loadbearing walls* (BRITISH..., 1948) was published through the good offices of the Ministry of Works – a government department. For very many years, since soon after the Great Fire of London in fact, there had been regulations for use in the city (the inner part of London as we know it today) initially covering construction so as to limit the spread of fire, but then covering the structural design of several materials in a very basic way. Masonry was given a huge boost by the Great Fire, as the rules to limit spread of fire effectively required masonry to be used (mostly clay with some stone) for the separation between dwellings. The design for masonry was simply a case of working out the pressure in the wall due to self weight and applied loads, in tons/square foot, and comparing the figure to permitted pressures for clay brickwork or stonework. The use of 'tons/square foot' (not sensibly converted to SI units!) illustrates the backwards attitude to masonry design; even in those early twentieth century days, stresses would have been designated in pounds per square inch (now N/mm^2). The walls that resulted from use of the rules were very thick because the assumed compressive strength of the clay bricks was low, as was the knowledge of the strength of mortar, and hence of the brickwork, built with those bricks.

Figure 1. *Ancient brickwork – the Chogha Zanbil ziggurat.*

CP 111 was a very basic code of practice, and was not originally written to include loadbearing concrete blockwork although it did include unreinforced concrete walls, rather strangely. It was based on some research work, mostly but not all done at the Building Research Station near London just before and after the Second World War on piers, not walls. Just two strengths were given for tensile resistance of clay brickwork – 10 and 20 lb/sq inch (0.07 and 0.14 N/mm^2) in the 'weak' and 'strong' directions respectively. There was no information for concrete blockwork tensile strengths. We know that the overall safety factors that had been applied to arrive at the permissible stresses were very high, but masonry was nevertheless used, apparently economically. Some amendments were made to the 1948 version and in 1964 the implied safety factors were reduced so that masonry started to become a more economical material than it had been. Although not a part of my presentation, it can be observed that the same situation existed during the same period in all of the Countries where masonry was used – massive cathedrals in Europe and elsewhere, heavy loadbearing masonry in 'new' Countries whose expertise arose through immigrants from Europe – the Monadnoc Building in Chicago for instance.

It must be emphasised that, in the UK, masonry was, and still is, mostly unreinforced, unless there is some reason for adding reinforcement. Perhaps this long tradition of use of unreinforced masonry stems from the fact that the UK is not in a sufficiently active seismic area to justify taking ground accelerations into account and so there has been no history of failures of unreinforced masonry that would have forced the addition of reinforcement.

2. TOWARDS MODERN MASONRY CONSTRUCTION

For better or worse, in the mass markets in which we live, designers need codes of practice to enable them to be able to design structures, be they reinforced concrete, structural steel, timber or masonry. A few forward thinking people, in the early development of structural engineering as a science, found it possible to arrive at good designs by developing their own methods using basic research data, but this approach is not really practicable for design offices working on a commercial basis. Hence codes of practice have become the normal route to design for all materials – and the easier it is made for designers to achieve an economical design for a material, the better the chance that design engineers will use that material.

During the 1960's and 1970's the UK masonry industry was at the forefront of sponsoring research to improve the economy of masonry design so that the highly conservative CP 111, which used permissible stresses, could be replaced with a more comprehensive and economical code. By this time the limit state approach was being promoted and was becoming increasingly popular as a basis for structural codes of practice. Much testing of full sized walls was carried out to establish rules for the compressive resistance of the masonry materials in most frequent use. In that halcyon period for research, it wasn't considered to be reliable enough to use small portions of walls to get the masonry strengths, in the UK at least, so that full sized wall testing was normal. It seems that the practice was rather the other way around in the Americas, where testing of 'prisms' was much more common than use of full sized walls.

The old CP 111 did not cover design of walls for lateral loads – wind, primarily, in the UK, indeed it didn't seem to be thought at the time that one needed to consider lateral loads if one had designed for vertical ones and for some eccentricity. Following the Ronan Point gas explosion collapse in London in May 1968, the Report of the Enquiry pointed out that the wind pressures that were then being recommended for design by the Code of Practice for loads were out of date and much higher pressures should be being used. There had also been quite a number of failures of roofs from uplift because tieing down was not taken seriously and the suction pressures given in the code were too low. The report of the enquiry resulted in a new wind loading code requiring much higher loads. The use of thinner walls, combined with the higher pressures, encouraged the design of walls for wind loading at the start of the 1970's but the embryo new masonry code, then in preparation, did not cover the subject and so a huge amount of research work was done on laterally loaded walls at Ceram in Stoke-on-Trent, and also in other places both in the UK and worldwide. Lateral load design had become a topical subject that spawned several theories and a large number of papers, starting with the 2nd IBMAC and continuing even until today.

