SABS

**DRAFT SOUTH AFRICAN STANDARD (DSS):
PUBLIC ENQUIRY STAGE**

| | | | |
|---|---|---|---|
| **Document number** | SANS 10160-4 | | |
| **Reference** | 7114/10160-4/DL | | |
| **Date of circulation** | 2009-10-13 | **Closing date** | 2009-12-15 |

**Number and title:**
SANS 10160-4: BASIS OF STRUCTURAL DESIGN AND ACTIONS FOR BUILDINGS AND INDUSTRIAL STRUCTURES — PART 4: SEISMIC ACTIONS AND GENERAL REQUIREMENTS FOR BUILDING

**Remarks:**

**PLEASE NOTE:**

- **The technical committee, SABS SC 59I responsible for the preparation of this standard has reached consensus that the attached document should become a South African standard. It is now made available by way of public enquiry to all interested and affected parties for public comment, and to the technical committee members for record purposes. Any comments should be sent by the indicated closing date, either by mail, or by fax, or by e-mail to**

  **SABS Standards Division**
  **Attention: Compliance and Development department**
  **Private Bag X191**
  **Pretoria**
  **0001**

  **Fax No.: (012) 344-1568 (for attention: dsscomments)**
  **E-mail: dsscomments@sabs.co.za**

  **Any comment on the draft must contain in its heading the number of the clause/subclause to which it refers. A comment shall be well motivated and, where applicable, contain the proposed amended text.**

- **The public enquiry stage will be repeated if the technical committee agrees to significant technical changes to the document as a result of public comment. Less urgent technical comments will be considered at the time of the next amendment.**

THIS DOCUMENT IS A DRAFT CIRCULATED FOR PUBLIC COMMENT. IT MAY NOT BE REFERRED TO AS A SOUTH AFRICAN STANDARD UNTIL PUBLISHED AS SUCH.

IN ADDITION TO THEIR EVALUATION AS BEING ACCEPTABLE FOR INDUSTRIAL, TECHNOLOGICAL, COMMERCIAL AND USER PURPOSES, DRAFT SOUTH AFRICAN STANDARDS MAY ON OCCASION HAVE TO BE CONSIDERED IN THE LIGHT OF THEIR POTENTIAL TO BECOME STANDARDS TO WHICH REFERENCE MAY BE MADE IN LAW.

ISBN 978-0-626-

**SANS 10160-4:2009**

Edition 1

# SOUTH AFRICAN NATIONAL STANDARD

# Basis of structural design and actions for buildings and industrial structures

# Part 4: Seismic actions and general requirements for building



**Published by SABS Standards Division**
**1 Dr Lategan Road Groenkloof ⌧ Private Bag X191 Pretoria 0001**
**Tel: +27 12 428 7911 Fax: +27 12 344 1568**
**www.sabs.co.za**

**SANS 10160-4:2009**
Edition 1

**Table of changes**

| Change No. | Date | Scope |
|---|---|---|
| | | |

## Foreword

This South African standard was approved by National Committee SABS SC 59I, *Construction standards – Basis for the design of structures*, in accordance with procedures of the SABS Standards Division, in compliance with annex 3 of the WTO/TBT agreement.

This edition cancels and replaces the second edition (SABS 0160:1989).

SANS 10160 consists of the following eight parts, under the general title *Basis of structural design and actions for buildings and industrial structures*:

SANS 10160-1, *Basis of structural design*

SANS 10160-2, *Self-weight and imposed loads*

SANS 10160-3, *Wind actions*

SANS 10160-4, *Seismic actions and general requirements for buildings*

SANS 10160-5, *Basis of geotechnical design and actions*

SANS 10160-6, *Actions induced by cranes and machinery*

SANS 10160-7, *Thermal actions*

SANS 10160-8, *Actions during execution*

# Contents

# Contents

# Basis of structural design and actions for buildings and industrial structures

**Part 4:**
Seismic actions and general requirements for buildings

## 1 Scope

This standard provides strategies and rules for the design of buildings subject to earthquake actions primarily to safeguard against major catastrophic structural failures and loss of life, not to prevent damage or to maintain function.

Structures in seismic zones (clause 4.2) shall, as a minimum, be designed and constructed to resist the effects of seismic ground motions as provided in this standard.

## 2 Normative references

The following referenced documents are indispensable for the application of this document. All normative documents are subject to revision and, since any reference to a normative document is deemed to be reference to the latest edition of that document, parties to agreement based on this document are encouraged to take steps to ensure the use of the most recent editions of the normative documents indicated below. Information on currently valid national and international standards can be obtained from Standards South Africa.

SANS 10100-1; *The structural use of concrete Part 1: Design*

SANS 10137; *The installation of glazing in buildings*

SANS 10160-1; *Basis of structural design*

SANS 10160-2; *Self-weight and imposed loads*

SANS 10160-3; *Wind actions*

SANS 10160-4; *Seismic actions and general requirements for buildings*

SANS 10160-5; *Basis for geotechnical design and actions*

SANS 10160-7; *Thermal actions*

SANS 10160-8; *Actions during execution*

SANS 10162-1; *The structural use of steel Part 1: Limit-state design of hot-rolled steelwork*

SANS 10162-2; *The structural use of steel Part 2: Limit-states design of cold-formed steelwork*

SANS 10162-4; *Structural use of steel Part 4: The design of cold-formed stainless steel structural members*

SANS 10163-1; *The structural use of timber Part 1: Limit-states design*

SANS 10164-2; *The structural use of masonry Part 2: Structural design and requirements for reinforced and pre-stressed masonry*

ISO 3898

# 3 Definitions and symbols

## 3.1 Definitions

For the purpose of this part of SANS 10160 the following definitions apply:

**3.1.1**
**bearing wall system**
provides support for all or most gravity walls. Resistance to lateral loads is provided by shear walls or braced frames

**3.1.2**
**boundary element**
region in a shear wall where confinement reinforcement is provided

**3.1.3**
**brickforce**
light, welded steel fabric comprising of two hard drawn wires

**3.1.4**
**building frame system**
a system with essentially a complete space frame providing support for gravity loads, with shear walls or vertical braced frames to resist lateral seismic forces

**3.1.5**
**column lateral link**
horizontal tie reinforcement in columns

**3.1.6**
**complex building**
buildings not complying with the definition of simple buildings as per Clause B.5, Annex B

**3.1.7**
**Coupling beam**
a beam connecting two shear walls

**3.1.8**
**cross tie**
reinforcement bar closing an open stirrup (Figure A.1)

**3.1.9**
**design base shear forc**
total lateral design shear force from the analysis for the seismic design situation

**3.1.10**
**elastic response spectrum**
elastic ground acceleration response spectrum

**3.1.11**
**factored compressive load**
ultimate limit state compressive load for the design situation considered

**3.1.12**
**horizontal diaphragm**
horizontal structural element capable of transmitting horizontal loads and tying vertical elements together, such as reinforced concrete floor slabs

**3.1.13**
**Horizontal peak ground acceleration**
seismic horizontal peak ground acceleration with a 10% probability of occurrence in 50 years

**3.1.14**
**Infill masonry**
masonry wall panels or part thereof

**3.1.15**
**internal ties**
horizontal tie reinforcement in columns

**3.1.16**
**isolated frame beam**
beams not monolithic with slab

**3.1.17**
**mining-induced seismicity**
seismic action caused by mining activities

**3.1.18**
**moment resisting frame**
a system with an essentially complete space frame providing support for vertical loads. Horizontal forces are mainly resisted by members acting in an essentially flexural manner.

**3.1.19**
**natural seismicity**
seismic action caused by natural events

**3.1.20**
**normalised design response spectra**
response spectra used to perform an elastic analysis based on a response spectrum reduced with respect to the elastic spectrum to allow for ductile behaviour of structural members. This reduction is accomplished by introducing the behaviour factor $q$

**3.1.21**
**ordinary reinforced concrete frame**
a moment resisting frame of ordinary reinforced concrete with provision for ductility in the load-carrying system according to this Standard and which complies with the provisions of SANS 10100, as opposed to a special moment resisting frame for which special detailing requirements apply, not provided in this Standard

**3.1.22**
**ordinary steel frame**
an ordinary steel frame which complies with the provisions of SANS 10162 and this Standard, as opposed to a special moment resisting frame for which special detailing requirements apply, not provided in this Standard

**3.1.23**
**P-delta effect**
additional bending moments created in structural elements due to the eccentricities which develop during deformation of the building under lateral load

**3.1.24**
**seismic hook**
a hook on a stirrup having a bend of not less than 135 degrees with a six bar diameter extension that engages the longitudinal reinforcement and extends into the interior of the section

**3.1.25**
**setbacks**
dimensions by which structural members on a building envelope deviate from the plan position of structural members on the building envelope of the floor below

**3.1.26**
**surface bed slabs**
reinforced or un-reinforced concrete slab on the ground

## 3.2 Symbols

### Latin upper case letters

$A_B$ Ground floor area of the structure or the average floor area where setbacks occur at levels, in [$m^2$]

$A_c$ Total effective area of shear walls in the first storey of the building, in [$m^2$] (subject to the walls remaining relatively unchanged over the height of the building), or the gross cross sectional area of a frame member

