The Way forward for Reinforced Masonry Design

B.A.Haseltine BSc ACGI DIC FICE FIStructE MConsE

Partner - Jenkins & Potter,London,England

ABSTRACT

Reinforced masonry has been used since 1825 and it has long been accepted that its design can be based on the principles used for reinforced concrete. There is a lack of detailed design guidance available,worldwide, but the CIB is extending its International Recommendations for Masonry Structures to include Reinforced Masonry; the base data is the advanced British Draft Code BS 5628 : Part 2, which is discussed in the paper.

1.0 INTRODUCTION

Reinforcement has been used in masonry, masonry meaning brickwork or blockwork, since about 1825 when Brunel reinforced his brick caissons for the construction of an underground railway. Although many structures have, since then, made use of the technique of reinforcing masonry, it has not made the impact of other structural materials, such as reinforced concrete. Much of the reinforced masonry used this century has been in countries,such as the USA or New Zealand, where the need to resist seismic forces makes unreinforced masonry unattractive. On the other hand, in countries with no seismic problems, it is possible to build such highly stressed brickwork that there has been no incentive to add reinforcement. This has been particularly true in the U.K where tall loadbearing brickwork buildings have been constructed without reinforcement (1,2). Another factor that has held back the use of reinforced masonry has been the relatively poor quality of the design guidance available, particularly in Codes of Practice. This situation is now changing so that reinforced masonry designers will have available, worldwide, codified methods of design on a par with those for reinforced concrete.

In the sections below, the situation in the United Kingdom, other countries and within the CIB are discussed.

2.0 UNITED KINGDOM

Despite the early use of reinforced brickwork by Brunel, it was in 1943 that the first codified design information was published as"British Standard Specification for Reinforced Brickwork". Strangely this code for reinforced brickwork preceded one for unreinforced,although one is talking only about simple design and then only of walls.

A draft Code of Practice for the design of all loadbearing walls,including the relevant part of the 1943 Code, was circulated for comment in 1946. It had been prepared by the Institution of Structural Engineers on behalf of the British Standards Institution (BSI) and included a general section on load-bearing walls, followed by sections on masonry,including brickwork (unreinforced), on reinforced masonry and on concrete cast insitu. After

appropriate discussion and revision the document was published in 1948 as CP 111 "Structural Recommendations for Loadbearing Walls" [3].

The first revision of this Code of Practice was published in 1964. The main change affecting brickwork and blockwork was an increase, usually substantial, in the permissible stresses; the basic stresses were altered slightly but the reduction factors for slenderness were made less onerous and were extended to include the effects of eccentric loads.

A further revision was published in 1970 as part of the programmed change in the construction industry from Imperial to SI units but, although there were other minor changes, the new code did not constitute a technical revision.

From the beginning, the code was based on the assumption that normal principles of structural design would be used to assess the loads resulting from a structure on its masonry elements. The detailed clauses of the code then gave guidance to enable wall thicknesses to be determined in relation to stresses that were considered to be safe and permissible, based on an assessment of experimental data and practical experience.

CP 111 contains a very short section on reinforced walls in Clause 320 which recognises that the design of reinforced brickwork and blockwork will be based on the same general principles of anlysis as those used for reinforced concrete, referring to CP 114, the Concrete Code [4]. Prestressed masonry is not mentioned and nor, of course, is CP 110 [5], which was not available in 1970. A modular ratio approach to the design of reinforced walls is suggested; although the whole of CP 111 is stated to be devoted to the design of load-bearing walls, there is recognition of flexural stresses, so there would be no difficulty in making use of CP 111 for other than reinforced walls, if the designer so wished.

Because there was so little guidance available on reinforced masonry a committee of the British Ceramic Research Association, the Structural Ceramics Advisory Group, which consists of engineers, architects, contractors and quantity surveyors active in the field of masonry, together with brickmakers, commenced work on a Design Guide for Reinforced Brickwork in 1972 and it was published in 1977 as SP 91 [6], in limit state philosophy.

Apart from CP 111, some information of use to designers has appeared in the form of technical papers and trade guidance, often reporting specific research projects. There are many documents available in the U.S.A. where reinforced masonry has been used to a large extent.

A revised version of CP 111 was issued for public comment in 1974, and, after much discussion the limit state code BS 5628 : Part 1 : Unreinforced Masonry [7] was published in October 1978. Immediately afterwards, consideration was given to preparing Part 2 to deal with reinforced and prestressed masonry.

The Property Services Agency let a contract to the British Ceramic Research Association to write a draft suitable for the 'Public Comment' stage of BSI's procedure with a timetable of 1 year for drafting. Naturally, the basis for the draft was SP 91 [6] although the considerable assistance of the Cement and Concrete Association enabled the purely brickwork parts to be expanded to include concrete block masonry. The draft was open for public comment from 1st May to 21st August 1981 and work in producing the final version of the code is now under way.