The gas explosion in Ronan Point had occurred in a large panel prefabricated concrete high rise block of apartments in London. Very little connection had been provided between the prefabricated components and the type of building was likened to a 'pack of cards'. The fall-out from the investigations that followed the partial collapse of the building could have been the death knell for unreinforced masonry as the investigations had pointed to their having been really high lateral pressures before walls were dislodged. Suddenly high pressures, 34kN/mm^2, were introduced for all design as one way to meet new requirements for accidental design situations, as the possibility of damage from explosions (and

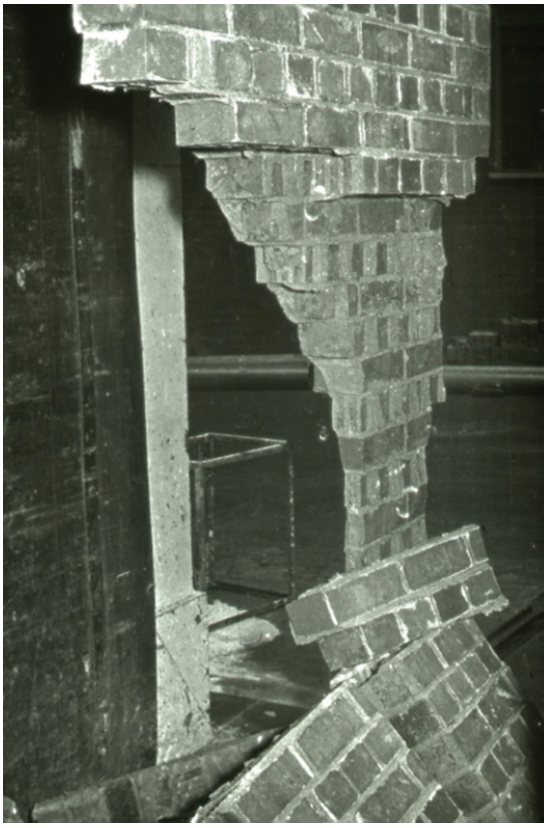

Figure 2. *A wall tested to destruction.*

also from mechanical accidents) became known. The clay brick industry had the foresight in late 1968, early 1969, before the report on the Ronan Point Explosion was published, to commission research work using real gas explosions in a full sized brick building, together with other complementary research. Somewhat surprisingly, for some outside the masonry industry, the full scale tests found that the brick building successfully withstood very large pressures. The static information on the resistance of clay brick walls to lateral forces that was found when the walls were also loaded vertically (precompressed), led to the result that traditional three-pin arch theory fitted the data remarkably well. As a result of the research work and changes in regulations, the new masonry code had a section added specifically dealing with accidental design, either by calculation or by the introduction of tieing forces, with consequential use of local reinforcement. The very well used phrase 'the damage shall not be disproportionate to the cause' was coined and sums up the overall philosophy of accidental damage design both then and now.

The end result from a long period of drafting taking into account the research work that was done and the analysis of it was the publication in 1978 by the British Standards Institution of the new limit state code for unreinforced masonry BS 5628: Part 1 *Code of practice for use of masonry – Part 1: Structural use of masonry* (BRITISH..., 1978).

3. REINFORCED MASONRY

The old code CP 111 had a very small section on reinforcing masonry, but it did not reflect modern design methods for use of reinforcement, for example in reinforced concrete. Having successfully published the new unreinforced masonry code, BS 5628: Part 1 (BRITISH..., 1978), attention moved to producing a part dealing with reinforced and prestressed masonry. Again, industry was very supportive of the work and a first draft was prepared by Ceram as early as 1977. In general the principles of reinforcing and prestressing concrete were followed in developing the Code for masonry, with adjustments where the research data had suggested variations. Research had provided detailed information on stress strain relationships, which introduced one of the variations from reinforced concrete design methods. Further research had also given information on the stressing of masonry in a longitudinal direction as opposed to the normal vertical one.

