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Structural assessment of dry-stack masonry building systems

Introduction

In recent years there has been a renewed interest in the dry-stack form of masonry construction for small buildings - mainly homes - due largely to the convenience and speed of erection possible with this form of construction and because of the possibility of creating a traditional masonry appearance in a system-built building.

This section sets out the criteria that apply to the structural assessment of masonry walling systems that are constructed by the dry-stack method.

The criteria given in this section are intended to ensure that buildings that meet all the criteria will be fit for purpose, safe and durable, from a structural point of view.

While solutions to constructional problems may be forthcoming from the testing and assessment work in the evaluation of a dry-stack building system, the tests are used to determine the capability of a system and are not done for the purpose of product development nor as an experimental design aid. Design solutions to construction and performance problems remain the responsibility of the applicant or certificate holder.

A full set of test procedures is described in this section, from which appropriate tests can be selected for the system to be evaluated. Note that although a large number of test procedures are described, it will rarely be necessary to execute all of them for the evaluation of any one system. It is assumed that the evaluator will be a competent professional engineer who will select those tests that are appropriate for the evaluation of a particular system.

Definition of dry-stack masonry

Dry-stack masonry construction refers to a method of building masonry walls in which most of the masonry units are laid without mortar in the joints, the units (usually) being stacked in a stretcher bond. The masonry units may be of brick or block proportions and may be nominally solid or hollow. The shape of the units usually incorporates geometry that provides an interlock between units when laid in a specified fashion. The building systems usually make it possible to incorporate steel reinforcement in concrete or mortar, forming column-like and beam-like in-fill to be cast within the standard wall thicknesses.

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Scope

The criteria detailed in this section apply to the following types of single storey buildings:

- residential structures such as detached houses, row houses and related outbuildings
- buildings for commercial use
- non-residential school buildings
- in-fill walling to framed structures.

In specific cases, where the capabilities of the building system allow, the scope may be extended to double storey buildings, at the discretion of Agrément South Africa.

This section addresses the following building performance areas:

- structural strength (resistance to all likely loadings)
- structural stability (under gravity and wind loading)
- in-service performance (resistance to door slamming and accidental loading).

The following aspects of the performance of buildings, which also need evaluation, are not addressed in this section:

- behaviour in fire
- acoustic performance (noise attenuation)
- thermal performance (indoor climate) and condensation
- weather-tightness
- durability
- ventilation and lighting
- protection against harmful substances.

Structural performance requirements

General performance requirements for buildings

Any building must be able to safely support the weight of its own components with an appropriate reserve of strength and stability.

In addition, any building must be capable of resisting likely additional gravity loads and other forces that are likely to impinge on the walls and roof the building, such as impact loads and wind loads - again, with sufficient reserve of strength and stability.

The criteria set out in this section relate to measures of building responses that can be used to assess whether the building performance, under the various load effects, is adequate.

Properties to be assessed for walls

The following properties of dry-stack walls will be assessed:

- vertical load-carrying capacity against both gravity and uplift forces
- horizontal load resistance against in-plane forces and forces transverse to the plane of the wall
- vertical load carrying capacity against both gravity and uplift forces

- horizontal load resistance against in-plane forces and forces transverse to the plane of the wall
- capacity to anchor the roof against uplift forces
- resistance to accidental loadings - soft-body and hard-body impacts
- load carrying capacity for fittings attached to walls
- resistance to the effects of door slamming forces
- strength of connections and interaction between internal and external walls and between roof and supporting walls

Evaluation methodology

The evaluation procedures and tests are intended to establish whether the general building requirements will be met and whether the performance meets the criteria set.

As in all Agrément evaluation work, where the assessment is not amenable to calculated responses, tests shall be carried out. The mechanical properties of walling constructed in dry-stack masonry are not amenable to mathematical analyses, nor can the material properties such as the compressive strength of masonry units be used to assess load-bearing capacity or flexural and shear strengths of walling. Thus testing is essential to correctly evaluate dry-stack walling systems - see the paragraph under General information: Wall strength versus unit strength.

It is the task of the evaluating agency to determine which of these tests would be relevant for the assessment of any particular system.

This section describes the various types of test in detail.

Where a system is to be used for one building layout only, subject to strict limitation in the certificate, it may not be necessary to do tests such as those on separate wall panels, if the test structure performance alone is likely to provide enough data for an assessment. Where a range of building plans are to be covered in the certificate, especially if some configurations are not defined specifically, then tests such as the horizontal load resistance determinations and racking tests will be needed for drawing up of essential design requirements.

Quality and characteristic material property measurement

There is a need for a standardised approach to determining strength and quality of production parameters that will be relevant for interlocking, sometimes hollow, brick and block masonry units that are used in dry-stacked masonry construction. None of the standard methods for testing bricks or blocks, known to the author, are suitable for the types of dry-stack masonry units with prominent interlocking features. There is thus a need for the development of an appropriate test or tests, that allow determination of relevant strength and shape parameters to be used as reference values by the assessor of a building system and as quality control tests by the manufacturer. It is envisaged that test specimens could be anything from a stack of three units to larger assemblies of more units.

Components of forces and test methods to assess the listed properties

Vertical (gravity) load-carrying capacity

Gravity forces comprise self-weight of wall, weight of roof and statutory superimposed design loads (to SABS 0160). Masonry walling of clay or cement bricks or blocks would generally have sufficient strength to support gravity loads by virtue of the relatively large cross-sections of such walling and tests are often not necessary. Where walls are slender or built of units with large voids, or of low-strength materials, a vertical load bearing test is essential. A sample length of wall would be subjected to vertical loading, representing the combined loads factored to specified overload levels, applied to the wall specimen in a fashion consistent with the system details. See Test 1.

Horizontal load resistance - wall spanning horizontally

Horizontal forces arising from wind effects usually constitute the controlling design case. Wind forces can be directed inwards or outwards on vertical faces of buildings, thus both directions of loading may be taken into account when applying horizontal loads to wall specimens. Depending on the configuration of door and window openings in external walls, the wall may be caused to span horizontally or vertically or both. The tests for assessing the wall properties are described separately. Test 2 on special wall specimens is a test of horizontal flexural resistance. The efficacy of ring-beam details or alternative structural solutions can be established and test data can assist in determining allowable room sizes.

Horizontal load resistance - wall spanning vertically

Sections of walling between openings have to span vertically between the lateral supports at the base and the top of the wall. This test is designed to assess the resistance of walling to transverse horizontal loading while spanning vertically. The capacities of the connection at the base of the wall to the foundation or floor slab and the connection at the top of the wall to the roof structure, in respect of resistance to horizontal forces is also tested. The test specimens and test procedure are described in Test 3. The capacity of the wall specimen to resist transverse horizontal forces combined with wind uplift acting on the roof is also tested.

In some cases, the horizontal line load case (SABS O160, reprinted in 1994, clause 5.4.5.2) may need to be considered, in which case Test 4 will apply.