$A_{cp}$ Cross-sectional area of a coupling beam

$A_d$ Design value of an accidental action

| | |
|---|---|
| $A_i$ | Effective cross sectional area of the shear wall $i$ in the first storey of the building |
| $A_{sb}$ | Area of confinement reinforcement in the boundary zone; |
| $A_{su}$ | Minimum cross-sectional area of rectangular column links |
| $A_{vd}$ | Total area of reinforcement in each group of diagonal bars in a diagonally reinforced coupling beam |
| $C_p$ | Seismic force coefficient |
| $C_T$ | Factor used to determine fundamental period of vibration |
| $C_{vx}$ | Factor used to determine lateral seismic force on level $x$ |
| $E_d$ | Design seismic load on an element of the structure |
| $E_x$, | Seismic load in directions $x$ resulting from the application of the seismic forces |
| $E_y$ | Seismic load in directions $y$ resulting from the application of the seismic forces |
| $E_v$ | Vertical component of seismic action |
| $F_{in}$ | Lateral shear force induced at any level $i$ |
| $F_p$ | Design seismic lateral force |
| $F_{pn}$ | Nominal seismic force acting on an element |
| $F_{xn}$ | Lateral seismic force acting on a storey level $x$ |
| $G_n$ | Nominal self-weight load |
| $L_{wi}$ | Length of the shear wall $i$ in the first storey in the direction parallel to the applied forces |
| $L_{wx}$ | Length of wall $x$ on level $i$ |
| $M_s$ | Portion of slab moment which is taken up by supports |
| $M_{tn}$ | Torsional moments |
| $N_{SPT}$ | Standard Penetration Test blow-count |
| $P_{tot}$ | Total gravity load at and above the storey considered in the seismic design situation |
| $Q_{ni}$ | Imposed vertical load $i$ |
| $R$ | Ratio of secondary moment to primary moments |
| $S$ | Soil factor |
| $S_d(T)$ | Design spectrum for elastic analysis |
| $T$ | Fundamental period of vibration |
| $T_B(s)$ | Factor used to define the design response spectra |
| $T_c$ | Corner period at the upper limit of the constant acceleration region of the elastic spectrum |
| $T_B, T_C$ | Limits of the constant spectral acceleration branch; |
| $T_D$ | Value defining the beginning of the constant displacement response range of the spectrum |
| $V_i$ | Total storey shear force at level $i$ |
| $V_n$ | Design base shear force |
| $V_u$ | Nominal shear strength |
| $V_{xn}$ | Total seismic storey shear at level $x$ |
| $W_i$ | Portion of vertical load at or assigned to level $i$ |
| $W_n$ | Nominal sustained vertical load (force) acting on the structure |

$W_{pn}$ Weight of the element under consideration, plus imposed load if applicable

$W_x$ Portion of vertical load at or assigned to level $x$

**Latin lower case letters**

$a_g$ Reference horizontal peak ground acceleration in Type 1 ground expressed in $g$ (earth gravity acceleration)

$b_w$ Shear wall width, section width

$c_u$ Un-drained shear strength of soil

$d$ Effective depth of section

$d_e$ Displacement from the static elastic analysis

$d_{s,i}$ lateral inelastic displacement of storey $i$

$d_{s,i+1}$ lateral inelastic displacement of storey $i+1$

$d_r$ Design inter-storey drift, evaluated from the average lateral displacement $d_s$ at the top and bottom of the storey under consideration

$d_s$ Maximum Inelastic Response Displacement

$d_{ri-j}$ Drift or horizontal displacement between two storeys due to seismic design load

$f_{cu}$ Specified characteristic strength of concrete.

$f_y$ Specified yield strength of reinforcement

$f_{yh}$ Specified yield strength of transverse reinforcement

$f_{yv}$ Specified yield strength of links

$g$ Earth gravity acceleration

$h_c$ Dimension of column core (largest link dimension), or dimension of the boundary element in the direction under consideration

$h_{ef}$ Clear height of masonry wall

$h_i$ Height above the base to level $i$

$h_{pl}$ Vertical extent of plastic region of shear wall

$h_s$ Storey height

$h_t$ Height of the building, in [m], from the foundation or from the top of a rigid basement

$h_w$ Height of shear wall, depth of beam

$h_x$ Height above the base to level $x$, or maximum horizontal spacing of legs of the confinement reinforcement

$l_c$ Extent of the boundary element

$l_{cr}$ Length over which stirrups need to be placed at reduced spacing

$l_n$ Span length of coupling beam

$l_o$ length over which special limits apply to link spacing

$l_w$ Length of the wall considered in direction of the shear force

$p_v$ Volumetric ratio of spiral or circular links

$q$ Behaviour factor

| | |
|---|---|
| $r_i$ | Maximum shear ratio for storey $i$ |
| $r_{max}$ | Maximum storey shear ratio |
| $s_o$ | Maximum spacing of links |
| $s_x$ | Vertical spacing of confinement reinforcement in the boundary element or column |
| $t_{eff}$ | Effective masonry wall thickness |
| $v_j; v_k$ | Shear force in two adjacent columns at level $i$ |
| $v_{s,30}$ | Average value of propagation of S-waves in the upper 30m of the soil profile at shear strains of $10^{-5}$ or less |
| $v_{xn}$ | Nominal seismic shear force |
| $v_x$ | Shear force in wall $x$ on level $i$ |
| $x_n$ | Distance of neutral axis from extreme compression fibre |
| $y_I$ | Building importance factor |

**Greek lower case letters**

| | |
|---|---|
| $\alpha$ | Angle with the horizontal of the diagonally placed bars in a coupling beam |
| $\beta$ | Lower bound factor for horizontal design spectrum |
| $\gamma_m$ | Masonry partial material resistance factor |
| $\gamma_s$ | Steel partial material resistance factor |
| $\psi_{i\ i}$ | Load combination factor |
| $\rho$ | Reliability or redundancy factor |

# 4 Ground conditions and seismic action

## 4.1 Ground conditions

Appropriate investigations shall be carried out in order to identify the ground conditions according to the types given in Table 1.

**Table 1 — Ground types**

| 1 | 2 | 3 | | |
|---|---|---|---|---|
| **Ground type** | **Description of stratigraphic profile** | **Parameters** | | |
| | | $v_{s,30}$ m/s | $N_{SPT}$ blows/30cm | $c_u$ kPa |
| 1 | Rock or other rock-like geological formation, including at most 5 m of weaker material at the surface | > 800 | - | - |
| 2 | Deposits of very dense sand, gravel, or very stiff clay, at least several tens of m in thickness, characterised by a gradual increase of mechanical properties with depth | 360 - 800 | >50 | >250 |
| 3 | Deep deposits of dense or medium dense sand, gravel or stiff clay with thickness from several tens to many hundreds of m | 180 - 360 | 15 – 50 | 70 - 250 |
| 4 | Deposits of loose-to-medium cohesion-less soil (with or without some soft cohesive layers), or of predominantly soft-to-firm cohesive soil | <180 | <15 | <70 |

where

$v_{s,30}$ is the average value of propagation of S-waves in the upper 30 m of the soil profile at shear strains of $10^{-5}$ or less

$N_{SPT}$ is the Standard Penetration Test blow-count

$c_u$ is the un-drained shear strength of soil (kPa)

When the site conditions are not fully known or if the site investigations do not enable any profiles to be used, the most unfavourable of the four curves shall be used (see Figure 2).

## 4.2 Seismic hazard zones

Seismic zones applicable to South Africa are given in Figure 1. Two zones are identified, namely :

a) Zone I : Natural seismic activity and

b) Zone II : Regions of mining-induced and natural seismic activity.

A reference peak ground acceleration is defined in clause 4.3 for buildings located in Zone 1.

Buildings of Importance Class I, II and III (Table 3) in Zone II need only comply with clause 5 and with the minimum requirements for structural and non-structural components and with the requirements for ties, continuity and anchorage, all as detailed in clause 9. Buildings of Importance Class IV in Zone II shall be treated as buildings located in Zone 1.

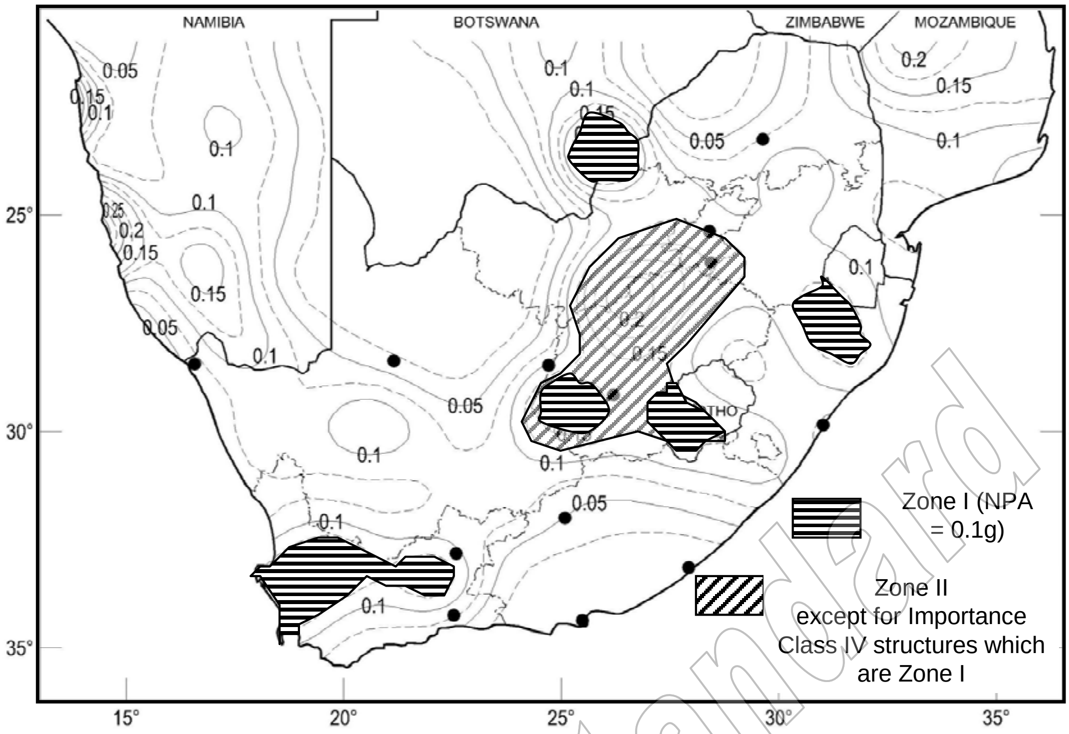



**Figure 1 — Seismic hazard zones of South Africa**

NOTE The above zones are determined from the seismic hazard map which presents the peak ground acceleration with a 10% probability of being exceeded in a 50-year period. It includes both natural and mining-induced seismicity). A recent seismic hazard map (2003) obtained from the Council for Geoscience is included in Annex C.

## 4.3 Basic representation of the Seismic action

The earthquake motion at a given point of the surface is represented by an elastic ground acceleration response spectrum called “elastic response spectrum”.

The horizontal seismic action is described by two orthogonal components considered as independent and represented by the same response spectrum.

