MASONRY FOR LOW COST HOUSING IN SOUTH AFRICA

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ABSTRACT

The paper covers developments in the structural performance criteria for masonry in low cost housing in South Africa over the last 50 years.

Key words Low cost housing, masonry materials, structural performance criteria, user performance levels, self-help, soft-body impact damage, hard body impact damage.

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INTRODUCTION

Masonry is the accepted and traditional form of wall construction for all housing in South Africa.

In the post World War II period, where there was a considerable demand for low cost housing, there was a need to re-assess all aspects of the structural performance criteria of house construction to ensure that limited financial resources were spent to optimum advantage. In particular the strength, stability, robustness, durability and serviceability of the masonry walling was important. Also important, but not covered in detail in this paper is the thermal performance, resistance to rain penetration, condensation and fire of walls. House plan areas, normally were generally around 30 to 50 m^2.

The CSIR National Building Research Institute summarised their findings in their publication costs of Urban Bantu Housing in South Africa (Bantu means the people) (CSIR, 1954).

In 2000 the Joint Structural Division of The South African Institution of Civil Engineering and The Institution of Structural Engineers (United Kingdom) published a code of practice Assessment of the performance of housing units in South Africa (JSD, 2000).

"It is generally accepted that where minimum structural performance criteria for housing have been established, structural engineers can design in a more cost efficient manner. In the absence of such criteria, there is a marked tendency to over-design structurally with wasteful expenditure or to overlook local materials with unknown performance characteristics" (JSD, 2000).

Two-user performance levels are recognised, the basic characteristics of which are given in Table 1.

Table 1. Basic characteristics of user performance levels

User performance level	Basic characteristics
1	Focus is on producing basic shelter/starter housing units (detached units) at low initial cost with limited finishes, recognising that shorter maintenance cycles then that contemplated in User Performance Level 2 may be required. Mortgage lending finance is not involved; short-term loan finance may be involved*. Limited moisture penetration through walls and roofs permitted in abnormal storms.
2	Focus is on producing a durable housing unit which requires infrequent maintenance. Mortgage lending finance is usually involved.

* Housing units may be constructed in terms of self-help / sweat equity schemes.

In Annex A details are given on the differences between user performance levels.

MASONRY MATERIALS

Masonry units

Burnt clay bricks of imperial size, 222 x 106 x 73 mm and hollow concrete blocks, 444 x 220 x 220 were the basic masonry-walling units in the 1950's with wall thicknesses of 220 mm (solid) or 270 mm (cavity).

In the second millennium wall thicknesses of 90 140 and 190 mm are specified, mostly single leaf walls with accent on the rationalization of sizes of modular dimension. Nominal compressive strengths of units specified are 5 MPa for solid units and 3 MPa for hollow units (based on load over overall area of unit). With concrete masonry units, drying shrinkage was limited to 0,06%. Burnt clay bricks (many sun dried clay bricks, normally referred to as Kimberly bricks, were used by pioneers developing the hinterland) were categorised for irreversible moisture expansion (category 1 0,00 – 0,05%, category 2 > 0,05 – 0,10%, category 3 > 0,10 – 0,20%) (SABS 227, 1986; SABS 1215, 1984).

Mortar

In the 1950's only ordinary and rapid hardening portland cements, were available. Masonry cement based on air-entraining principles was marketed in 1970 and masonry cement based on additives such as limestone being marketed in the 1990's. Hydrated bedding lime in paper bags became available in 1972 while in the early days loose quick lime in trucks was delivered to site and knocked up into 'coarse stuff' viz lime mixed with sand and water and left to hydrate for a durtion of around three weeks.

Mortar mixes varied from 1:0–1:6 to 1:0–2:9 parts cement, lime and sand and these are still used now though the 1:0–1:6 mix has become the most used of mortar mixes (Class II) (SABS 0145,1978; SABS 0164:1, 1980; SABS 0249,1993).

Wall ties, bedding reinforcement etc.

Metal wall ties, often galvanised, of standard shape are specified in cavity walls, though single leaf and collar-jointed walls (vertical longitudinal joint between adjacent leaves of masonry filled with mortar or grout) are the acceptable economic types of wall. Bedding joint reinforcement of ladder or truss type consisting of two longitudinal wires of ± 2,5 mm diameter are used in walls with solid units. Horizontal and vertical reinforcement in low cost housing using hollow block size units is seldom used. Foundation details generally are such to reduce the likelihood of cracking rather than reinforcing the wall to avoid cracks.

STRUCTURAL PERFORMANCE CRITERIA

Substructure (foundation) requirements

There has been a significant change in the last five years to reduce so-called defects in a house that arise from the original design i.e. patent defects.