BS 5628: Part 2 *Code of practice for use of masonry – Part 2: Structural use of reinforced and prestressed masonry* was published by the British Standards Institution in 1985 (BRITISH..., 1985a).

4. GETTING MATERIALS AND WORKMANSHIP RIGHT

CP 111 had been complemented by another code of practice, CP 121 *Code of practice for walling Part 1 Brick and block masonry* (BRITISH..., 1973), which dealt with the choice of materials for use in masonry and covered to a limited extent workmanship on the building site. It was as woefully out of date by the 1970's as was CP111.

Durability of masonry had not always proved to be as good as it should have been and the materials, principally clay bricks, but also mortar and concrete products, sometimes suffered adversely from the effects of freeze thaw cycles when saturated. Mortars sometimes suffered from being adversely affected by chemicals leaching from clay bricks – sulphate attack. Other problems could leave owners being less than happy with their masonry building, so the subjects had to be addressed.

Detailing for the exclusion of water from the fabric of the building was only covered in specialist text books, rather than concise codes of practice; the new part of BS 5628 dealt with such aspects and also with the ancillary components needed to complete wall construction. It was published first in 1985, also (BRITISH..., 1985b).

Workmanship is always a difficult subject to deal with in code type material as a line has to be dawn between aspects that are necessary to guard the safety of the structure and 'how to' type guidance that is not relevant to a code. The masonry code in the UK tends to be firmly aimed at the former point – maintaining safety, and not much 'how to' guidance. However, there is a separate BSI document 'Workmanship on building sites', that covers many different materials and does go into more detail about construction.

All these missing or inadequately covered ones were brought together in a third part of the BS 5628 series as BS 5628: Part 3 in 1985 (BRITISH..., 1985b). For the first time the UK had a suite of Code of Practice that covered masonry comprehensively.

Figure 3. *High rise loadbearing construction.*

5. NEW MATERIALS AND METHODS OF USING MASONRY

As stated in the introduction, traditionally, masonry was clay brickwork or stonework. New ways of making concrete blocks, initially using waste materials like coal ash, caused some of the common bricks (ones not having facing quality) to be replaced, but not when 'heavily' loadbearing. Use of quality concretes in the blocks meant that they rapidly replaced clay bricks for use in 'hidden' loadbearing walls; some designers liked using concrete blocks for facing, as well.

The traditional clay brick wall that is used for facing but not loadbearing purposes is a 'half brick' one – in UK terms 102.5 mm thick; a 'half brick' wall is likely to be a part of a cavity wall system with the inner leaf being in some form of concrete block, nowadays. The traditional loadbearing brick wall was 'one brick' – 215 mm thick. Many, if not most, clay brick 215 walls are now built using concrete blockwork. A progressive brick manufacturer tried to improve efficiency of both cavity wall and solid wall construction by making special bricks. One, called the V-brick, was 215 wide, and had two 'leafs' joined together with clay webs. A divided bed of mortar achieved a one piece cavity wall. A 13 storey loadbearing block of apartments was built using the brick and has performed satisfactorily, but the brick never 'caught on' and production soon stopped.

The second attempt at innovation of units was a 170 mm wide brick for use in party walls, instead of 215 brickwork. In a period of sustained building of social housing, this new product was extensively used, but new rules about sound insulation of separating walls proved difficult to meet, and the brick fell out of favour. The clay brick industry has all but lost the market for internal walls of apartments, anyway.

A Scandinavian development enabled blocks to be made using a slurry of cement and a suitable fine material (fine sand or pulverised fly ash), made to 'rise' with aluminium powder and then autoclaved (autoclaved aerated concrete or aircrete). The resulting blocks are light weight, thus having very good thermal insulation properties, but achieve useful strengths for loadbearing use.

Aircrete blocks are used extensively for low rise buildings. A new innovation, imported from the Continent of Europe, is to lay accurately thicknessed blocks on a very thin layer of a special mortar, so that walls can be put up very quickly – so-called thin joint masonry; a 'flattened' bed joint reinforcement is often added as well to reduce the cracking that can result from shrinkage with these blocks.