Racking resistance of walls

The lateral stability of buildings is usually achieved by the mutually stabilising action of walls at right angles to each other. The wall oriented parallel to the destabilising force provides resistance in the plane of the wall, referred to as racking resistance. Racking resistance tests are required in some instances to assess the capacity of relatively short lengths of wall to provide the necessary resistance. Test 5 is designed to determine racking resistance as well as the behaviour of (internal to external) wall junctions. The tests can include assessment of racking resistance in combination with wind uplift from the roof.

Combined vertical and horizontal load components

The response of a building to wind loads (as defined in SABS 0160) involves the combined effect of gravity and wind loading. Test 6 on small structures (complete buildings or portions of buildings) is intended to examine a number of building responses to such combined loads. Test 6 generates lateral flexure of walls and in-plane racking, coupled with vertical uplift, from roof reactions. The applied loads will be to factored load levels for the serviceability limit state, as well as the ultimate load limit state.

These tests assist assessment of roof anchorage - see the paragraph below, cross-wall to external wall connections, gable end behaviour, influence of door and window openings, and bracing elements such as wind girders in the roof structure.

Horizontal load on door and window openings

Test 7 is intended to test the effectiveness of the connections between window and door frames and the walls when subjected to the effects of wind forces.

Roof anchorage

Roof geometries that give rise to uplift forces on the roof under wind effects, can result in roof reactions that require anchorage of the roof to the wall. Roof anchorage capacity may be controlled by the anchorage device or by the attachment to, or embedment in, the wall and will generally be assessed by the tests for combined vertical and horizontal load resistance discussed above. Separate tests would be executed if necessary.

Gable wall performance

The transverse flexure of a gable wall is frequently a problem area associated with the effectiveness of connections to the roof structure and to eaves walls as well as the effectiveness of eaves walls to provide racking resistance. Where these aspects are difficult to isolate in the tests on a complete test structure, an independent test of a gable may be warranted. Test 8 sets out details of the test specimen and test method.

Accidental loadings

For the purpose of Agrément evaluation, accidental loading has been limited to impacts from humans and small hard objects such as furniture, wheelbarrows and the like; vehicle impacts are excluded. Standard soft-body and hard-body impact tests will be applied to wall specimens. See Test 9 and Test 10.

Capacity to support the weight of fittings

Depending on the massiveness of the system, it may or may not be necessary to test this aspect. Standard mounting brackets would be used, with fixings specified by the designer of the building system, to test the resistance to gravity loads.

The relevant tests are described in the section Structural strength and stability. Effects of door slamming

Where deemed necessary, repeated opening and slamming of an ordinary door, by means of a dead-weight and pulley rig, would be used to simulate wind-driven door slamming occurrences. This test is described in the section Structural strength and stability.

Structural loading sequence and criteria for Agrément technical assessments

Standard loading sequence for Test 3 to Test 8

1. Apply 25 % of the service load. Release all load.
2. Set all deflection readings to zero.
3. Load to full service load in a minimum of three increments. Measure deflections and examine the test specimen at each increment. After reaching full service load, release all load.
4. Repeat the loading to full service load as above.
5. Load to full ultimate load in a minimum of five increments. Measure deflections and examine the test specimen at each increment. After reaching full ultimate load, release all load.

Performance criteria

Performance criteria for walls

1. The structure must resist all likely loads with well controlled deflections and an adequate reserve of strength. Deflections shall be deemed acceptable if the criteria at service load level, set out under 2, are met. The reserve of strength shall be deemed adequate, if after application of the test loads at ultimate load level, the structure, or any part of it, has not collapsed and criteria 3 and 4 are met.
2. Following the standard loading sequence, the deflection of walls under the second cycle of full service load shall not exceed the following:
    - 10 % more than the deflection under the first cycle
    - 25 % of the finished thickness of the wall.
3. The structure must remain stable during and after the action of any test load and the whole structural system must demonstrate ductile behaviour.
4. There shall be no separation between interdependent structural components as a result of application of the test loads.
5. Walls must be able to survive loads of the accidental category, with limited damage. The extent of cracking or permanent deformation must not be so extensive or severe that it cannot be adequately repaired with reasonable ease, or that it renders the building unsuitable for habitation.
6. Walls must be able to support doors and fixtures in a manner that will remain serviceable under all normal loading conditions. Performance shall be deemed acceptable if no cracking or permanent displacement of masonry units occurs on application of the prescribed test loads and the door frame or fixture-mounting bracket does not become loose or detached from the wall as a result of the application of test loads set out under Test loads for walls.

Performance criteria for buildings as a whole

1. Foundations as such are not normally evaluated because there are no generic solutions for foundations and they need to be designed for specific site conditions.

Any walling between foundations and the damp-proof course at floor level would have to function as retaining walls for the compacted fill under floors and must be capable of supporting the lateral earth pressure associated with the depth of fill.

2. All building configurations of the system as a whole must have the features of the successful test structure, to ensure ductile structural continuity under all likely loading conditions.
3. The structural system must have clearly identifiable load paths to transmit all forces acting on the structure to its foundations.
4. The structure must be sufficiently durable to perform adequately for a substantial period of time. External walls must resist normal weather effects, such as wind-driven rain. Tests of the material's physical, mechanical and chemical properties and the results of exposure tests, shall indicate that a life expectancy of 25 years or more is likely to be achieved.

This paragraph may properly belong under a different category of Agrément performance criteria and not under structural strength and stability, but has been included here because there is an overlap in the broad sense of stability.

Test loads for walls

All test loads on walls are based on the requirements of SABS 0160 in terms of load levels for the serviceability limit state, as well as the ultimate load limit state.

The test loads to be applied in evaluations are somewhat higher than the usual design loads, for the following reasons. The test structure is a single sample that has to represent a potentially large number of similar buildings. Those buildings will inevitably have structural properties differing to various degrees from that of the test structure: some of the buildings that are to be built will have structural properties that are not as good as the properties of the test structure, some may be better and, generally, most buildings will have properties similar to those of the test structure. To be conservative, therefore, it must be assumed that the test structure has structural properties that are better than the mean and that the condition of the test structure at the design load levels of interest for the typical structure will be reached at higher loads - see Statistics and variation of structural properties.

Since the statistics of the potential variations in the structural properties of dry-stack buildings will in general be unknown, the allowance that needs to be made will have to be arbitrary to a large extent. The allowances that have been proposed are based on experience of structural behaviour in general and are considered to be reasonable.

External walls and party walls

Uniform pressures over wall surfaces

The controlling load is usually the horizontal load arising from wind effects. The design value for free stream velocity pressure is 0,37 kPa, which is converted to an effective force per unit area by multiplying by an appropriate pressure coefficient.

The possible range of wind forces that can develop on the surfaces of a building is very wide and the combination of forces acting simultaneously on walls and roofs are very complex, depending upon the configuration of the building and wind direction relative to the building.

For the information of the evaluator, the process is illustrated by the content in Tables 1 and 2 which set out the pressure coefficients concerned. These coefficients would apply to small rectangular buildings with a pitched roof having a slope of 10 °.

Table 2 is the simplification in which coefficients less than 0,4 are regarded as insignificant.