In order to avoid explicit inelastic analysis in design, the capacity of the structure to dissipate energy through ductile behaviour is taken into account by reducing the elastic response spectrum by a behaviour factor $q$. The normalized design response spectra $S(T)/a_g$ corresponding to the ground condition types defined in Table 1, are given in Figure 2 for 5% damping and for a behaviour factor of $q$ = 1,0. The equations on which these curves are based are :

$$0 \le T \le T_B : S_d(T) = a_g \times S\left[\frac{2}{3} + \frac{T}{T_B}\left(\frac{2,5}{q} - \frac{2}{3}\right)\right] \qquad (1)$$

$$T_B \le T \le T_c : S_d(T) = a_g \times S\frac{2,5}{q} \qquad (2)$$

$$T_C \leq T \leq T_D : S_d(T)\left\{ = a_g \times S \frac{2,5}{q}\left[\frac{T_c}{T}\right]\right\} \text{ but } \geq \beta \times a_g \qquad (3)$$

$$T_D \leq T : S_d(T)\left\{ = a_g \times S \frac{2,5}{q}\left[\frac{T_C \times T_D}{T^2}\right]\right\} \text{ but } \geq \beta \times a_g \qquad (4)$$

Where

| | |
|---|---|
| $a_g$ | is the reference horizontal peak ground acceleration factor in Type 1 ground expressed in $g$ ($a_g$ =0,1 for Zone 1 areas) |
| $T$ | is the vibration period of a linear single-degree-of-freedom system (seconds) |
| $S, T_B, T_C, T_D$ | refer to Table 2, with |
| $T_{B,} T_C$ | are the limits of the constant spectral acceleration branch (period in seconds) |
| $T_D$ | value defining the beginning of the constant displacement range of the spectrum (period in seconds) |
| $S_d(T)$ | is the design response spectrum for elastic analysis (non-dimensional value) |
| $q$ | is the behaviour factor (Table 4) |
| $\beta$ | is the lower bound factor for horizontal design spectrum. A value of $\beta$ = 0,2 is recommended |

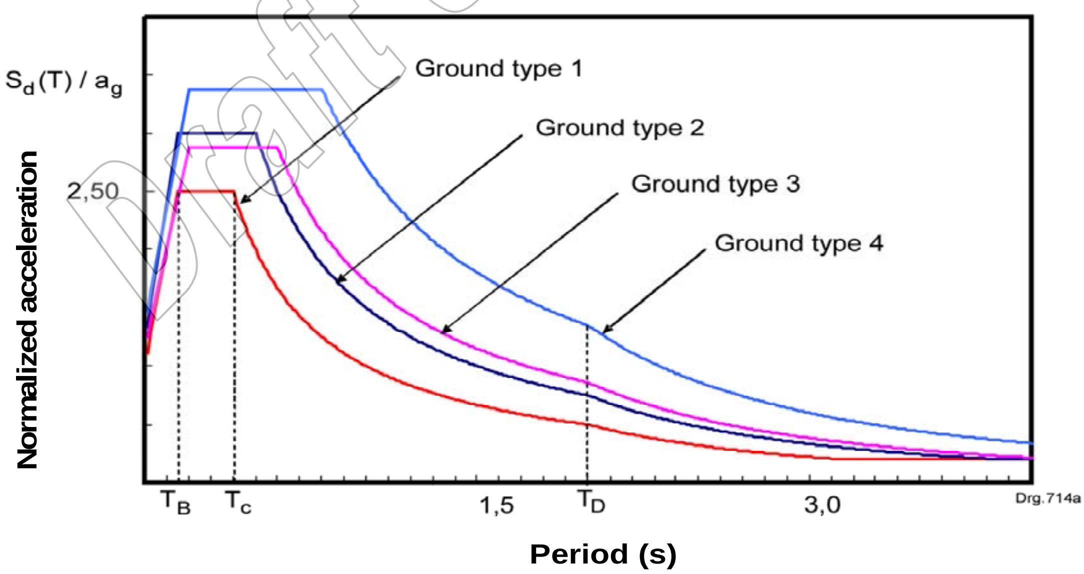


**Figure 2 — Normalized design response spectra $S_d(T)/a_g$ for 5% damping and $q$ = 1.0**

**Table 2 — Values of the parameters describing the design response spectra**

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| **Ground type** | **Parameters*** | | | |
| | $S$ | $T_B$ | $T_C$ | $T_D$ |
| 1 | 1,0 | 0,15 | 0,4 | 2,0 |
| 2 | 1,2 | 0,15 | 0,5 | 2,0 |
| 3 | 1,15 | 0,20 | 0,6 | 2,0 |
| 4 | 1,35 | 0,20 | 0,8 | 2,0 |

(*Parameters are defined above)

# 5 Design of buildings

## 5.1 Multi-storey buildings in Zones I & II

### 5.1.1 General

Buildings of more than one storey are considered under this clause.

### 5.1.2 Basic principles of conceptual design

Seismic hazard shall be taken into account in the early stages of conceptual design of buildings in seismic regions to achieve cost effective structural systems which will satisfy the fundamental in the scope.

The guiding principles governing conceptual design against seismic hazards are:

a) structural simplicity;

b) uniformity, symmetry and redundancy;

c) multi-directional resistance and stiffness;

d) torsional resistance and stiffness;

e) diaphragm behaviour of floors;

f) adequate foundation system and

g) non-structural infill panels.

### 5.1.3 Structural simplicity

Clear and direct paths for the transmission of seismic forces shall be pursued in the layout of the building.

NOTE Structures with clear and direct paths for the transmission of seismic forces generally perform better in earthquakes than those with complex force paths; as well as allowing more reliable seismic behaviour prediction as modelling, analysis, dimensioning, detailing and construction are subject to much less uncertainty.

### 5.1.4 Uniformity, symmetry and redundancy

**5.1.4.1** Uniformity in-plan shall be achieved by even distribution of structural elements which allows short and direct transmission of inertia forces resulting from the distributed masses of the building. Uniformity may be realised by subdividing the building into dynamically independent units, but possible pounding of individual units shall be considered in the design of joints.

**5.1.4.2** Uniformity up the height of the structure shall be maintained to eliminate sensitive zones where stress concentrations or large ductility demands might cause premature collapse.

**5.1.4.3** A close relationship between distribution of masses and distribution of resistance and stiffness shall be maintained to eliminate large eccentricities between mass and stiffness.

**5.1.4.4** A symmetrical or quasi-symmetrical building configuration shall be used to achieve a symmetrical structural layout, uniformly distributed in-plan.

**5.1.4.5** An even distribution of structural elements increases redundancy and allows favourable redistribution of action effects and energy dissipation.

### 5.1.5 Multi-directional resistance and stiffness

**5.1.5.1** Horizontal seismic motion is a multi-directional phenomenon and structures shall therefore be designed to resist horizontal actions in any direction (see clause 7.6).

**5.1.5.2** To satisfy the above, structural elements shall be arranged in an orthogonal configuration in plan to provide similar resistance and stiffness characteristics in both main directions.

**5.1.5.3** Stiffness characteristics of the structure shall be determined or selected to minimise effects of the seismic action, but also to prevent excessive displacements that could lead to instabilities and significant damage due to second order effects (see clause 8)

### 5.1.6 Torsional resistance and stiffness

Building structures shall have adequate torsional resistance and stiffness to limit the magnitude of torsional motions (see clause 7.5.4).

NOTE structures subject to torsion can experience irregular stresses in unexpected locations in members. torsional motions tend to stress the different structural elements of a building in a non-uniform way structural configurations with seismic resisting elements distributed close to the building periphery provide effective torsional resistance.

### 5.1.7 Diaphragm behaviour of floors

**5.1.7.1** Floors shall act as horizontal diaphragms to transmit lateral inertia forces to the vertical structural systems and to ensure that the vertical systems act together in resisting the horizontal seismic action.

**5.1.7.2** Floors shall have adequate in-plane stiffness and resistance with effective connection to the vertical structural systems.

NOTE Particular care shall be taken in cases of non-compact or very elongated in-plan shapes and in cases where large openings in floors occur in close proximity to vertical structural elements with the associated potential impact on effective connectivity between horizontal and vertical structural elements.

**5.1.7.3** Diaphragms shall have sufficient in-plane stiffness to distribute horizontal and inertia forces to the vertical structural systems in accordance with the design assumptions (e.g. diaphragm rigidity), especially where significant changes occur in stiffness or offsets of vertical elements above and below the diaphragm.

### 5.1.8 Adequate foundation

**5.1.8.1** The design and construction of foundations and their connections to the superstructure shall ensure that the whole building is subjected to a uniform seismic excitation.

**5.1.8.2** Rigid, box-type or cellular foundations shall be chosen for structures composed of a discrete number of structural walls of differing width or stiffness (or both).

**5.1.8.3** Reinforced foundation slabs or tie-beams (in both main directions) shall be used to link piled foundations of buildings with individual elements used for the lateral stability of the structural system.

**5.1.8.4** For buildings where the basement is designed as a rigid structure, the level of embedment shall be taken as the level of the first floor slab below ground level.

**5.1.8.5** For structures on piles the level of embedment shall be taken as that of the pile caps.

**5.1.8.6** The self-weight and other actions which act at the level of embedment need not be taken into account for the determination of the equivalent force.

### 5.1.9 Infill panels

**5.1.9.1** If engineered masonry infill constitute part of the seismic resistant structural system, analysis and design shall be carried out according to the criteria and rules given for confined masonry in specialist literature.

**5.1.9.2** If masonry infill panels are not considered as part of the seismic resistant structural system, then either sufficient separation joints shall be provided to allow for the expected frame displacements and the panels be sufficiently stabilized, or the infill panels shall comply with 9.6.

**5.1.9.3** The effect of partial height infill panels (Figure 3) on columns shall be considered (see also 9.6).

NOTE Partial-height infill panels create short column conditions that could lead to severe damage to columns during seismic events, and such infill panels should be avoided if at all possible. If such panels cannot be avoided, movement joints of sufficient width to accommodate the anticipated inelastic horizontal deformations of the framing structure should be provided. Care shall be taken to ensure adequate detailing to provide lateral stability of such panels to out-of-plane forces

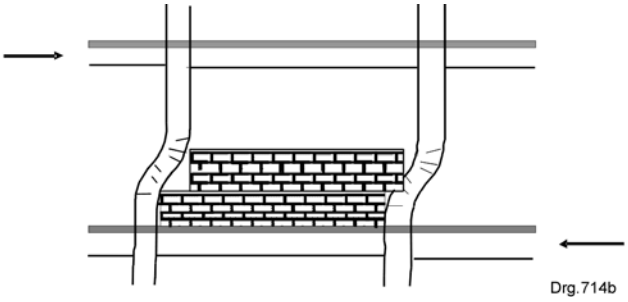



**Figure 3 — Partial height infill panel**

## 5.2 Low-rise buildings in Zones I & II

### 5.2.1 Plan symmetry

Single-storey buildings shall be so planned that there is a good distribution of bracing walls to provide adequate lateral stability.