In view of the importance of BS 5628 : Part 2 to the way forward (see section on CIB) some of the contents are discussed below:

2.1 Design Principles

The purpose of design is defined as the achievement of acceptable probabilities that the part of the structure being designed will not become unfit for the use for which it is required, i.e. that it will not reach a limit state.

Two limit states are recognised :

a) The ultimate limit state. In this an assessment using the design loads should ensure that an ultimate limit state is not reached as a result of rupture of one or more critical sections by overturning, buckling or twisting, caused by elastic or plastic instability. The layout on plan is required to ensure a robust and stable design, with some allowance for accidental loads.

b) The serviceability limit state. In this, it is required that deflection and cracking should not affect adversely the appearance or efficiency of the structure.

2.1.1 Loading

The loads to be applied should ideally have been determined statistically, but it is recognised that it is rarely possible to do this at the moment and so code loadings are required to be used, multiplied by a partial safety factor γ_f to give the design load. The values of γ_f are similar to those in BS 5628 : Part 1.

2.1.2 Materials

The design strength of the material is the characteristic strength divided by another partial safety factor γ_m,which varies for brickwork in compression (γ_{mm}), brickwork in shear (γ_{mv}), steel (γ_{ms}) and for certain other uses. γ_{mm} may be varied according to the level of manufacturing control exercised in the production of the units.

2.2 Characteristic Strengths

The characteristic compressive strength of masonry stressed perpendicular to the normal bed joints is the same as for unreinforced masonry, except that the range of mortars permitted is restricted to the two strongest designations.

The same figures are permitted for solid or frogged units even when they are stressed in other directions; for perforated bricks only 0.4 of the tabulated strengths may be used when the units are stressed other than perpendicular to the normal bed joints and for unfilled hollow blocks tests must be used for the particular direction of loading.

A factor of 1.2 is permitted on the direct compressive strength for bending compression; this enhancement has been the subject of considerable debate and may be modified.

Shear seems always to present a problem and it has in Part 2. For sections in which the reinforcement is placed in mortar (i.e. bed joints or small cavities formed by the bond of the units) the characteristic shear strength is 0.35 N/mm^2. Where the steel will be surrounded by concrete the value ranges from 0.35 to 0.65 N/mm^2 depending on the percentage of steel used. Racking shear is given as in Part 1 i.e. (0.35 + 0.6 x design vertical load) N/mm^2.

The strength of reinforcement and prestressing strand are based on those in CP 110.

2.3 Axial compression

The strength of reinforced members in compression is treated in a similar way to unreinforced in Part 1; a slenderness ratio reduction factor approach is used, but the additional strength given by the steel is allowed for.

2.4 Bending

The bending strength of reinforced masonry is based on the following assumptions :

a) Plane sections remain plane.

b) The stress distribution in the masonry is rectangular with an intensity of the characteristic bending compressive strength divided by γ_{mm}.

c) The maximum strain in the compression zone is 0.0035.

d) The depth of the compression stress block does not exceed half the effective depth.

The resulting formula for the Moment of resistance of the masonry is

$$\frac{0.375\ f_f\ bd^2}{\gamma_{mm}}$$

where f_f is the bending compressive strength (see 2.2)

Deflection and cracking must not be such as to cause serviceability problems, but it has to be admitted that the means of calculating these two items are not very satisfactory.

2.5 Combined Bending and Compression.

Columns and walls are divided into those that are "short", i.e. where buckling is unlikely and those that are "slender" where second order effects may be important.

In the former case no additional bending moment due to buckling is to be allowed for, whereas in the latter, second order effects are included in the formulae given.

2.6 Prestressed Masonry

The general principles of prestressed concrete design are used and only supplemented as necessary for masonry. In the absence of better information creep is assumed to be numerically equal to twice the elastic deformation under the action of the prestressing force.

2.7 Corrosion Protection

Probably the aspect of reinforced or prestressed masonry that receives most discussion, at present, is the protection of the reinforcement to prevent corrosion. It seems to be agreed that where reinforcement may be contained in mortar or concrete that will carbonate and then be subjected to wetting and drying cycles, so that fresh oxygen can reach the steel, then only heavily protected steel, or stainless steel, should be used [9,10,11]. Once that decision is made, the cover for exposed reinforced masonry becomes a matter only for bond and structural considerations.

It appears that mortars carbonate quickly if they are porous, or are between gas porous bricks. Concrete and dense mortars, especially when used with high strength bricks, carbonate slowly, and corrosion of steel in those cases is less likely.