The worst case loadings, to be applied in tests, are clearly those when the internal pressure coefficient Cpi is + 0,8.

Table 1: Wind load pressure coefficients Cp for a roof slope of 10 ° and the extreme internal pressure values only

Wind direction	Building element ww = windward lw = leeward	Square or near square plan, side ratios 1:1 to 1,5:1		Rectangular plan, side ratios 1,5:1 to 4:1, eaves longer than gable		Rectangular plan, side ratios 1,5:1 to 4:1, gable longer than eaves	
		Cpi = -0,3	Cpi = +0,8	Cpi = -0,3	Cpi = +0,8	Cpi = -0,3	Cpi = +0,8
Parallel to gables In the case of hipped roofs:- • eaves are walls perpendicular to wind direction • gables are walls parallel to wind direction	ww eave	+1,0	-0,1	+1,0	-0,1	+1,0	-0,1
	lw eave	+0,1	-1,0	+0,05	-1,05	+0,2	-0,9
	gables	-0,2	-1,3	-0,3	-1,4	-0,2	-1,3
	roof ww slope	-0,9	-2,0	-0,9	-2,0	-0,9	-2,0
	roof lw slope	-0,1	-1,2	-0,1	-1,2	-0,1	-1,2
Parallel to eaves	eaves	-0,2	-1,3	-0,2	-1,3	-0,3	-1,4
	ww gable	+1,0	-0,1	+1,0	-0,1	+1,0	-0,1
	lw gable	+0,2	-0,9	+0,2	-0,9	+0,05	-1,05
	roof ww edge	-0,5	-1,6	-0,5	-1,6	-0,5	-1,6
	roof lw edge	-0,3	-1,4	-0,3	-1,4	-0,3	-1,4

Notes:

For hipped roofs, the coefficients in the upper part of the table always apply. The side slopes have coefficients of -0,4 and -0,5 for the given Cpi values.

Cp = Cpe + Cpi (see SABS 0160)

Table 2: Condensation of Table 1 to simplified loadings only for any rectangular building: Wind loading pressure coefficients (Cp)

Wind direction	**Building element** **ww = windward** **lw = leeward**	**Cpi = -0,3**	**Cpi = +0,8**
Parallel to gables	ww eave	+1,0	0
	lw eave	0	-1,0
	gables	0	-1,4
	roof ww slope	-0,9	-2,0
	roof lw slope	-0,1	-1,2
Parallel to eaves	eaves	0	-1,4
	ww gable	+1,0	0
	lw gable	0	-1,0
	roof ww edge	-0,5	-1,6
	roof lw edge	-0,3	-1,4

Note: The interpretation of terms eaves and gables when the roof is a hipped roof, is the same as for Table 1.

The paragraphs above illustrate the range of force combinations that may need to be considered.

However, for purposes of assessment of building systems, only two greatly simplified sets of load combinations are used.

For the purpose of performance assessments, wind pressures are considered to act as uniform pressures over entire wall surfaces. The forces per unit area to be applied on the walls and roof of a test structure (see Test 6) are to be calculated as follows:

- at service load level P_{serv} = 0,37 x Cp x 1,2 kPa
- at ultimate load level P_{ult} = P_{serv} x 1,3 kPa

where Cp is the pressure coefficient applicable to the building element concerned as set out below.

Pressure coefficients for assessments of building elements

Load combination	Building element	Pressure coefficient (Cp)
1	Both eaves walls Leeward gable wall Roof - windward half Roof - leeward half	- 1,4 (outward force) - 1,0 (outward force) -1,6 (upward force) - 1,6 (upward force)
2	Leeward eaves wall Both gable walls Roof - windward eaves wall side Roof - leeward eaves walls side	- 1,0 (outward force) - 1,4 (outward force) - 2,0 (upward force) - 1,2 (upward force)

Thus, for example, the test loading on eaves walls in load combination 1 would be

- at service load level P_{serv} = 0,37 x 1,4 x 1,2 = 0,62 kN/m^2
- at ultimate load level P_{ult} = 0,62 x 1,3 = 0,81 kN/m^2

It is assumed that such pressure may be represented by an array of point loads applied to the test wall.

Concentrated or line loads

The need for applying the concentrated load or line load case as specified in SABS 0160, is to be investigated by calculation and if found to be significant the following loads would have to be applied:

- a line load at 1,3 metres above floor level (see Test 4) with the following test values:
  - service load of 600 N/m
  - ultimate load of 960 N/m.
- a point load normal to the surface acting over a 0,1 metre square, at any point 1,3 metre above floor level, or at a lower level if the system details are such that a more critical level exists below 1,3 m, with the following test values:
  - service load of 600 N
  - ultimate load of 960 N.

Internal walls

The same line and point loading as that for external walls applies to internal walls. Wind forces mostly do not apply, but where there is a dominant opening in an external wall, a wind load component of 0,2 kPa would be relevant for certain internal walls.

Impact tests and criteria for internal and external walls

The impact loadings to be applied are soft-body impacts from a 30 kg sandbag, generating impact energies between 132 joules and 412 joules and hard-body impacts from a 1,8 kg steel chisel impact tool, generating impact energies between 5 and 8 joules. The heights of swing of the pendulum apparatuses are detailed in the tables below together with the associated criteria.

Soft-body impact tests with a 30 kg sand bag

Wall location	**Serviceability test**		**Safety/strength test**	
	Height of swing (impact energy)	**Performance criterion**	**Height of swing** (impact energy)	**Performance criterion**
Internal walls and interior faces of external walls	450 mm (132 J)	Max crack width 0,3 mm Maximum transverse dis-placement of any unit 3 mm The extent of cracking or permanent deformation must not be so extensive or severe that it cannot be adequately repaired with reasonable ease or that it renders the building unsuitable for habitation	900 mm (265 J)	Wall may not collapse
Exterior faces of external walls	900 mm (265 J)		1 400 mm (412 J)	

At the serviceability level, the extent of cracking or permanent deformation must not be so extensive or severe that it cannot be adequately repaired with reasonable ease or that it renders the building unsuitable for habitation.

At the ultimate load level of impact, the wall must not collapse.

Steel tool impact tests with a 1,8 kg chisel impactor

Height of swing for internal and external walls (approximate impact energy)	
Internal walls other than loadbearing walls Interior face of external walls at ground floor level (impact from "inside")	Loadbearing internal walls Exterior face of external walls at ground floor level (impact from "outside")
250 mm (5,3 J)	375 mm (7,9 J)

The resistance of the wall to damage by the impact must be as follows:

- the wall surface must not be punctured nor must it be indented or locally displaced by more than 3 mm after two blows by the steel tool from the heights given above
- there must also be no readily visible cracks (ie wider than 0,25 mm) and their aggregate length must not exceed 300 mm.