NOTE Layouts should preferably be of simple box plan (see Figure 4a) providing reasonably symmetrical resistance in two orthogonal directions. Slender wings and buildings or rooms with essentially three resisting walls (see Figure 4b), should be avoided as far as possible; where such walls can not be avoided, care shall be taken to ensure adequate detailing to provide lateral stability.

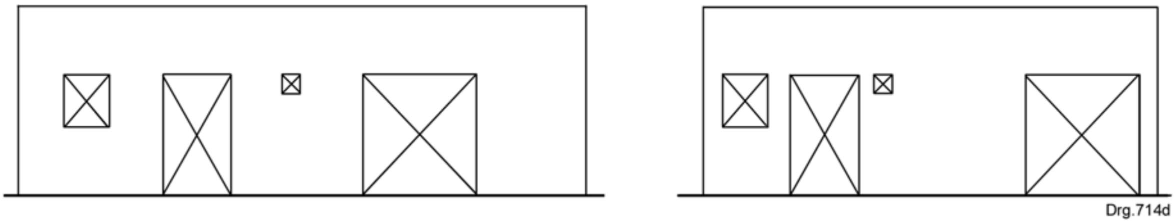

**a) Simple box plan** **b) Room with three resisting walls**

**Figure 4 — Plans of shear walls in low-rise housing**

### 5.2.2 Openings in walls

The total area of openings in walls shall not exceed one-third of the wall area

NOTE Openings for doors or windows require care in positioning and detailing in order to obtain a uniform distribution of strength. The distribution of openings in walls shall be as uniform as possible (see Figure 5a). Large openings in masonry walls are undesirable, particularly in external walls near corners (see Figure 5b). Where such conditions cannot be avoided, care shall be taken to ensure adequate detailing to provide lateral stability.




a) Uniform openings b) Large opening near wall end

**Figure 5 — Openings in low-rise masonry construction**

### 5.2.3 Roofs

Adequate detailing shall be provided to ensure lateral stability for heavy roof structures on lightweight wall construction.

NOTE Heavy roof structures such as tiled roofs are undesirable, especially on lightweight wall construction.

### 5.2.4 Walls

Horizontal bed joint reinforcing shall be provided to enhance ductility of masonry walls. Such reinforcement can however not be considered as providing a “reinforced masonry construction”.

NOTE Masonry walls reinforced with steel bars or wire will minimize deformation and possibly prevent catastrophic collapse.

### 5.2.5 Gables and parapet walls

Masonry gables and parapet walls shall be buttressed with transverse walls or pilasters or be reinforced to ensure lateral stability. Tall free-standing sections shall be avoided. Hipped roofs are preferred to gables in areas of high seismicity.

### 5.2.6 Horizontal continuity

Horizontal continuity shall be provided at floor and roof levels, using suitable ties and anchorages to ensure adequate load transfer capacity between horizontal and vertical structural elements. Refer to clause 9.

### 5.2.7 Chimneys and decorative panels

For elements that are stiffer and heavier than the rest of the building ensure adequate detailing to provide lateral stability

NOTE Masonry chimneys and heavy decorative panels are undesirable.

### 5.2.8 Articulation

Suitable continuity and articulation details shall be provided to accommodate differential movement on the horizontal and vertical directions in low-rise buildings on conventional foundations. For calculation of displacements see clause 8.

# 6 Load effects and considerations

**6.1** The design of structures shall consider seismic zoning, site characteristics, building importance, structural system and height.

**6.2** Seismic design situations are covered in SANS 10160-1.

**6.3** The seismic loads to be used in the load combinations set out in SANS 10160-1 shall be determined as follows:

$$E_d = \rho \times \gamma_1 \left( E_x "+" 0{,}3E_y \right) + E_v \qquad [5]$$

where

$\gamma_1$ is the building importance factor as given in Table 3;

$E_d$ is the design seismic load on an element of the structure to be used in the seismic load combination covered in SANS 10160-1 (where $A_d = E_d$);

$E_v$ is the vertical component of seismic action (see clause 7.7);

$E_x, E_y$ is the seismic load in two orthogonal directions $x$ and $y$ resulting from the application of the seismic forces in clause 7 to the structure;

$\rho$ is the Reliability/Redundancy factor as given by the following formula

$$\rho = 2 - \frac{6{,}1}{r_{max}\sqrt{A_B}} \qquad 1{,}2 \le \rho \le 1{,}5 \qquad [6]$$

where

$A_B$ is the ground floor area of the structure or the average floor area where setbacks occur at higher levels, in square metres;

$r_{max}$ is the maximum storey shear ratio. For a given direction of loading and for a given storey $i$, the storey shear ratio $r_i$ is the ratio of the design storey shear in the most heavily loaded single element divided by the total design storey shear. The maximum value of $r_i$ for the lower two-thirds height of the building is $r_{max}$.

**For moment frames** : $r_i$ shall be taken as the maximum of the sum of the shears in any two adjacent columns in a moment frame bay divided by the storey shear:

$$r_{max} = max\left[ r_i \right]$$

$$r_i = max\left(\frac{v_j + v_k}{V_i}\right) \quad (7)$$

where

$r_i$ is the maximum shear ratio for storey $i$

$v_i$ and $v_k$ is the shear force in two adjacent columns at level

$V_i$ is the total storey shear force at level $i$

For columns common to two bays with moment-resisting connections on opposite sides at level $i$ in the direction under consideration, 70 % of the shear in that column may be used in the column shear summation.

**For shear walls** : $r_i$ shall be taken as the maximum value of the wall shear multiplied by $3{,}0/L_{wx}$ and divided by the total storey shear, where $L_{wx}$ is the length of the wall, in metres.

$$r_{max} = max[r_i]$$

$$r_i = max\left(\frac{v_x \times \frac{3}{L_{wx}}}{V_i}\right) \quad (8)$$

$r_i$ is the maximum shear ratio for storey $i$;
$v_x$ is the shear force in wall $x$ on level ;
$L_{wx}$ is the length of wall $x$ on level $i$ in metres;
$V_i$ is the total storey shear force at level $i$ in MPa.

**Table 3 — Importance classes for buildings**

| 1 | 2 | 3 |
|---|---|---|
| **Importance class** | **Buildings** | **Importance factor** $\gamma_i$ |
| I | Buildings of minor importance for public safety, e.g. agricultural buildings, etc. | 0,8 |
| II | Ordinary buildings, not belonging to the other categories. | 1,0 |
| III | Buildings for which seismic resistance is of importance in view of the consequences associated with a collapse, e.g. schools, assembly halls, cultural institutions, etc. | 1,2 |
| IV | Buildings for which integrity during earthquakes is of vital importance for protection, e.g. hospitals, fire stations, power plants, etc. | 1,4 |
| Note : The numbering of importance classes differ from those in the Eurocode where from these definitions were taken. | | |

# 7 Structural analysis

## 7.1 Modelling

The model of the building shall adequately represent the distribution of stiffness and mass so that all significant deformation shapes and inertia forces are properly accounted for under the seismic action considered. In the case of non-linear analysis, the model shall also adequately represent the distribution of strength.

Non-structural elements, which may influence the response of the main resisting structural system, shall also be accounted for.

In general the structure may be considered to consist of a number of vertical and lateral load resisting systems, connected by horizontal diaphragms.

NOTE In concrete buildings, in composite steel-concrete buildings and in masonry buildings the stiffness of the load bearing elements should, in general, be evaluated taking into account the effect of cracking. Such stiffness should correspond to the initiation of yielding of the reinforcement.

Infill walls which contribute significantly to the lateral stiffness and resistance of the building shall be taken into account. See clause 9.6 for masonry infill of concrete, steel or composite frames.

## 7.2 Behaviour factor and energy dissipation

**7.2.1** The plastic deformation capacity and the over strength of structural elements are taken into account by means of a behaviour factor $q$. In the absence of a more detailed assessment the $q$ factors (behaviour factors) given in Table 4 may be used. It is imperative that the minimum detailing requirements are followed to allow the use of these factors to ensure that the ductility capacity of lateral force resisting systems is acceptable.

Where required, the behaviour factor is set to 1,5 when determining the vertical component of the seismic action.

**7.2.2** The structural systems in Table 4 are defined as follows (refer to Figure 6):

a) Bearing wall system — bearing walls provide support for all or most gravity loads. Resistance to lateral loads is provided by shear walls or braced frames. The shear walls shall conform to the requirements of SANS 10100-1 for reinforced concrete and of SANS 10162-1 and SANS 10162-2 for structural steel, in addition to the requirements of this Standard.

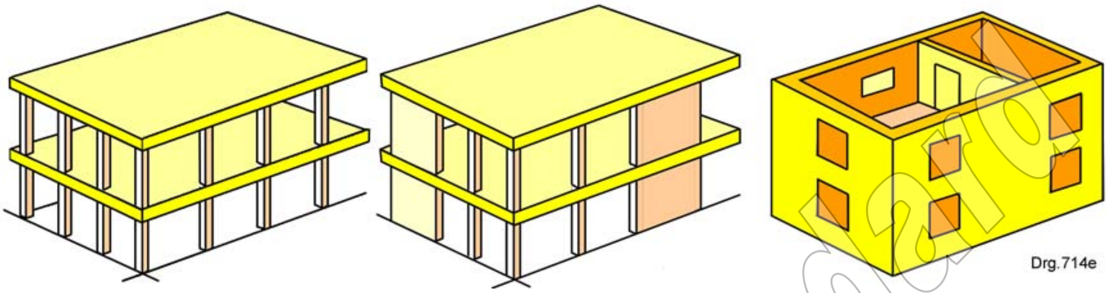
b) Building frame system — a system with essentially a complete space frame providing support for gravity loads, with shear walls or vertical braced frames to resist lateral seismic forces. The shear walls shall conform to the requirements of SANS 10100-1 for reinforced concrete and of SANS 10162-1 and SANS 10162-2 for structural steel, in addition to the requirements of this standard.

c) Moment resisting frame — a structural system with an essentially complete space frame providing support for vertical loads. The provisions of this code are limited to dealing with only the following types of moment resisting frames :

i) Ordinary reinforced concrete frame : A moment-resisting frame of ordinary reinforced concrete with provision for ductility in the load-carrying system according to this standard and which complies with the provisions of SANS 10100-1.

ii) Ordinary steel frame An ordinary steel frame which complies with the provisions of SANS 10162-1 and this standard.