For a while, calcium silicate bricks also made a contribution to masonry, but their use has almost died out in the UK, partly for the absence of plentiful suitable sand supplies. In some European Continental Countries, calcium silicate masonry has proved to be very popular, however.

The design of masonry, whether using clay bricks, concrete bricks and blocks, aircrete blocks, or stone, follows the same principles and is covered in the same codes.

The extensive use of unreinforced masonry for loadbearing walls was nevertheless limiting if high walls that were likely to be subjected to lateral forces, for example sports halls or factory buildings, were needed. Several innovative designs were developed to enable masonry to be used for these sorts of buildings by increasing the thickness of the overall construction without increasing greatly the volume of the materials used. These were known as 'fin walls' and 'diaphragm walls'. No reinforcement was added so economy was achieved. The current requirements for avoiding cold bridges, meaning breaks in the structural complex system, have reduced somewhat the use of these sorts of complex shapes.

Prefabrication of masonry has been an attractive idea for many years and there have been a number of attempts to make use of the technique to achieve on-site efficiencies. The construction industry and government regard factory production as an established method of being 'modern'. Unfortunately, most of the attempts at prefabrication in the UK have foundered for a variety of reasons, but a consistent one has been the cost. It seems to be remarkably difficult to save enough cost in the efficiencies of prefabricated construction to offset the costs of transport and erection.

6. EUROCODES

Since the original formation of the European Common Market, there have been Directives and laws having the objective of unifying many aspects of European commerce. The European Union, as it is now known, encouraged the production of codes of practice for structural design and construction for many years. The rationale was that having different design methods in different Countries erected a barrier to trade for those wishing to 'design and build' across EU borders. Development of the codes was very slow, not perhaps surprising given the huge range of views in the many Countries who participated in the drafting. The codes have gone through several stages of comment or experimental use, but now the Eurocodes, as they are known, are complete and the 58 parts that have been developed should be in use in all of the European Countries in the Union and some others that are linked in through the European standardisation body CEN. They are being adopted by Countries outside the EU, especially those that had previously used codes published by historically connected Countries. The Eurocodes cover the main structural materials, concrete, steel, composite steel/concrete, timber, masonry and aluminium and provide a common basis of design with parts for geotechnical design and seismic design.

Masonry should now be being designed to EN 1996-1-1 (BRITISH..., 2005a), unreinforced masonry and reinforced masonry design, EN 1996-1-2 (BRITISH..., 2005b), fire design, EN 1996-2 (BRITISH..., 2006a), materials and workmanship, and EN 1996-3 (BRITISH..., 2006b), simplified methods of design.

When drafting the Eurocodes, the only way that it was possible to reach agreement on many aspects of structural design was by allowing certain numbers or methods to be left open for national choice. In the case of geotechnical, geographical or meteorological variations, national or area changes were inevitable, but it became uncomfortably normal for simple things like strength of masonry, to be made a national choice. National variations became known as Nationally Determined Parameters - NDPs. To those involved in the drafting of the codes, the expression became uncomfortably repetitive.

Each Country must publish, unaltered, the Eurocodes, but it may then add a National Annex that gives the chosen values or methods listed as NPDs for that Country. The user then has to amalgamate the code and the national annex – a not terribly convenient way of working.

Since a Country has the ability to settle the many factors open through the NDPs for change, it should be possible to ensure that the economy of the relevant material in maintained or even enhanced, if justified. Unfortunately, despite a great deal of calibration work, it now seems that some of the NDPs chosen for use in the UK do not give as high a level of economy as did the now withdrawn British Code. This problem is receiving urgent attention.

7. THE FUTURE

For a Country that has such a rich history of masonry construction, particularly in clay brickwork and stonework, I hope that there is a good future for masonry for many years to come. It is uncomfortably true, however, that clay masonry is now mostly used for its appearance as a facing and not for loadbearing purposes. The replacement for the clay walls that were used to support load are built in concrete blockwork of various types according to the circumstances, but even there, the high rise side of construction has moved very much towards reinforced concrete or structural steel.

The Eurocodes are the future as far as design is concerned, and designers need to become familiar with the slightly different ways of working that they entail. We need to get some of the 'conversion bugs' out of the system to let industry get on with promotion of their undoubtedly desirable products.

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