Tests for the attachment of fittings and door slamming

Bracket loads and criteria for attachment of fittings to walls

The test loads for lightweight and mediumweight fittings that are not likely to be used by people to stand upon, are as follows:

- lightweight fittings such as coat hooks, towel rails, notice boards, medicine cabinets, to carry up to a maximum of 8 kg shall be loaded in two stages to a weight of 10 kg: 100 N
- mediumweight fittings such as hand basins and medium sized cupboards carrying between 8 kg and 20 kg shall be loaded in two stages to a weight of 25 kg: 250 N
- heavy-weight fittings that have a high probability of being used by people to stand upon, such as wash troughs, fire hose reels and geysers, shall be loaded to a test weight of 135 kg: 1350 N.

No block or brick may be dislodged by more than 1 mm, nor may the overall change in flatness of the wall be more than 1/1500 of the height of the wall. Further, the lateral deflection of the wall on completion of the test must be limited such that the overall deviation from plane does not exceed 1/800 of the height of the wall.

Criteria for resistance to door slamming

Walls in buildings are required to withstand, without damage, the slamming of doors that can occur in everyday use. In addition, door frames are required to be built-in in a manner that will prevent them from becoming loose or detached from the wall when the door slams.

General information

In the assessment of dry-stack building systems, it is important that the evaluating agency take into account a number of characteristics that are peculiar to dry-stack walling.

Key features of dry-stack systems

The precision of the shape of masonry units and the uniformity of size is very much more important for dry stack laying than it is in mortar bedded masonry, for obvious reasons. What is not so obvious is that a dry-stacked wall, which may look much like a conventional mortar-jointed wall, does not have the same mechanical properties: it has no real tensile strength, being made up of discrete units that can only transfer forces in compression or by friction.

Interlocking brick or block shapes can prevent large relative displacement between units and thereby maintain sufficient integrity for an assembly to act as a structural entity, provided the edges are protected or restrained, by elements such as the foundation at the base, an anchored wall plate or ring-beam at the top and bonded masonry or other continuous elements at the sides.

Wall strength versus unit strength

The designer of any masonry wall serving a structural purpose should be aware that the compressive strength of a masonry unit (brick or block) does not give a direct indication of the potential strength of walling built from the units, because the presence and the nature of the joints between the masonry units have an overriding effect on wall strength. Masonry wall strength is also influenced by the shape and size of the units (and in the case of conventional masonry also by the mortar properties). For these reasons, it is necessary to establish the properties of new forms of masonry by testing wall specimens.

The need for compressive strength testing of individual units remains, because the manufacturer needs a quality control procedure. Compressive strength tests on interlocking types of masonry unit are difficult unless there are matching units that can be stack-bonded with mortar joints, to present a specimen, three units tall, with a flat base and flat top, so that it can be used as a test specimen (to be tested in a regular compression testing machine).

External walls in dry-stack systems

All of the dry-stack systems examined thus far have been moderately heavy to heavyweight systems that have been capable of supporting vertical loads. All systems have had some treatment of the uppermost courses to create what has been termed a ring-beam in conventional blockwork construction. Most dry-stack systems have incorporated mortar or concrete filled vertical cores that have been reinforced with steel rod reinforcement and located at corners and on either side of openings.

Such common practices have developed in order to provide the containment of the dry-stacked units and make it possible for such systems to function as safe load-bearing walls. The depth of ring-beam required over openings in load-bearing walls will be dictated by the width of opening and the superimposed loading thereon.

Internal walls in dry-stack systems

Horizontal strengthening along the top of the internal wall, similar to a ring-beam, is required, to enable internal walls to act in a racking mode, for the purpose of providing lateral stability to the external walls. This is because diagonal forces can only be transmitted in compression through the dry-stacked masonry and in order to stabilise an external wall against outward displacement, it is necessary to transfer the tensile reaction at the top of the wall to the far side of the internal wall.

The ring-beam is also required to bridge door openings and, where a wall is load-bearing and has openings greater than 1 metre in width a double beam may be required over the openings, in order to serve as a lintel. Such beams should extend beyond the opening to half the width of the opening, on either side.

In some systems, vertical filled cores may be required as for external walls.

Interaction between roof structure and walls

Building systems may include the roof structure as part of the structural assembly.

The purpose of doing so would normally be to provide lateral stability to the tops of external walls by providing a suitable roof construction that is properly attached to the walls and which can provide restraint and support at the tops of walls, including gable ends (if any), so that the entire building can act as a unit, having competent load paths to direct the combined vertical and horizontal components of all forces to the foundations.

The ability of walls to withstand horizontal loads and direct them to the (non-brittle) elements that frame them, will remain a requirement.

Double-storey construction

A reinforced concrete first floor would be an excellent diaphragm to provide lateral bracing to the tops of the ground floor walls to assist in transferring horizontal components of force into cross-walls, but racking stiffness of internal and external cross-walls would have to be adequate under the considerably increased horizontal wind loading.

Wind loads on the first floor and roof would be calculated according to the height of the apex of that storey above ground and the shape of the building, using the wind load rules in SABS 0160. Tests would have to be carried out on a test structure representative of the intended building configurations to be covered in the certificate. Combined gravity and wind loading would be applied up to the design ultimate load level, factored to account for statistical variations in strength.

The potential behaviour under seismic load conditions would have to be considered.

Description of tests

Test 1: Vertical load-bearing capacity of walls

Three wall specimens, each with a length of 0,4 to 1,8 metres are required, depending on the planned proximity of adjacent openings and to suit multiples of the masonry unit size. These specimens, of eaves wall height, are built on concrete base pieces, either on a laboratory test floor, or on the transverse beam of an appropriate compression testing machine.

A line load is applied to the top of the wall specimen, offset from the mid-plane position so that an eccentricity exists consistent with the roof to wall connection detail.

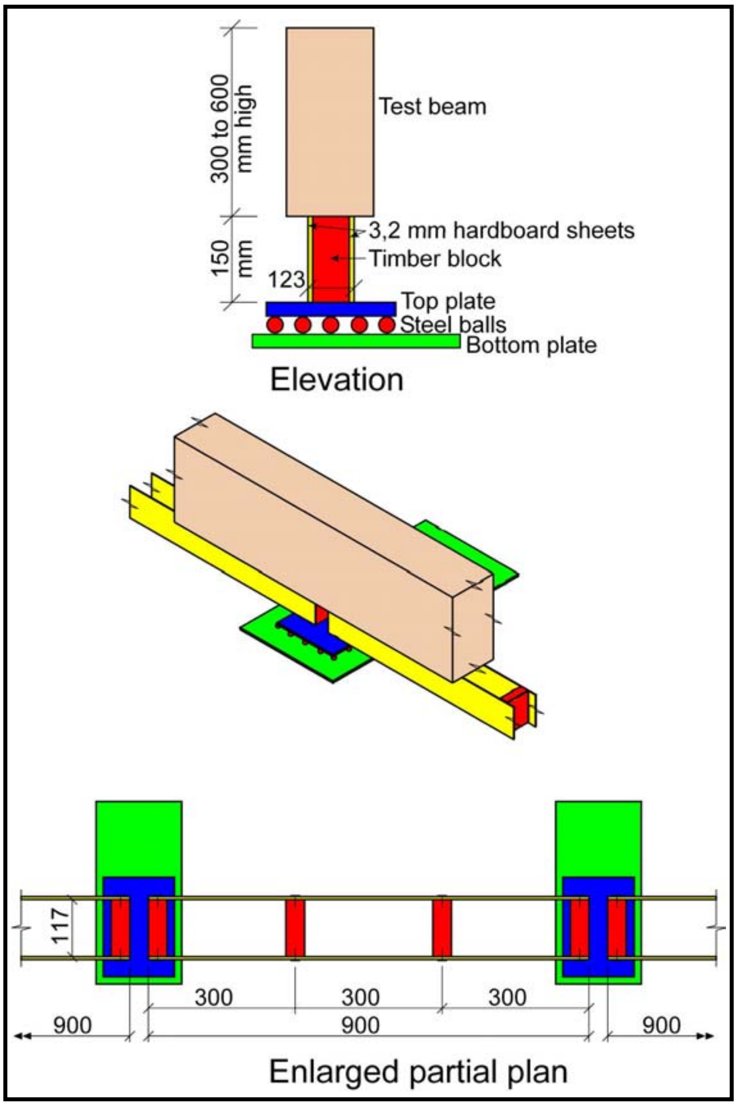
Load is applied initially in 1 kN increments and the vertical displacement of the loading plate is recorded as well as the horizontal displacement of the wall at mid-height. The increments may be increased to 2 kN or larger intervals if the wall is found to resist more than 10 kN per metre run before failure, recording the vertical and horizontal displacements of the wall at each increment. A total of at least 5 load increments between zero and maximum load is required to obtain sufficient data.