NOTE Definitions of special frame types that dissipate greater amounts of inelastic energy are outside the scope of this code.




a) Moment resisting frame b) Building frame system c) Bearing wall system

**Figure 6 — The structural systems**

**Table 4 – Behaviour factors $q$ for structural systems**

| 1 | 2 | 3 |
|---|---|---|
| **Structural system** | **Detail** | **Behaviour factor $q$** |
| Bearing wall system | Unreinforced masonry walls (see Annex B) | 1,5 |
| | Reinforced concrete walls (detailed in accordance with SANS 10100 and Annex A) | 5,0 |
| | Reinforced concrete walls not detailed in accordance with Annex A) | 2,5 |
| | Reinforced masonry walls (with reinforcement provided in both the horizontal and vertical directions, all designed according to the requirements for reinforced masonry)[1] | 2,5 |
| Building frame system | With reinforced concrete shear walls (detailed in accordance with SANS 10100 –1 and Annex A) | 5,0 |
| | With reinforced concrete shear walls not detailed in accordance with Annex 8A | 2,0 |
| | Ordinary braced steel frames | 5,0 |
| Moment-resisting frame system | Ordinary concrete frames (detailed in accordance with SANS 10100-1 and Annex A) | 3,0 |
| | Ordinary concrete frames not detailed to Annex A | 2,0 |
| | Ordinary steel frames | 4,5 |
| Structures required to remain elastic | All | 1,0 |

NOTE 1 The use of only horizontal bed reinforcement in masonry is not considered to provide a system of reinforced masonry

NOTE 2 When designing floor slabs for bending moments and shear forces which result from lateral drift under seismic loads, the behaviour factor shall be reduced by a factor of 1,2 for use with structures comprising reinforced concrete flat or waffle slabs, and by a factor of 1,4 for the use with structures comprising prestressed concrete flat or waffle slabs.

NOTE 3 Reference can be made to international recognized building codes for guidance on behaviour factors for buildings elements or systems not listed in the table.

## 7.3 Sustained vertical load

The sustained vertical load shall be taken as the total nominal weight of the building (including partitions and permanent equipment) and the sustained portions of the imposed vertical loads. In the absence of other information, the sustained vertical loads ($W_n$) shall be taken as :

$$W_n = G_n + \sum_i \varphi_i \times Q_{ni}$$ [9]

where

$G_n$ nominal self-weight load

$Q_{ni}$ i imposed vertical load

$\varphi_i$ $\varphi_1$ load combination factor (See SANS 10160-1)

## 7.4 Method of analysis

**7.4.1** The effect of the seismic forces can be determined by using a linear elastic structural model. The nonlinear and plastic deformations as well as the over-strength capacity are considered by the correct use of the behaviour factor $q$ (clauses 7.2 and 8.2).

**7.4.2** Regardless of the type of analysis used, the design base shear shall not be less than the value determined in clause 7.5.

NOTE When using the response spectrum analysis method the design base shear may be reduced by taking 85% of the value calculated in clause 7.5 provided that the structural layout complies with the criteria in clause 7.4.3

**7.4.3** The equivalent static lateral force procedure may be used for buildings whose response is not significantly affected by contributions from higher modes of vibration. This requirement is deemed to be satisfied if the building fulfils the following conditions:

a) The fundamental period of vibration $T \leq 4T_C$ or $T \leq 2{,}0$ (seconds) (refer to clause 4.3 for $T_C$ and to clause 7.5.2 for $T$ );

b) All lateral load resisting systems (cores, walls, frames) run without interruption from their base to the top of the building, or if setbacks at different heights are present, to the top of the relevant zone of the building;

c) Both lateral stiffness and the mass of the individual storeys remain constant or reduce gradually, without abrupt changes, from the base to the top;

d) The sum of setbacks at any storey is less than 30% of the plan dimension at the first storey and less than 10% of the previous plan dimension and

e) The plan layout of the building regarding the stiffness of the lateral force resisting elements, and the distribution of mass are approximately symmetric with respect to the two orthogonal directions and without significant discontinuities throughout the height of the building.

**7.4.4** If a structure does not comply with the above requirements specialist literature shall be consulted for appropriate rigorous methods of analysis, which can include the response spectrum method, time history analysis and others.

## 7.5 Equivalent static lateral force procedure

### 7.5.1 Design base shear

The design base shear force ($V_n$) shall be calculated as follows:

$$V_n = S_d(T) \times W_n \quad [10]$$

where

$S_d(T)$ is the non-dimensional value from the normalized design response spectra (see clause 4.3)

$W_n$ is the nominal sustained vertical load (force) acting on the structure in kN (see clause 7.3)

### 7.5.2 Fundamental period of vibration

**7.5.2.1** The fundamental period of vibration $T$ (in seconds), in the direction being analysed, may be calculated using the following formula (buildings up to 40 m in height):

$$T = C_T \times h_t^{3/4} \quad [11]$$

where

$C_T$ = 0,085 for steel frames

$C_T$ = 0,075 for reinforced concrete moment-resisting frames and for eccentrically braced frames or

$C_T$ = 0,05 for all other buildings

$h_t$ is the height of the building, in m, from the foundation or from the top of a rigid basement in metres.

Alternatively, for structures with concrete or masonry shear walls, the value of $C_T$ may be taken as:

$$C_T = \frac{0{,}075}{\sqrt{A_c}} \quad [12]$$

where

$$A_C = \Sigma\left[A_i\left(0{,}2 + \left(\frac{L_{wi}}{h_t}\right)^2\right)\right] \quad [13]$$

$A_C$ total effective area of shear walls in the first storey of the building (subject to walls remaining relatively unchanged over the height of the building) in square metres

$A_i$ effective cross sectional area of the shear wall $i$ in the first storey of the building in square metres

$h_t$ as defined for equation (11)

$L_{wi}$ length of the shear wall $i$ in the first storey in the direction parallel to the applied forces with the restriction that $L_{wi}/h_t$ shall not exceed 0,9 in metres

**7.5.2.2** As an alternative to the above, the fundamental period $T$ may be calculated using the structural properties and deformation characteristics of the resisting elements in a properly substantiated analysis. However, the value of $T$ computed by such methods may not exceed $1{,}4T$ where $T$ is calculated by the equation (11).

NOTE The mathematical model should include all elements of the lateral force resisting system. The model shall also include the stiffness and strength of elements, which are significant to the distribution of forces, and shall represent the spatial distribution of the mass and stiffness of the structure. Unless a more accurate analysis of the cracked elements is performed, the elastic flexural and shear stiffness properties of concrete and masonry elements may be taken equal to one-half of the corresponding stiffness of the un-cracked element. This assumption on flexural stiffness properties depends on the structural configuration, loading, and location of an element in the structure, and should be seen as a guideline

### 7.5.3 Vertical distribution of seismic forces

The lateral seismic force $F_{xn}$ acting on a storey at level $x$ shall be determined in accordance with the following equation:

$$F_{xn} = C_{vx} \times V_n \qquad [14]$$

where

$V_n$ seismic base shear force from equation 10

$$C_{vx} = \frac{W_x \times h_x}{\sum_{i=1}^{n} W_i \times h_i} \qquad [15]$$

where

$W_x$, $W_i$ is the portion of the vertical load at or assigned to level $x$ or $i$, respectively

$h_x$, $h_i$ is the height above the base to level $x$ or $i$, respectively

$i$ is the storey number

$n$ is the total number of storeys

### 7.5.4 Horizontal shear and torsion

**7.5.4.1** The nominal seismic shear force $V_{xn}$ at any level $x$ shall be determined in accordance with the following formula :

$$V_{xn} = \sum_{i=1}^{t} F_{in} \qquad [16]$$

where

$F_{in}$ is the lateral shear force induced at any level $i$, determined in accordance with equation 14

$t$ is the top level

**7.5.4.2** The force $V_{xn}$ shall be distributed to the various vertical components of the seismic-resisting system in the storey below level $x$, with due consideration given to the relative stiffness of the vertical components and the diaphragm.

**7.5.4.3** The torsional moments $M_{tn}$ on the structure shall be considered in the design as caused by assumed displacement of the mass each way from its actual location by a distance equal to 5% of the dimensions of the building perpendicular to the direction of the applied forces.

**7.5.4.4** For asymmetric buildings, the design shall in addition provide for the torsion moment $M_{tn}$ resulting from the location of the building masses.

## 7.6 Orthogonal effects

The requirement that horizontal forces in all horizontal directions be considered (clause 5.1.5) may be satisfied by designing elements for 100 % of the design seismic forces in one direction plus 30 % of the design seismic forces in the perpendicular direction (see equation 5).

## 7.7 Vertical component

If the nominal peak ground acceleration is greater than 0,25 $g$ ($a_g$ = 0,25) then the vertical component of the seismic action shall be taken into account.

## 7.8 Overturning

The structure as a whole shall be checked to be stable under the design seismic action. Both overturning and sliding stability shall be considered.

# 8 Displacements

## 8.1 General

The drift or horizontal displacement of the structure (due to the design seismic load), $d_s$, shall be calculated using a static elastic analysis method. In order to calculate $d_s$, the design seismic forces as determined by clause 7.5.3 shall be applied to the lateral force resisting system.

$d_s$ shall include translation and torsional deflection and shall consider $P-\varDelta$ effects (second order effects of vertical forces on displaced elements).

## 8.2 Inelastic displacement

**8.2.1** The maximum inelastic response displacement, $d_s$ (in metres) shall be calculated using equation 17

$$d_s = 0{,}7q \times d_e \qquad [17]$$

where

$q$ is defined in 7.2;

$d_e$ is the displacements from the static elastic analysis in metres.

## 8.3 Storey drift limitations

**8.3.1** The storey drift ($d_{r\,i-j}$) between two storeys $i$ and $j$ (with $j = i+1$) shall be limited as follows:

$$d_{r\,i-j} \le 0{,}025h_s \quad \text{if} \quad T < 0{,}7s \qquad [18]$$

$$d_{r\,i-j} \le 0{,}020h_s \quad \text{if} \quad T > 0{,}7s \qquad [19]$$

where

$d_{r\,i-j} = d_{si+1} - d_{si}$

$h_s$ is the storey height in metres;
$T$ is as defined in clause 7.5.2;
$d_{si}$ lateral inelastic displacement of storey $i$ (in metres);
$d_{s1+1}$ lateral inelastic displacement of storey $i+1$ (in metres).