"It is acknowledged that minor foundation movements occur on nearly all sites and that it is not possible to design a foundation that will economically protect buildings from movements under all circumstances. Accordingly this code of practice is aimed at the avoidance of significant damage provided that sites are properly maintained" (JSD, 1995).

The National Home Builders Registration Council in their structural warranty scheme accept damage that may occur in masonry walls associated with ground movement viz. fine internal cracks which can easily be treated during normal decoration, with cracks rarely visible in external masonry, crack width being less than 1 mm – isolated and localised (NHBRC, 1999).

However, in the case of single storey construction on sites as designated as being of poorer foundation support the level of expected damaged may be higher provided that this level of damage is stated clearly and unambiguously in the written contract with the purchaser.

In principle, foundations should be designed and constructed to transmit loads from superstructures and substructures to soil horizons safely and without causing excessive movements or distress in the elements they support.

The total settlement of a housing unit after completion should not exceed 20 mm and 10 mm for user performance levels 1 and 2 respectively.

Tilt in walls (and floors) should not exceed 1:100 to 1:200 for user performance levels 1 and 2 respectively.

In general, the level of expected damage is mainly of an aesthetic nature can easily be attended to in the course of normal redecoration.

Superstructure requirements

Superstructure walls should be designed and constructed to safely withstand any load which they are likely to be subjected to over the lifetime of the structure without impairing weather tightness and without distortion and distress (cracking and deflection).

Structural strength and stability

Housing units should withstand small or moderate intensity earthquakes without structural damage and with non-structural damage not more severe than associated with small differential ground movements (JSD, 2000).

Damage from winds associated with a 50-year occurrence interval should not cause damage to the inhabitants though the roof covering may blow off. With say intense thunderstorms the structure should not collapse.

Robustness (vulnerability to damage)

Walls are required to have a reasonable degree of resistance to damage from any impact that is likely to occur during construction and in normal everyday use. The impact could be the result of people colliding with walls or localised blows from sharp-edged objects such as furniture. Walls should also withstand door slamming and be able to support fixtures which homeowners wish to attach to such walls. Walls should also resist hail damage.

Walls should not collapse or be permanently deformed or displaced by more than 1/600th of their height or have cracks that cannot be readily repaired of aggregate length not exceeding 300 mm and width not wider than 0,5 mm when struck by a soft body having an impact as set out in Tables 2 and 3.

Note: Where it can be demonstrated by means of a rational design that a wall is capable of withstanding a horizontal concentrated force of 0,5kN acting normal to the wall surface over an area of 0,1 m x 0,1 m at any point at a height of 1,3 m above the floor level or a horizontal distributed force of 9,5 kN/m at a height of 1,3 m, whichever is the most severe, the wall may be deemed to have sufficient robustness and as such to satisfy the robustness requirements.

Table 2. User performance level 1 – Resistance levels of wall surfaces to soft body impact damage

Type of wall	Impact resistance energy levels (Joules)			
	Internal Walls (Impact from Inside@)		External Walls (Impact from Outside@)	
	Without causing appreciable cracking or permanent deformation	Without causing collapse	Without causing appreciable cracking or permanent deformation	Without causing collapse
Masonry or heavy weight construction	132	265	265	412
Light weight construction	132	265	265	412

Walls shall not be punctured nor, in the case of materials of a non-fibrous nature, be indented or locally displaced by more than 3 mm after two blows from sharp edged or pointed tools generating impact energies of 4,2 Joules in respect of User Performance Level 1 and the values tabulated in Table 4 in respect of User Performance Level 2. There must also be no readily visible cracks (i.e. wider than 0,25 mm) and their aggregate length must not exceed 300 mm.

Table 3. User performance level 2 – Resistance levels of wall surfaces to soft-body impact damage

<table>
<tr><td rowspan="3">Type of Wall</td><td colspan="4">Impact resistance energy levels (Joules)</td></tr>
<tr><td colspan="2">Internal walls other than those mentioned in column on the right.
External walls at ground floor level (impact from “inside”).
External walls at first floor and higher levels (impact from “outside”).</td><td colspan="2">Internal walls around lift shafts, stairwells, escape routes, load bearing internal walls.
External walls at first floor and higher levels (impact “inside).
External walls at ground floor level (impact from “outside”).</td></tr>
<tr><td>Without causing appreciable cracking or permanent deformation</td><td>Without causing collapse</td><td>Without causing appreciable cracking or permanent deformation</td><td>Without causing collapse</td></tr>
<tr><td>Masonry or heavy weight construction</td><td>176</td><td>412</td><td>265</td><td>530</td></tr>
<tr><td>Light weight construction</td><td>132
(framing)
88
(cladding)</td><td>265

265</td><td>265

265</td><td>412

412</td></tr>
</table>

Table 4. Resistance levels of wall surfaces to hard body impact damage (user performance level 2)