As discussed in General information, it is important to recognise that knowledge of the compressive strength of the masonry unit itself does not provide a direct indication of the compressive strength of walling built with those units. However, the compressive strength of the brick or block would be an important quality control indicator for the assessor and the manufacturer and should be determined as a reference parameter in all evaluations, as a companion test to Test 1.

In the case of interlocking units it would be necessary to devise a special test specimen that could be used as a standard for the particular unit.

Test 2: Transverse flexure of walls

The test is designed to assess the ability of the external walling above top of window/door level to resist horizontal wind load by spanning horizontally between supporting cross-walls and/or external walls. Note that this walling provides horizontal support to the walling below itself and above itself.

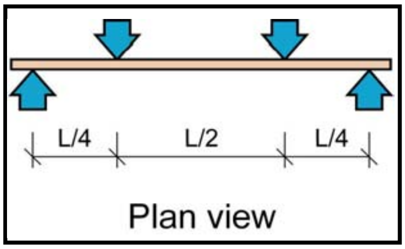


Two identical test beams are required, each beam being long enough to represent the maximum intended span between cross-walls. The height of the beams should represent the construction of the external walling above top of window/door level and below minimum wall plate level. Typically the height of the beams is between 300 mm and 600 mm.

The test beams are to built in a structural laboratory, on special short beams and bearings. The purpose of the these short beams and bearings is to provide vertical support to the test beams while providing only negligible horizontal support. The short beams span from bearing to bearing. Each bearing consists of two smooth steel plates, separated by a minimum of eight 13 mm diameter steel balls. The lower plate of each bearing rests directly on the laboratory floor. The bearings are spaced 900 mm apart. Each short beam typically consists of two sheets of 3,2 mm thick hardboard, 900 mm long x 150 mm wide. The two sheets of hardboard are each stood on edge, with their 150 mm sides vertical.

The spacing of these two sheets is such as to provide vertical support to the units making up the test beams. The two sheets of hardboard are held apart by suitable short pieces of timber (for example if the sheets of hardboard are to be 120 mm apart, use 114 x 38 timber cut into 117 mm lengths). The assembly is nailed together.

Horizontal support is provided at each end of the test beams, representing cross walls at their maximum intended spacing.



Two tension loads are applied simultaneously to the test beam at one-quarter span and at three-quarter span.

The recommended application of the test load is to drill a hole through the test beam at each position. A threaded rod is passed through each of these holes and fastened to a 300 mm to 600 mm long timber spreader beam (orientated vertically).

Each threaded rod is connected to a tension jack and a load cell.

The required test load should be calculated prior to the commencement of the test, using the test loadings derived from the table under Test loads for walls and the calculation procedures discussed in the Supplementary Notes at the end of the section Structural strength and stability.

During the test every effort should be made to ensure that the bearing plates are offering negligible resistance to the horizontal displacement of the beam. A means of ensuring this is to continually tap the plates with a hammer during the test.

Loading is applied in two stages. In the first stage the load is applied in a minimum of two increments up to half of the service load level of wind load. Horizontal displacements at mid-span are recorded at each load increment. The applied load is then removed and the displacements again recorded. The maximum acceptable displacement at mid-span for this load level is the lesser of span/200 or 15 % of the wall thickness.

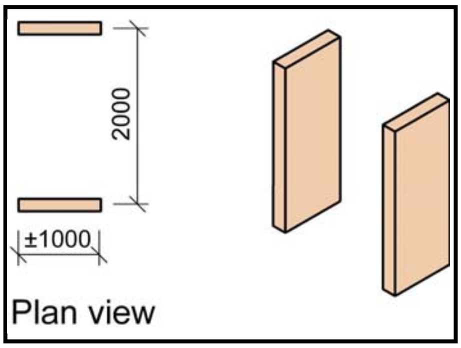
The load is then re-applied in a minimum of four increments up to the full service load level and the mid-span displacement recorded. The maximum acceptable displacement at mid-span at this level is span/150. On removal of the horizontal load the wall is required to show at least a 50 % recovery towards its original shape.

Finally, the horizontal loading is re-applied in increments up to the nominal ultimate load level. The wall is required to resist this loading without collapse.

Where the form of construction links opposite external walls in a structurally effective manner, the resistance to horizontal loading can be shared between such walls. In this case, the test loads can be reduced to 60 % of the above values.

Test 3: Horizontal load resistance - vertical spanning

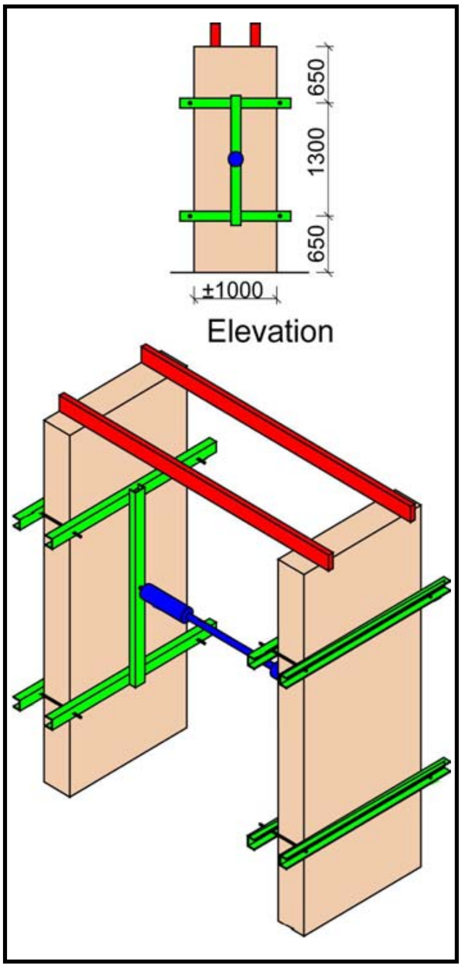
Two sample panels are required, each about 1000 mm long and built to the maximum required eaves height (usually about 2700 mm)



The panels are to be built outside, on their own foundations/floor slab, using the layout shown below.