**8.3.2** The drift limits may be exceeded when it can be demonstrated that greater drift can be tolerated by both structural and non-structural elements that could affect life safety. The drift used in this assessment shall be based upon the maximum inelastic response displacement $d_s$.

### 8.4 P-delta effect

P-delta effects need not be considered when the ratio of secondary moment to primary moments ($R$) does not exceed 0,10. This ratio may be evaluated for any storey as follows:

$$R = \frac{P_{tot} \times d_r}{V_{xn} \times h} \leq 0{,}10 \qquad [20]$$

where

$P_{tot}$ is the total gravity load at and above the storey considered in the seismic design situation;

$d_r$ is the design inter-storey drift, calculated in accordance with clause 8.3;

$V_{xn}$ is the total seismic storey shear at that level;

$h$ is the storey height in metres.

## 9 Structural and non-structural component load effects

### 9.1 General

For loads on the main structural system refer to clause 7. This section considers loads on elements of structures not considered to be part of the main force resisting system, and on non-structural elements.

### 9.2 Lateral forces on elements of structures and non-structural components

Parts of structures, non structural components, and their anchorages to the main structural system shall be designed to resist a lateral force equal to

$$F_{pn} = a_g \times C_p \times W_{pn} \qquad [21]$$

where

$F_{pn}$ nominal seismic force acting on element in kN;

$a_g$ nominal peak ground acceleration normalized by $g$, but at least 0,1;

$C_p$ a seismic force coefficient given in Table 5;

$W_{pn}$ weight of the element under consideration plus imposed load if applicable.

The distribution of these forces shall be in accordance with the vertical loads pertaining thereto.

**Table 5 — Seismic force coefficients $C_p$ for elements of structures and non structural components**

| 1 | 2 |
|---|---|
| **Structural elements or non structural components** | **Seismic force coefficient $C_p$** |
| Cantilever elements such as parapets, cantilever walls and chimneys on buildings | 2,0 |
| Load bearing and non load bearing wall elements, cladding elements and partitions. | 1,0 |
| Various installations in buildings such as pumps, machines, tanks, pipes, etc. | 0,5 to 1,0 |

## 9.3 Ties and continuity

As a minimum, a satisfactory connection of each beam, girder or truss shall be provided which is capable of resisting horizontal transverse and axial loads of at least 5 % of the combined self weight load and the imposed live load. This minimum applies only if it exceeds the computed forces.

## 9.4 Concrete or masonry wall anchorage

Concrete and masonry walls shall be anchored to the roof and to all floors that provide lateral support for the wall. The anchorage shall provide a direct connection between the walls and roof. The connections shall be capable of resisting a design seismic lateral force $F_p$ induced by the wall of at least $15\,a_g$ kN per linear meter of wall, where $a_g$ is the nominal peak ground acceleration normalized by $g$ of at least 0,1. Walls shall be designed to resist bending between anchors where the anchor spacing exceeds 1,5 m

## 9.5 Diaphragms

Floor and roof diaphragms shall be designed to resist a horizontal force $F_{pn}$ (see clause 9.2) with a minimum value not less than:

a) $0{,}5\,a_g$ times the weight of the diaphragms and other elements of the building attached thereto, plus

b) the portion of $V_{xn}$ (clause 7.5.4.1) required to be transferred to the components of the vertical seismic resisting system because of offsets or changes in stiffness of the vertical components above and below the diaphragm.

All requirements of clause 7.5.4 shall be complied with.

## 9.6 Additional measures for masonry in-filled frames

**9.6.1** Frame systems with interacting non-engineered infill masonry shall fulfil the following conditions:

a) the infill has been constructed after the concrete of the frames has achieved adequate strength or after the assembly of the steel frame;

b) the infill is in contact with the frame (i.e. without special separation joints to allow for the expected frame displacements), but without structural connection to it (through ties, belts, posts or shear connectors) and

c) infills are considered in principle as non-structural elements.

**9.6.2** The following requirements shall be complied with:

a) For panels that may be vulnerable to out-of-plane failure, the ties must control the hazard from falling masonry.

b) For bearing wall systems or building frame systems (refer to clause 7.2.2) , as well as for braced steel or steel-concrete composite systems, the interaction with the masonry infill may be neglected.

c) The consequences of irregularity in plan or irregularity in elevation produced by the infill shall be taken into account.

d) Account shall be taken of the high uncertainties related to the behaviour of the infill (namely, the variability of their mechanical properties and of their attachment to the surrounding frame, their possible modification during the use of the building, as well as the non-uniform degree of damage suffered during the earthquake itself).

e) The possibly adverse local effects due to the frame-infill-interaction (e.g. shear failure of slender columns under forces induced by the diagonal strut action of infill) shall be taken into account.

f) Strongly irregular, non-symmetric or non-uniform arrangement of infill in plan shall be avoided (taking into account the extent of openings and perforations in infill panels).

g) In case of severe irregularities in plan due to the unsymmetrical arrangement of the infill (e.g. existence of infill mainly along two adjacent faces of the building), spatial models shall be used for the analysis of the structure.

NOTE The infill shall be included in the model and a sensitivity analysis regarding the position and the properties of the infill should be performed (e.g. by disregarding one out of three or four infill panels in a planar frame, especially on the more flexible sides). Special attention should be paid to the verification of structural elements on the flexible sides of the plan (i.e. furthest away from the side where the infills are concentrated) against the effects of any torsional response caused by the infills.

h) Appropriate measures shall be taken to avoid brittle failure and premature disintegration of the infill walls (in particular of masonry panels with openings or of friable materials), as well as out-of plane collapse of slender masonry panels or parts thereof. Particular attention shall be paid to masonry panels with slenderness ratio greater than 15 (ratio of the lesser of length or height to thickness).

NOTE Examples of measures to improve both in-plane and out of plane integrity and behaviour, include light wire meshes well anchored on one face of the wall, wall ties fixed to the columns and cast into the bedding planes of the masonry, “wind posts” and concrete belts across the panels and through the full thickness of the wall. If there are large openings or perforations in an infill panel, their edges should be trimmed with belts and posts.

# 10 Materials

## 10.1 General

In order to ensure adequate ductility for structural members, structures subjected to seismic action shall comply with detailing rules over and above those presented in the material design standards.

## 10.2 Reinforced concrete

Normative rules for reinforced concrete structures and elements in seismic zone 1 are presented in Annex A.

## 10.3 Reinforced and unreinforced masonry

Normative rules for masonry structures and elements in seismic zone 1 are presented in Annex B.

## 10.4 Structural steelwork

See SANS 10162-1 and SANS 10162-2 for further detail. For more severe seismic loadings refer to EN 1998-1 for detailing rules of structural steelwork structures.

## 10.5 Timber

See EN 1998-1 or other specialist literature for detailing rules of structural timber structures and members in seismic zone 1

## 10.6 Composite construction

See EN 1998-1 or other specialist literature for detailing rules of composite structures in seismic zone 1.

# Annex A
(Informative)

# Detailing of reinforcement of concrete

## A.1 General

In Seismic Hazard Zone 1, members designed to resist forces induced by earthquake forces shall satisfy the detailing requirements of this annex in addition to those of SANS 10100-1.

## A.2 Detailing of reinforcement in superstructures

### A.2.1 Minimum requirements for frames

#### A.2.1.1 Principle

**A.2.1.1.1** Reinforcement details in a frame member should satisfy A.2.1.2 if the factored compressive load for the member does not exceed $A_c f_{cu}/12{,}5$ where $A_c$ is gross area of concrete section, and $f_{cu}$ is specified characteristic strength of concrete. If the factored compressive load is larger, reinforcement details should satisfy A.2.1.3 and A.2.1.4. If a two-way slab system without beams is treated as part of a frame resisting earthquake effect, reinforcement details in any span resisting moments caused by lateral force should satisfy A.2.1.5.

**A.2.1.1.2** Design shear strength of beams, columns and two-way slabs resisting earthquake effect should not be less than either:

a) sum of the shear associated with the development of nominal moment strengths of the member at each restrained end of the clear span and the shear calculated for gravity loads, or

b) the maximum shear obtained from design load combinations which include earthquake effect $E_d$ (clause 6.3)

#### A.2.1.2 Beams

**A.2.1.2.1** Positive-moment strength at the face of the column-beam joint should not be less than one third of the negative-moment strength provided at that face of the joint. Neither the negative- nor the positive-moment strength at any section along the length of the member should be less than one fifth the maximum moment strength provided at the face of either joint.

**A.2.1.2.2** At both ends of the member stirrups should be provided over lengths $l_{cr}$ equal to twice the member depth ($h_w$) measured from the face of the supporting member towards midspan (Figure A.2). The first stirrup should be located not more than 50mm from the face of the supporting member.

Maximum stirrup spacing should not exceed:

a) $d/4$ (where $d$ is the effective depth of the section);

b) eight times the diameter of the smallest longitudinal bar enclosed;

c) 24 times the diameter of the stirrup bar and

d) 150 mm.

**A.2.1.2.3** Stirrups should be placed at not more than d/2 throughout the length of the member.

**A.2.1.2.4** Stirrups in plastic zones should be closed and bent with seismic hooks or using shape codes which will prevent opening of the stirrup in the case of loss of concrete cover (Figure A.1).

NOTE A seismic hook is a hook on a stirrup having a bend of not less than 135 degrees with a six bar diameter extension that engages the longitudinal reinforcement and extends into the interior of the section.