Type of Wall	Impact energy (Joules)
External walls	
- at ground level (impact from inside)	5.3
- at ground level (impact from outside)	7.9
- at first floor and higher levels (impact from inside)	5.3
- at first floor and higher levels (impact from outside)	7.9
Internal walls	
- non load bearing	5.3
- load bearing	7.9
- around lift shafts, escape routes	7.9

Walls shall be able to support the following fittings under the conditions stipulated:

- Lightweight fittings having a maximum loaded mass 8 kg, such as coat hooks, towel rails, notice boards and medicine cabinets, at any location within the wall;
- Medium weight fittings having a maximum loaded mass of 25 kg, such as hand basins, cisterns and medium sized cupboards, at designated locations within the wall.

The loosening and withdrawal of the fixing devices shall not cause more than minor, readily repairable damage to the wall.

Doors shall be attached to walls in such a manner that the slamming of a door will not cause damage to a wall or cause the frame to detach from the wall.

Walls of housing units located in areas where severe hailstorms are likely shall withstand a kinetic energy of not less than 10 ± 2 J.

CONCLUSION

The basic structural performance criteria for masonry in low cost housing have remained virtually unchanged over the last 50 years though they have been re-evaluated and re-assessed at regular intervals.

Essentially they are based on safety and health considerations in the generally benign climate of the country.

Hollow block size units mostly made of concrete are used extensively, the quality varying from those made in the modern urban based plants to those made on site in remote rural areas.

In the structural limit state design of highly stressed masonry walls the quality of the masonry products used, and the quality of workmanship is considered. For single storey low cost housing the criteria set out in this paper are accepted as satisfactory.

ANNEX A

Differences between user performance levels

Technical Aspect	Differences between user performance levels
Size and type of home	User Performance Level 1 housing units are restricted to those which have no basement, are of single storey construction, have floor areas of less than 80 m^2 and have a maximum length between intersecting walls or members providing lateral support of 6,0 metres.
Maintenance cycles	Housing units built in terms of User Performance Level 1 may require more frequent maintenance.
Earthquake	Nil
Windstorms	Nil
Deflection and deviation from the horizontal and vertical	User Performance Level 1 deflections and deviation from the horizontal and vertical are greater than those associated with User Performance Level 2 and may be visible/noticeable to a trained eye although structural performance and safety is not impaired.
Expected damage in walls and floors	The degree of expected damage will generally be greater where user Performance Level 1 is selected; such damage will nevertheless be of a minor nature and be repairable during the course of normal redecoration.
Behaviour in fire	Restrictions will be placed on the size and layout of the housing unit in the case where User Performance Level 1 is selected.
Severe condensation and consequential mould growth	No prohibition placed on the use of housing units with poor thermal performance in areas with high winter rainfall and humidity such as the southern Cape Condensation Problem areas, provided that it can be demonstrated that the housing unit is upgradeable to User Performance Level 2 without having to rebuild the structure[#].
Attack by biological agents	Nil
Abrasion resistance	Nil
Rising damp	Nil
Resistance of walls and roofs to rain penetration	Minor ingress may be experienced in infrequent major storms but not to the extent that any permanent damage may be caused[+].
Hail resistance	Where User Performance Level 1 is selected, elements other than normal glazing may be more susceptible to hail damage in severe hailstorms.
Resistance to local damage/soft body impact	The resistance to local damage when struck by sharp edged objects and the ability to hold fittings and the impact resistance to soft body impacts will be lower in the case of User Performance Level 1 than that for User Performance Level 2. The reduction in performance does not compromise the safety of the structure in any way under all normal circumstances of use.

Differences between user performance levels (continued)

Technical Aspect	Differences between user performance levels
Accuracy of construction	Tolerances will be greater (i.e. relaxed) in User Performance Level 1 housing.

Sufficient information must be provided to potential end-users so that they are aware of the severity of the indoor conditions that they might encounter and the steps they can take to upgrade the unit.

+ It is possible by means of surface coatings to upgrade a User Performance Level 1 housing unit to a User Performance Level 2 housing unit in this aspect.

ANNEX B

Sandbag impact test (soft body impacts)

The test is carried out on a representative wall specimen, approximately 4,0 m long and of storey height (see Figure B.1). The wall must include a standard door opening positioned between 300 mm and 450 mm from one end of the wall. The top and bottom of the wall are fixed and both ends supported as in practice; end returns may be provided for this purpose if necessary.