Note that these two wall panels must be built on the same level.

The two wall panels should be provided with two 114 x 38 mm planks, each 3600 mm long, fastened to the top of the wall panels in exactly the same manner and spacing as roof trusses or rafters would be attached to the top of eaves walls according to the building system specification. The



top of the wall, between the timbers, is to be finished with beam filling.

The test load on each wall panel is applied as two horizontal line loads, loading each wall of the pair simultaneously. The recommended application of the test load is via an H-shaped spreader beam as shown below.

The positions above floor level of the line loads are 25 % and 75 % of the distance between floor level and underside of wall plate level. The line loads should be applied across at least 80 % of the length of the wall.

A compression jack and a load cell are attached to the centre of the H spreader beam on each specimen.

The required test load should be calculated prior to commencement of the test, using the pressure coefficients given in the table in Test loads for walls and the calculation procedures given under the heading Supplementary Notes at the end of the section Structural strength and stability.

After the wall panels have successfully withstood the required outward horizontal load, the outward horizontal load should be reapplied and held and then simultaneously an upward force should be applied to the timbers to simulate the required net uplift load resulting from wind uplift on the roof less the minimum selfweight of the roof.

If one wall panel can take no more load, prematurely, it should be propped using an adjustable prop and the test should be continued until the second wall being tested reaches its test load, or fails.

Test 4: Horizontal line load resistance

For this test, a part of the test structure described in Test 6 may be used or a length of walling with short returns at each end may be built to the dimensions of the largest room size intended. This wall specimen must contain a door opening as well as the largest intended window opening.

A horizontal line load is to be applied at a height of 1,3 metres, or at a lower level if this is likely to be more critical, by means of an articulated load spreading rig. Loads are to be applied in at least 5 increments between zero and 960 N/metre (factored ultimate load) and the condition of the wall and mid-span horizontal displacement must be observed at each load level.

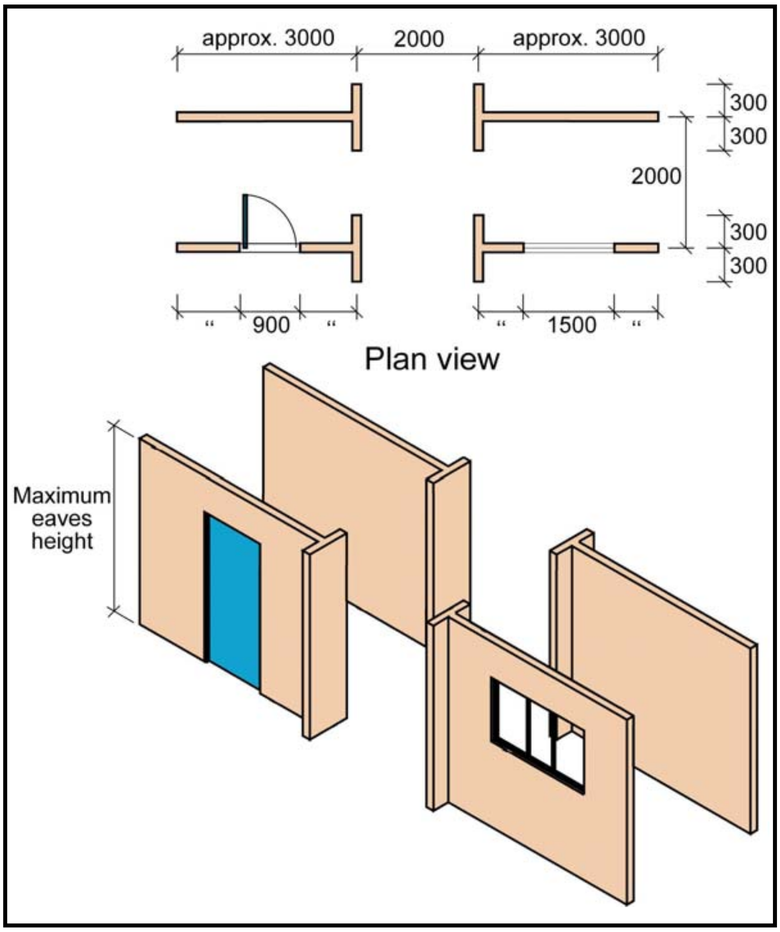
The loads are taken from SABS 0160 (reprinted in 1994), clause 5.4.5.2:

- service load of 500 N/m x 1,2 = 600 N/m
- ultimate load of 600 N/m x 1,6 = 960 N/m

Test 5: Racking load resistance

Where specific data are required on the racking resistance of walling systems, for the purpose of drawing up essential design requirements, a set of four or more specimens are required conforming to the following details.

Specimens have a T-shape in plan as indicated in the diagram. The wall to be tested for racking resistance forms the stem of the T. The specimen represents a junction between two walls, usually



an internal and external wall junction. These junctions must be built according to the system specifications. The height of the wall panels must be the minimum eaves height intended for the system (often about 2 400 mm).

Two plain wall panels, about 3 000 mm long and built to minimum eaves height intended for the system. One wall panel (3 000 mm x 2 400 mm) with a 1 500 mm wide x 1 200 mm deep window. The window opening shall be placed centrally in the length of the panel and at a height above the base consistent with the system details. (If larger windows are required by the applicant, the size of the panel should be reconsidered to accommodate the larger opening.)

One wall panel with a standard door opening, nominally 900 mm wide x 2000 mm high. The door opening shall be placed centrally in the length of the panel.

If the internal walls are of a different construction and/or thickness to the external walls, two plain wall panels, about 2 000 mm long, are required. A pair of opposing specimens is required for each thickness or form of construction of walling that provides lateral stability to another wall.

The panels are to built outside, on their own foundations/floor slab, using the orientation shown, all built at the same level.

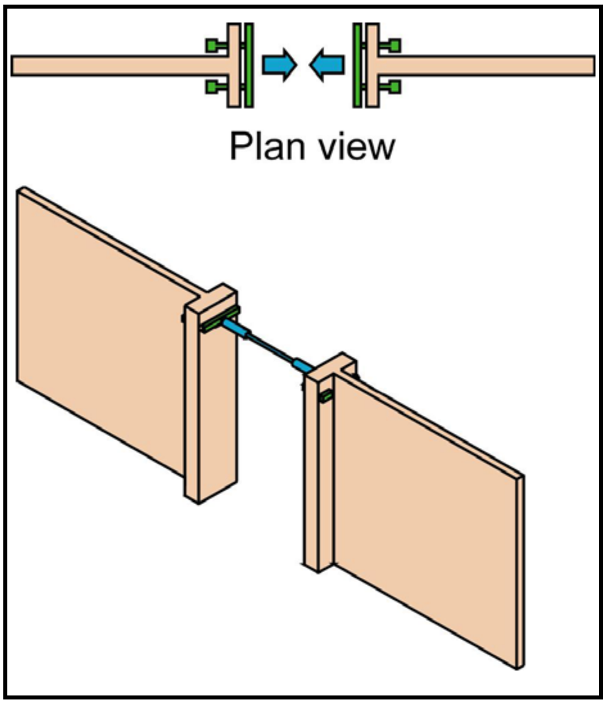
If six panels are required, the additional pair of panels should be built 2000 mm from the above four panels and in line with each other.