Stirrups in plastic zones in flexural members acting as T-beams should be permitted to be made up of two pieces of reinforcement: A stirrup having seismic hooks on both ends at the top of the T-beam and closed by a cross tie. Consecutive cross ties engaging the same longitudinal bar should have their 90 degree hooks at opposite sides of the member. Cross ties should have seismic hooks as shown in Figure A.1. Only closed links with seismic hooks should be used in the plastic zones of isolated frame beams

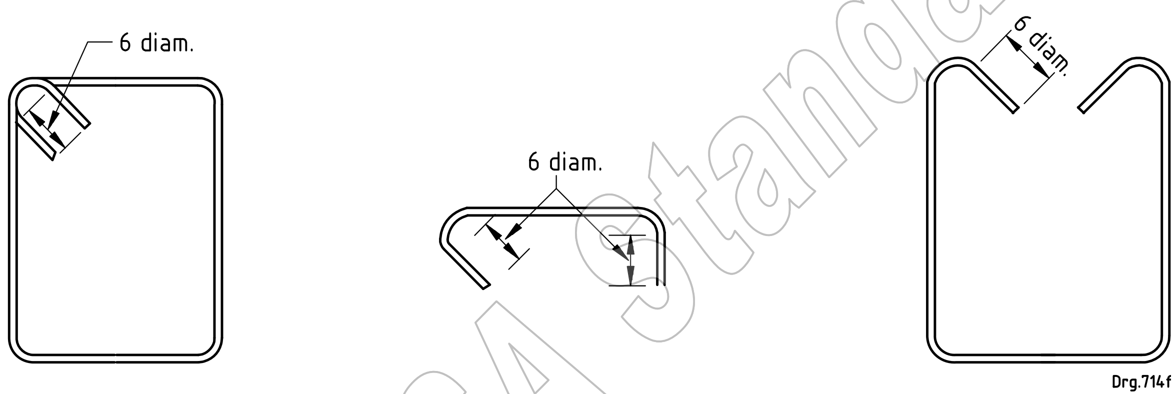



**Figure A.1 — Stirrups with seismic hooks and stirrups using cross ties over open stirrups**

### A.2.1.3 Columns

**A.2.1.3.1** Maximum link spacing should not exceed $s_0$ over a length $l_0$ measured from the joint face (see Figure A.2) with $s_0$ and $l_0$ as defined below.

**A 2.1.3.1.1 Spacing**

The maximum link spacing, $s_0$ , is defined as :

a) eight times the diameter of the smallest longitudinal bar enclosed;

b) 24 times the diameter of the link bar;

c) one half of the smallest cross sectional dimension of the frame member, and

d) 150mm.

**A.2.1.3.1.2 Length**

The length, $l_0$ should not be less than:

a) one sixth of the clear height of the member;

b) maximum cross sectional dimension of the member, and

c) 450 mm.

**A.2.1.3.2** The first link should be located at not more than $s_0 / 2$ from the joint face.

**A.2.1.3.3** Link spacing outside the length $l_0$ should not exceed twice the spacing $s_0$ .

**A.2.1.3.4** In the plastic zone every second longitudinal bar should be supported by the confining stirrups or cross ties. The spacing between supported longitudinal bars should not exceed 200 mm.

**A.2.1.3.5** Column lateral links should, in addition to the above, comply with the requirements of SANS 10100-1.

**A.2.1.3.6** Column links in plastic regions should be closed with seismic hooks (Figure A.1). Cross ties may be used as internal ties in the plastic regions provided that they are bent with seismic hooks at both ends

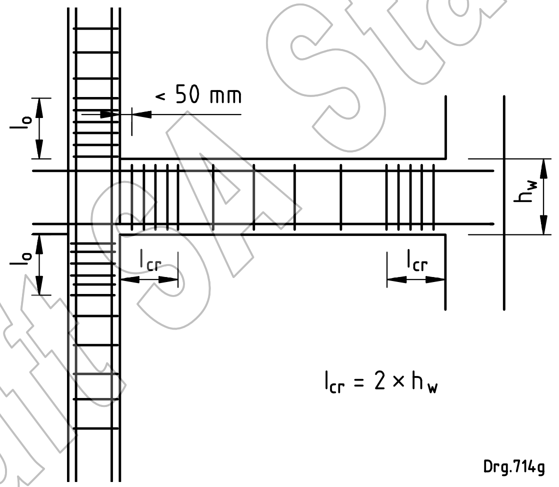



**Figure A.2 — Beam and column stirrups in plastic regions**



**A.2.1.4 Columns supporting discontinuous systems**

**A.2.1.4.1** A discontinuous system occurs where a structural wall is not vertically continuous to the foundation, but transfers its vertical load to a column or columns.

**A.2.1.4.2** For rectangular columns, links should be provided such that each link has a cross sectional area of not less than:

$$A_{su} = 0{,}077\left(s \times h_c \times f_{cu} / f_{yv}\right) \qquad \text{[A1]}$$

where

$A_{su}$ is the cross sectional area of each link in square metres;

$s_x$ is the spacing of links in mm;

$h_c$ is the dimension of column core (largest link dimension) in metres;

$f_{cu}$ is the characteristic concrete strength in MPa;

$f_{yv}$ is the specified yield strength of links in MPa.

In a column with one long side, a cross link may be used to reduce the core dimension $h_c$.

**A.2.1.4.3** For round columns the volumetric ratio of spiral or circular links ($p_v$) should not be less than

$$p_v = 0{,}10\left(\frac{f_{cu}}{f_{yv}}\right) \qquad \text{[A.2]}$$

where

$p_v$ is the ratio of volume of spiral reinforcement or links to the core volume confined by the spiral reinforcement (measured on the outside of the spiral reinforcement).

**A.2.1.4.4** The links or spiral reinforcement should be provided over the full length of the column. The links should extend into the beam zone above for the full depth of the beam. Where the column rests on a wall, the links should extend into the wall for at least the anchorage length of the largest column reinforcement. At footings or bases, the links should extend at least 300 mm into the base.

### A.2.1.5 Two-way slabs without beams

**A.2.1.5.1** Factored slab moment at supports related to earthquake effect should be determined for the load combinations defined in SANS 10160-1. All reinforcement provided to resist $M_s$, the portion of slab moment which is taken by the supports, should be placed within the column strip as defined in SANS 10100-1.

**A.2.1.5.2** Not less than one fourth of the top reinforcement at the support in the column strip should be continuous throughout the span.

**A.2.1.5.3** Continuous bottom reinforcement in the column strip should not be less than one third of the top reinforcement at the support at the column strip.
Not less than half of all bottom reinforcement at midspan should be continuous and should develop its yield strength at face of the support.

**A.2.1.5.4** At discontinuous edges of the slab, all top and bottom reinforcement should be developed at the face of the support as prescribed in SANS 10100-1.

## A.3 Shear walls and coupling beams

### A.3.1 Shear walls

#### A.3.1.1 Dimensions

**A.3.1.1.1** Structural walls should be designed in accordance with the requirements of SANS 10100-1. The effect of openings should be considered.

**A.3.1.1.2** Effective flange width of flanged sections should extend from the face of the web a distance equal to the smaller of one-half the distance to an adjacent wall web and 25 percent of the total wall height.

#### A.3.1.2 Boundary elements

**A.3.1.2.1** Boundary elements are portions in the plastic region of a shear wall along the structural wall edges and strengthened by longitudinal and transverse reinforcement. Boundary elements should be provided as in A.3.1.2.2 to A.3.1.2.4 (see Figures A.3 and A.4).

**A.3.1.2.2** This clause applies to walls that are effectively continuous from the base of the structure to top of wall and designed to have a single critical section for flexure and axial loads. Walls not satisfying these requirements should be designed according to A.3.1.2.3. The extent of the boundary element $l_c$ is based on the distance of the neutral axis from the compression edge ($x_n$). The extent of the boundary element $l_c$ is defined in A.3.1.2.4. If the neutral axis is not known, the distance $x_n$ may be taken as $x_n = l_w / 4$, where $l_w$ is the length of the wall considered in direction of the shear force.

The vertical extent of the plastic region $h_{pl}$ of a shear wall should comply with the following requirement :

$h_{pl} > l_w$ and

$h_{pl} \geq h_w / 6$

If $h_s \geq 2l_w / 3$ and $h_s \geq h_w / 9$ are both complied with, then $h_{pl} = h_s$ may be assumed (see Figure A.3).

Lapping of vertical bars between the anchorage zone (base) and the height of the boundary element should be strongly avoided.

**A.3.1.2.3** Structural walls not satisfying the requirements of A.3.1.2.2 should have boundary elements at boundaries and edges of openings where the maximum extreme fibre compressive stress, corresponding to factored forces including earthquake effect, exceeds $0{,}20 f_{cu}$. The boundary element may be discontinued where the compressive stress is less than $0{,}15 f_{cu}$. Stresses should be calculated for the factored forces using a linear elastic model and gross section properties.

**A.3.1.2.4** Where boundary elements are required by A.3.1.2.1 and A.3.1.2.2, the following should be satisfied:

a) the boundary element should extend horizontally from the extreme compression fibre a distance $l_c$ of not less than the larger of $x_n - 0{,}1 l_w$ and $x_n / 2$;

b) in flanged sections, the boundary element should include the effective flange width in compression and should extend at least 300 mm into the web;

c) boundary element transverse reinforcement should satisfy the following requirements:

$$A_{sb} > 0.077 s_x . h_c . \frac{f_{cu}}{f_{yh}}$$

$$s_x < 100 + \frac{350 - h_x}{3}$$

$$s_x < h_x / 4$$

$s_x < 6$ x longitudinal bar diameter

100mm < $s_x$ < 150mm

where

$A_{sb}$ is the area of confinement reinforcement in the boundary zone in square metres;

$s_x$ is the vertical spacing of confinement reinforcement in the boundary element in mm;

$h_c$ is the dimension of the boundary element in the direction under consideration in metres;

$h_x$ is the maximum horizontal spacing of legs of the confinement reinforcement in metres;

$f_{cu}$ is the concrete characteristic strength in MPa;

$f_{yh}$ is the specified yield strength of transverse reinforcement in MPa.

d) boundary element transverse reinforcement at the wall base should extend at least 300 mm into the footing or mat and

e) horizontal reinforcement in the wall web should be anchored to develop the specified yield strength within the confined core of the boundary element.