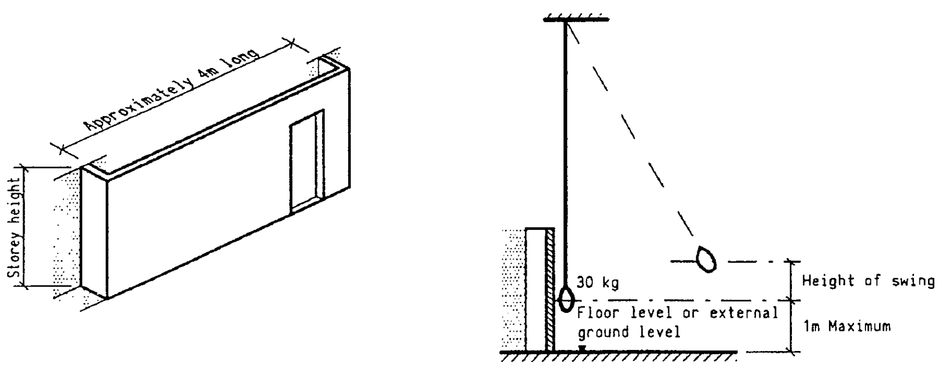

Figure B.1. Sandbag impact test

A 250 mm diameter leather or fabric bag containing 30 kg of sand is suspended by a rope from a convenient point above the top of the wall (see Figure B.1). The bag should touch the surface of the wall lightly and its centre of mass should be within 1000 mm above “floor level” or ground level, as appropriate for internal and external faces respectively, when it is hanging freely at rest. The bag may impact any other point deemed necessary by the evaluator.

The bag is drawn away pendulum fashion from the wall at right angles to the face of the wall until its centre of mass is at the required height of swing above its initial free hanging position. It is then released and allowed to swing pendulum-wise and strike the wall. Two impacts are made from each height of swing on each point tested.

When the test structure is of unframed construction, this operation is carried out as near as possible to a point midway in the length of the wall. It is also repeated near the end of the wall farthest from the door. If the wall is of framed construction, points of impact are chosen that are both between and on the line of the framing and joints (if applicable).

The height of swing that will provide the required level of impact energy is set out in Table B.1.

Table B.1. Height of swing in sandbag test required to simulate a range of impacts on walls

Height of swing (mm)	Impact (Joules)
300	88
450	132
600	176
900	265
1400	412
1800	530

ANNEX C

Steel Tool Test (hard-body impacts)

The test may be carried out on the same structure that is used for the sandbag test or a separate wall specimen at least 1,0 m wide. A 38 mm diameter steel impact tool with a mass of 1,8 kg, shaped like a chisel with a hardened edge 38 mm wide, rounded to a 2,5 mm radius and attached to a rigid pendulum which pivots in a metal frame is used (see Figure C.1).

The tool is positioned so that when it is hanging freely at rest the chisel edge lightly touches the surface of the wall with the tool’s long axis at right angles to the wall and the chisel edge horizontal. The tool is drawn away from the wall, pendulum fashion, until its centre of mass is at the required height of swing above its initial free-hanging position. The tool is released to swing back and strike the wall with the full width of its edge. Two impacts are made on each point tested from each height of swing.

If the wall is of framed construction, then the test is performed on the line of framing, close to, but not on the line of the framing, and midway between lines of the framing.

The height of swing that will provide the required level of energy to is set out in Table C.1

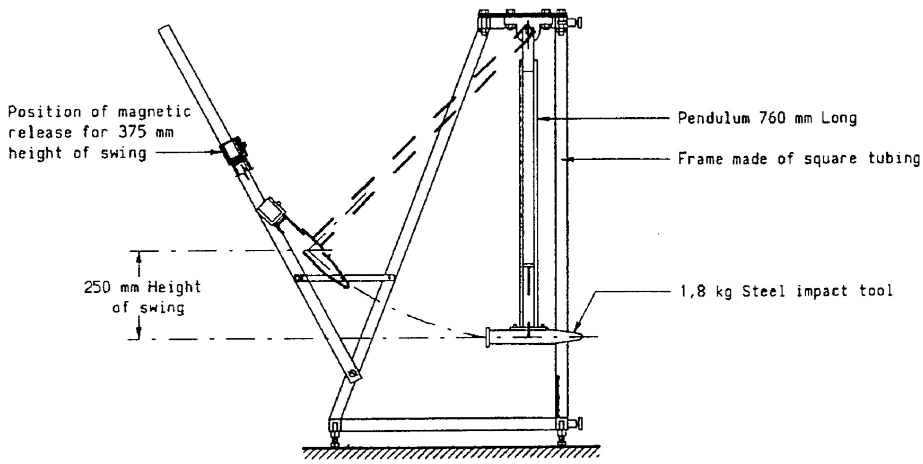

Figure C.1. Steel tool impact resistance test apparatus

Table C.1 Height of swing required in steel tool impact resistance test to simulate a range of impacts on walls

Height of swing (mm)	Impact (Joules)
200	4.2
250	5.3
375	7.9

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