Each pair of wall panels should be provided with a minimum of four 114 x 38 mm planks, each 3 600 mm long, fastened to the top of the wall panels in exactly the same manner and spacing as roof trusses or rafters would be attached to the top of eaves walls as per the building system's specification. The top of the wall, between the timbers, is to be finished with beam filling.

Two wall panels are tested simultaneously by pulling from one panel to the other by means of a simple rig.

The required test load should be calculated prior to the commencement of the test, using the pressure coefficients given in the Table under Test loads for walls and the calculation procedures given under the heading Supplementary Notes at the end of the section Structural strength and stability.

The recommended assembly of the test rig is to drill a hole in each of the arms of the Ts at about 200 mm from the centre of the test wall. A threaded rod is passed through each of these holes and fastened to a 300 mm long timber spreader beam (orientated vertically). The two threaded rods of each panel's T are connected to a 600 mm long horizontal spreader beam and a tension jack and a load cell are attached to the centre of the 600 mm long spreader beam.



The rig is fitted at a height midway between the top of the window/door level and the underside of the wall plate level.

After the wall panels have successfully withstood the required racking load, the racking load should be reapplied and held and then simultaneously an upward force should be applied to the timbers to simulate the required net uplift load resulting from wind uplift on the roof less the minimum selfweight of the roof.

After the wall panels have successfully withstood the combined racking load and uplift load, both the racking load and the uplift load should be reapplied and held and then simultaneously a horizontal outward force should be applied at about 100 mm from the bottom of the walls, via a spreader beam on each wall, to simulate the required outward load resulting from wind suction on the walls. If one wall panel can take no more load, prematurely, it should be propped using an adjustable prop or stayed back to the ground and the test continued until the second wall being tested reaches its test load or fails.

Test 6: Response of buildings to simulated wind loading

The response of walling to the combined effect of horizontal wind forces and wind uplift forces is particularly significant for dry-stack systems, because all of the potentially weak features of such systems are brought into play simultaneously. The strength of walling in transverse flexure, racking strength and stiffness and the resistance to roof uplift, as well as the effectiveness of internal wall to external wall connections and roof to wall connections are tested simultaneously.

The test structure is usually a complete building, if the type of structure to be covered by a certificate is a small dwelling or similar building. When larger buildings are to be certified, the test structure is generally part of a building. In both cases, the test structure has to include the largest room size and largest window and door opening size planned to be covered in the certificate. If the design of the building includes gable ends, then one of the walls of the test building must be a gable end. The location of door and window openings in the wall that is to be tested under simulated wind suction must represent the most vulnerable arrangement that is intended to be covered in the certificate.

For designs in which opposite external walls are made to function in tandem (for example, the roof structure links opposite external walls together, so that horizontal loads are shared between those walls) it may be necessary to execute horizontal loading tests in the direction of each orthogonal axis of the building. External walls that act together may be tested as well as walls that have to act independently.

The test loading is designed to represent the wind forces on the walls of the building as well as uplift on the roof, for buildings with shallow roof slopes, according to the procedures in SABS 0160. Loads have to be calculated for the specific size of the test building, representing the most severe loadings that can occur.

The forces to be applied in the test are calculated from the relationship:

Force on a specified area of an element = P x area of element x statistical factor where

- test pressure P = free stream velocity pressure x pressure coefficient Cp
- Cp = external pressure coefficient Cpe + internal pressure coefficient Cpi (see SABS 0160 procedure)
- statistical factor is discussed in Statistics and variation of structural properties.

For practical reasons it is necessary to limit the number of load cases that have to be simulated, even though many significant variations are possible. The approach adopted has been to simplify the complex wind load possibilities by eliminating all but the "worst case" loads.

Forces are applied by means of mechanical and hydraulic jacks acting via cables or struts and load spreading rigs that simulate distributed loads by an array of point loads.

Displacement measuring devices such as dial gauges or electronic displacement transducers are to be used to monitor:

- horizontal displacement of the walling
  - at eaves level
  - at the apex of gable walls
- vertical displacement of the roof structure relative to the top of the eaves walls.

The loading is to be applied in a minimum of five increments up to the ultimate load level and all displacements monitored at each load level. Careful observations of the condition of the walls are to be made, including cross-wall to external wall junctions, to detect crack development or separation between masonry units.

When testing the test structure as a whole, loading points are not to be directly onto window frames or door frames. The resistance of window frames and door frames to outward pressures are tested separately as described in Test 7 by applying outward forces directly onto the frames, following the same incremental load procedures as used for testing the walls. The structure must be examined for displacement, loosening or detachment of the frames from the walls at each load level.

Test 7: Horizontal load on doors and windows and their immediate surround

The tests are designed to assess the ability of the windows and doors and their connections to the walls to resist horizontal (out of plane) loads. When performing this test it is important that separate loads should be applied to those parts of the walls immediately below and immediately above the window or door.

One door should be tested and one window; preferably the largest window which the applicant wishes to use should be tested. The specimens used for racking tests, containing a door and containing a window may be used for this test, or parts of the test structure may be used.

The direction of the test load should be decided by the assessor after consideration of which direction is likely to be the weaker. Usually, because of water sealing requirements, this is the outward direction.

The required test load should be calculated prior to commencing the test, using the pressure coefficients given in the table under Test loads for walls and the calculation procedures given under the heading Supplementary Notes at the end of the section Structural strength and stability.

Test 8: Transverse flexure of gable wall

Gable wall test (without roof)

The test is designed to assess:

- the ability of the gable wall to resist direct wind loading
- the ability of the side walls to resist racking
- the ability of the corner connections between the gable wall and the two side walls to transmit the forces causing the racking
- the ability of the connection between the foundation/floor slab and the wall panels to transmit horizontal load into the foundations.

Gable wall test (with roof)

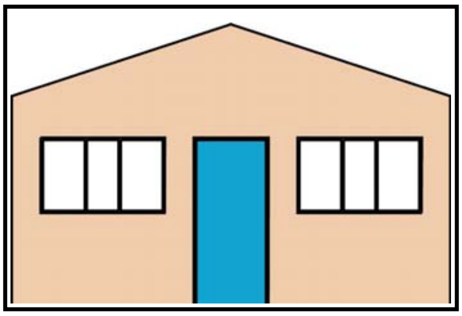
If it is a principle of the building system that the gable wall should be attached to the roof and that the roof should provide horizontal support to the gable wall, then the gable test wall should be provided with a roof.