3.0 OTHER COUNTRIES

A number of countries have codes that contain some information about reinforced masonry, but it appears that no-one has yet completed a limit state code dealing especially with this subject. New Zealand, a country that has, for many years, used reinforcement to enable masonry buildings to resist seismic forces, has recently reached the same stage as the U.K. in seeking public comment on a draft code in limit state terms.

Probably the country where most reinforced masonry has been constructed is the U.S.A. and in particular, several of the States that suffer earth tremors. However, the use of reinforcement to make brickwork beams, retaining walls, pools, tall advertising structures and interesting large walls, has taken reinforced masonry far more into the general structural field than merely resisting seismic actions. Unfortunately the Codification process in the U.S.A. is as backward as are their structures advanced (some people would say the two are connected!) The National Bureau of Standards does not have a structural code but there are four choices open to designers:

Brick Institute of America (BIA) - Building Code Requirements for Engineered Brick Masonry.

Uniform Building Code (also Southern Standard Code and Basic Building Code) contains masonry sections.

American Concrete Institute (ACI) - Building Code Requirements for Concrete Masonry Structures.

National Concrete Manufacturers Association(NCMA) now relies mainly on ACI Code.

A joint committee of the ACI and ASCE is trying to produce a masonry code acceptable to all, and presumably to try to replace the other four documnts. Progress seems to be slow and, for the moment it does not appear that USA Codes or Standards will help in paving a way forward for reinforced masonry.

4.0 CONSEIL INTERNATIONAL DU BATIMENT (CIB)

Commission W23 of the CIB "Structures by bearing walls" has published a set of International Recommendations for the Design of Masonry Structures (8) (publication No.58) as one of the suite of six JCSS codes. This is the only fully International set of recommendations for the design of unreinforced masonry and is expected to form a basis for the coming Eurocode No.6.

Having completed recommendations for unreinforced masonry, work has now commenced on extending them to reinforced and prestressed masonry, so that, when complete, there will be International recommendations on reinforced masonry available to all countries - a major step forward.

The working group of W23 has decided that the draft British Code, BS 5628 : Part 2 will form the basis for integrating reinforced masonry clauses into Publication 58, hence the importance of BS 5628 : Part 2. The revised publication 58 will not be as detailed as a working code, for the declared intention of CIB W23 has been to produce recommendations to assist code drafters in preparing a code for their own country. However, it will still be available to individuals to use and also will enable the European Commission to extend Eurocode 6 to include reinforced masonry.

As CIB W23 has also a working group for the seismic design of masonry, the importance of an extended publication 58 cannot be over-emphasised.

5.0 CONCLUSIONS

The worldwide interest in reinforced masonry has been patchy and often related to areas of seismic action. There have been many exciting examples of how brickwork and blockwork can be transformed by the inclusion of reinforcement, but there are few guidance documents of standing.

The U.K. is now in an advanced stage of producing a reinforced and prestressed masonry code, which is also being used as a basis for including these materials in an extended set of CIB International Recommendations for Masonry Structures, which will make available truly worldwide guidance with which engineers can design all types of masonry structures.

REFERENCES

1. JENKINS, R.S., and HASELTINE, B.A., Recent Experiences with Calculated Loadbearing Brickwork, British Ceramic Society Proceedings No.11 July 1968.

2. HASELTINE, B.A., and AU, Y.T., Design and Construction of a Nineteen Storey Loadbearing Brick Building, British Ceramic Research Association, Proceedings of Second International British Masonry Conference.

3. BRITISH STANDARDS INSTITUTION, Structural Recommendations for Loadbearing Walls. CP 111 : 1970.

4. BRITISH STANDARDS INSTITUTION, The Structural Use of Reinforced Concrete in Buildings.

5. BRITISH STANDARDS INSTITUTION, The Structural Use of Concrete.

6. BRITISH CERAMIC RESEARCH ASSOCIATION, Design Guide for Reinforced and Prestressed Clay Brickwork, B.Ceram.R.A. Spec. Pub. 91 1977.

7. BRITISH STANDARDS INSTITUTION, Structural Use of Masonry BS 5628 : Part 1 : 1978.

8. CONSEIL INTERNATIONAL DU BATIMENT, International Recommendations for Masonry Structures, Publication No.58.

9. DE VEKEY, Dr.R, Durability of Reinforced Masonry, Institution of Structural Engineers, Reinforced and Prestressed Masonry July 1981.

10. FOSTER, D., THOMAS, A., Aspects of Durability of Clay Brickwork, Institution of Structural Engineers, Reinforced and Prestressed Masonry July 1981.

11. ROBERTS, Dr.J.J., Interim Results from an investigation of the durability of Reinforcing Steel in Reinforced Concrete Blockwork, Institution of Structural Engineers, Reinforced and Prestressed Masonry July 1981.