In such a case, the test is also designed to assess the following in addition to the preceding:

- the ability of the connection of the gable wall to the roof to transmit horizontal loads
- the ability of the roof to transmit horizontal loads horizontally to the eaves walls
- the ability of the connections of the roof to the eaves walls to transmit these horizontal loads.

In some circumstances it may also be possible to use this test to assess the ability of the connection of the roof to the eaves walls to transmit wind uplift forces.

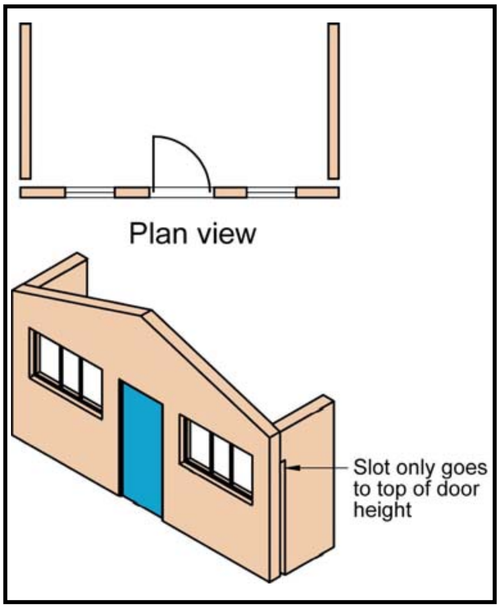
Gable wall for test purposes



The gable wall should represent that layout of windows and doors which results in the weakest possible gable wall.

A symmetrical layout consisting of a door in the middle of the gable wall, flanked by two windows on either side of the door is suggested. The length of the two eaves walls stabilizing the gable wall is a function of the weight of these walls. This length should be calculated. Typically, for heavy weight walling, and a 6,0 m wide gable, the eaves walls need to be between 2 m and 2,5 m long.

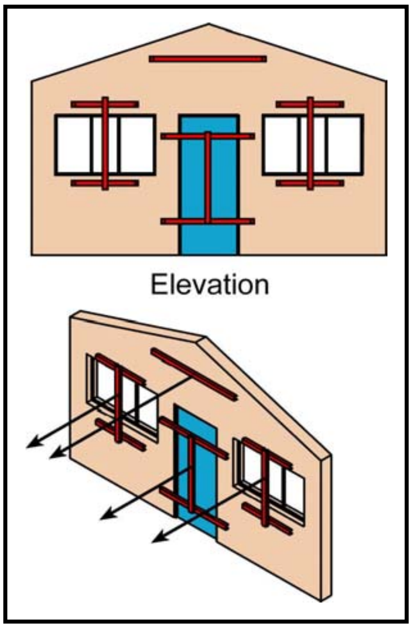
Each eaves wall should be provided with a 50 mm wide x 2050 mm slot next to the corner with the gable wall. This slot is intended to simulate a door opening in the eaves wall. See the plan view of



gable wall and eaves walls in the figure. The top of the eaves walls should be built exactly as it would be in the actual building system, complete with wall plates, beam infilling and/or slots for the roof trusses.

The test loading is 14 to 18 tension loads each applied simultaneously to the gable wall. The positions and amounts of each tension load is such as to simulate the uniformly distributed wind load on the entire gable wall, but at the same time taking account of the positions of windows and doors in the gable wall.

The centroid of the test loading must be the same as the centroid of the uniformly distributed wind load on the entire gable wall. The recommended application of the test loads is to drill holes through the gable wall. A threaded rod is passed through each of these holes and fastened to a 600 mm long timber spreader beam on the inside of the gable wall (usually orientated vertically). Each set of four threaded rods is connected to an adjustable H-spreader.



A tension jack and a load cell are attached to the centre of each of the H-spreaders.

A 6 m wide gable wall of typical heights requires a total test loading of about 15 kN applied with a centroid about 1,6 m above floor level of the gable wall. In order to provide a suitable reaction for such a loading a purpose made steel rig mounted and bolted on a 5 ton flat-bed lorry has been used.

The required test load should be calculated prior to the test, using the test loadings derived from the table under Test loads for walls and the calculation procedures discussed under the heading Supplementary Notes at the end of the section Structural strength and stability.

Horizontal displacements at mid-wall, directly above the door and at the apex are recorded.

Test 9: Soft-body impact test

The soft-body impact test normally carried out on walls is described in the section Structural strength and stability.

The test is carried out on a representative wall, either in an existing building or test structure, or on a specimen, approximately 4,0 m long and of storey height. The test wall should preferably 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. (This same test specimen can often also be used for the steel tool impact test and for the tests for the attachment of fittings to walls, depending of the amount of damage that results from the preceding tests)

The test 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.

Sometimes two different heights of swing are used for the bag - a lower one from which two blows must not cause any unacceptable cracking or permanent deformation in a wall (serviceability criterion), and a higher one from which two blows must not cause collapse of a wall (safety criterion).

Test 10: Steel tool impact test (hard-body impact test)

The steel tool impact test normally carried out on walls is described in the section Structural strength and stability.

Tests for attachment of fittings and door slamming

Tests for attachment of fittings and the door slamming test are described in the section Structural strength and stability.

Statistics and variation of structural properties

Because the building process for creating masonry structures is prone to much variation, both in the mechanical properties of the masonry units and in the control of construction on site, masonry buildings vary greatly in their structural properties, even though they are nominally similar structures. Since it is impractical to test more than one structure in the evaluation of a building system, there is a difficulty in extrapolating the test results to indicate what the structural performance of any other nominally similar building might be.

The actual structural properties of a large number of similar buildings will vary between a low performance level and a high performance level and properties of the the test structure will lie somewhere between these extremes.

When the statistics of variation of a variable are known, there are established methods of dealing with the problem. A widely accepted concept is that of the characteristic value which is a value below the mean usually chosen to be that value below which not more than 5 % of all results are likely to lie (when the distribution of values is Gaussian, then this level is at 1,645 standard deviations below the mean).

Where the mean value and the standard deviation are not known, it is not possible to determine a characteristic value, but the notion of the characteristic value can be utilised. The broad principles of these statistical considerations need to be exploited in order to make use of results of a single test to assess the probable properties of the poorest acceptable building. The main points that have to be considered are: What is the distribution of these properties like? Where does the test structure lie within this distribution (above, below or near the mean) and how far below the mean does the characteristic lie?

In order to be conservative, it must be assumed that the test structure properties are likely to be better than the mean. The characteristic structural performance is by definition below the mean. In this case, the single test structure, having properties above the mean, would need to be loaded to a higher level than would be used in the normal design calculations for such a structure, because normal design calculations are for the characteristic structure. The performance criteria for the test structure are therefore set 20 % higher than the usual design equivalents. It is only in this way that one can ensure that the average and less than average building that is likely to be constructed, will have a satisfactory performance.

Acknowledgement

This section of the Agrément performance criteria is largely based on work done for Agrément South Africa by

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Certain parts were carried over from earlier publications of the Agrément performance criteria.

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