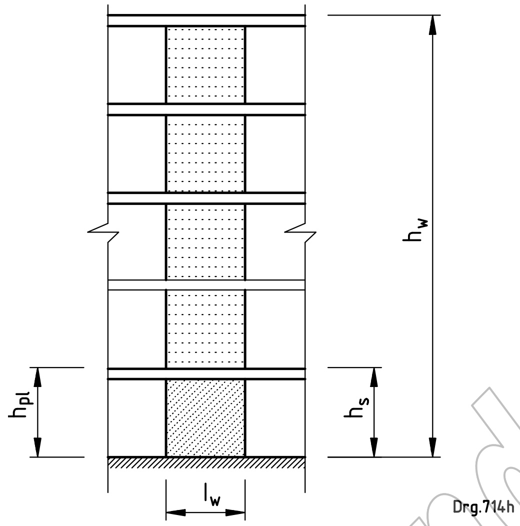



**Figure A.3 — Height of plastic region at the base of a shear wall**

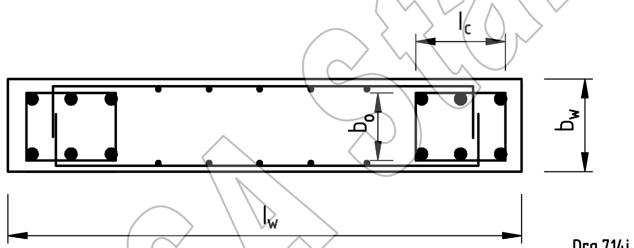



**Figure A.4 — Boundary elements in walls section**



## A.3.2 Coupling Beams

### A.3.2.1 General

Coupling beams are beams connecting two shear walls (see Figure A.5).

### A.3.2.2 Aspect ratio

**A.3.2.2.1** Coupling beams with aspect ratio $l_n / h_w \geq 4$ should satisfy the requirements of A.2.1.2.

**A.3.2.2.2** Coupling beams with aspect ratio $l_n / h_w < 4$, should be permitted to be reinforced by means of two intersecting groups of diagonal bars symmetrical about the midspan.

**A.3.2.2.3** Coupling beams with aspect ratio $l_n / h_w < 2$, and with factored shear stress exceeding $0,3\sqrt{f_{cu}}$ should be reinforced by means of two intersecting groups of diagonal bars symmetrical about the midspan, unless it can be shown that loss of stiffness and strength of the coupling beams will not impair the load carrying capacity of the structure.

### A.3.2.3 Intersecting groups

Coupling beams reinforced with two intersecting groups of diagonally placed bars should satisfy the following:

a) each group of diagonally placed bars should consist of a minimum of four bars assembled in a core having sides measured to the outside of transverse reinforcement no smaller than $b_w / 2$ perpendicular to the plane of the beam and $b_w / 5$ in the plane of the beam and perpendicular to the diagonal bars (with $b_w$ the section width).

b) the nominal shear strength $V_u$ should be determined by

$$V_u = 2.A_{vd} \cdot f_{yh}.sin\alpha \leq 0,8.\sqrt{f_{cu}}.A_{cp} \qquad [A.3]$$

where

$A_{vb}$ is the total area of each group of diagonal bars;

$\alpha$ is the angle of the diagonal bars with the horizontal;

$A_{cp}$ is the gross concrete cross sectional area

$f_{cu}$ is the characteristic strength of concrete (in MPa);

$f_{yh}$ specified yield strength of transverse reinforcement

c) each group of diagonally placed bars should be enclosed in transverse reinforcement satisfying the link requirements of A.2.1.4. The diagonally placed bars should be developed for tension in the wall.

d) the diagonally placed bars should be considered to contribute to nominal flexural strength of the coupling beam.

e) reinforcement parallel and transverse to the longitudinal axis should conform to the minimum reinforcement prescribed by SANS 10100-1.

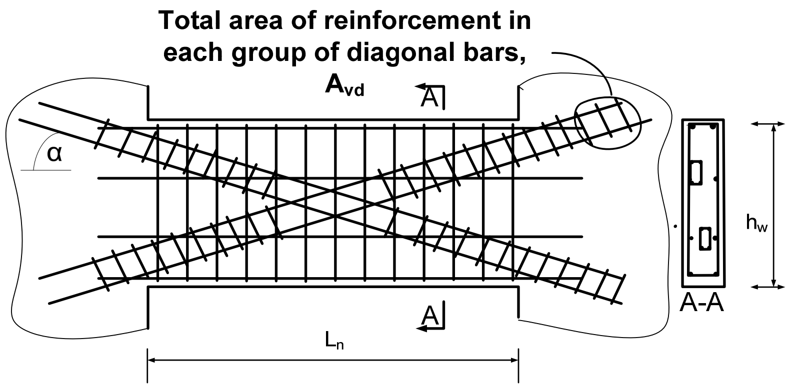



**Figure A.5 — Coupling beam with diagonally oriented reinforcement**

## A.4 Foundations

### A.4.1 Scope

**A.4.1.1** Foundations resisting earthquake-induced forces or transferring earthquake-induced forces between structure and ground should comply with A.4 and other applicable provisions of Annexure A.

**A.4.1.2** The provisions for piles, caissons, and surface bed slabs should supplement other applicable SANS standard's design and construction criteria .

### A.4.2 Footings, foundation mats and pile caps

**A.4.2.1** Longitudinal reinforcement of columns and structural walls resisting forces induced by earthquake effects should extend into the footing, mat, or pile cap, and should be fully developed for tension at the interface.

**A.4.2.2** Columns designed assuming fixed end conditions at the foundation should comply with A.4.2.1 and, if hooks are required, longitudinal reinforcement resisting flexure should have 90 degree hooks near the bottom of the foundation with the free end of the hooks oriented towards the centre of the column.

**A.4.2.3** Columns or boundary elements of reinforced structural walls that have an edge within one-half the footing depth from the edge of the footing should have transverse reinforcement in accordance with A.4 provided below the top of the footing. This reinforcement should extend into the footing a distance not less than the smaller of the depth of the footing, raft, or pile cap, or the tension anchorage length of the longitudinal reinforcement.

**A.4.2.4** Where earthquake forces create uplift forces in boundary elements of structural walls or columns, flexural reinforcement should be provided in the top of the footing, raft or pile cap to resist the design load combinations.

## A.4.3 Ground beams and surface bed slabs

**A.4.3.1** Ground beams designed to act as horizontal ties between pile caps or footings should have continuous longitudinal reinforcement that should have an anchorage length developed within or beyond the supported column or anchored within the pile cap or footing at all discontinuities.

**A.4.3.2** Ground beams designed to act as horizontal ties between pile caps or footings should have a smallest cross-sectional dimension equal to or greater than the clear spacing between connected columns divided by 20, but need not be greater than 450mm. These beams should have along their full length a reinforcement ratio of at least 0,4% at both top and bottom. Links should be provided at a spacing not to exceed the lesser of one half the smallest cross sectional dimension or 300mm.

**A.4.3.3** Ground beams that are part of a raft foundation subjected to flexure from columns that are part of the lateral force-resisting system should conform to A.2.1.

**A.4.3.4** Surface bed slabs that resist seismic forces from walls or columns that are part of the lateral force resisting system should be designed as structural diaphragms. The minimum reinforcement ratio for such diaphragms should be 0,2 %. Reinforcement spacing each way should not exceed 450 mm. Reinforcement provided for shear should be continuous and should be distributed evenly across the shear plane. All continuous reinforcement should have full tensile strength anchorage or splice lengths.

## A.4.4 Piles and caissons

**A.4.4.1** The provisions of A.4.4 should apply to piles and caissons supporting structures designed for earthquake resistance.

**A.4.4.2** Piles or caissons resisting tension loads should have continuous longitudinal reinforcement over the length resisting design tension forces. The longitudinal reinforcement should be detailed to transfer tension forces within the pile cap to supported structural members.

**A.4.4.3** Piles or caissons should have transverse reinforcement in accordance with A.2.1.3 at the following locations:

a) at the top of the member for at least 5 times the member cross sectional dimension.

b) for the portion of piles in soil that is not capable of providing lateral support, or in air or water, along the entire unsupported length plus 5 times the member cross sectional dimension.

# Annex B
(normative)

# Specific rules for masonry buildings

## B.1 General

These provisions apply to structures in Seismic Hazard Zones 1. Members designed to resist forces induced by earthquake motions, should satisfy the requirements of this section in addition to those of SANS 10164-1.

If it is found by applying the information below that complex buildings, buildings of more than 3 storeys, or buildings of importance Class III & IV (Table 3) can not be assessed with the available information, then specialist literature should be consulted, or reference should be made to EN 1998-1.

## B.2 Structural analysis

The base shear in the various walls, as obtained by the linear analysis described in clause 7, may be redistributed among the walls, provided that:

a) the global equilibrium is satisfied (i.e. the same total base shear and position of the force resultant is achieved);

b) the shear in any wall is neither reduced more than 25 %, nor increased by more than one-third; and

c) the consequences of the redistribution for the diaphragm(s) are taken into account.

## B.3 Design criteria and construction rules

**B.3.1** Shear walls should be provided in at least 2 orthogonal directions.

**B.3.2** The diaphragm behaviour of the floors should satisfy the requirements of 5.1.6.

**B.3.3** Unless verified by other analysis means, the following criteria should be fulfilled:

a) The $t_{eff}$ of shear wall may not be less than 190mm for solid walls and 150 mm for cavity walls.

b) The ratio of $h_{eff} / t_{eff}$ of a shear wall should not exceed 17.

c) The shear wall ratio of the length of the wall to the greater clear height of the openings adjacent to the wall must not exceed 0,5.

d) For solid walls 190 mm and wider, the minimum percentage of horizontal bed joint reinforcing in the wall, compared to the gross area of the section, should not be less than 0,025%.

e) For cavity walls, the minimum percentage of horizontal bed joint reinforcing in the wall, compared to the gross area of the section, should not be less than 0,05 %.

f) the four courses of brickwork above all openings should be reinforced with horizontal bed joint reinforcing that extends at least 1m past the opening.

In the above clauses, $t_{eff}$ is the effective wall thickness, and $h_{eff}$ the clear wall height, all as defined in SANS 10614-1.

## B.4 Safety verification

The verification of the building's safety against collapse should be explicitly provided, except for buildings satisfying the rules for "simple masonry buildings" given in B.5.

For the verification of safety against collapse, the design resistance of each structural element should be evaluated on the basis of SANS 10164-1.

In ultimate limit state verifications for the seismic design situation, partial factors $\gamma_m$ for masonry properties and $\gamma_s$ for reinforcing steel should be used. The recommended value for $\gamma$m is 2/3 of the value specified in SANS 10164-1. The recommended value for $\gamma$s is: $\gamma$s = 1,0.

## B.5 Rules for "simple masonry buildings"

Provided that the recommendations with regard to shear walls as per B.3.3 are satisfied, and the minimum area of shear wall as per B.5 (e) below is provided, explicit safety verification for simple masonry buildings is not mandatory. For masonry buildings to be classed as simple, the following criteria should be fulfilled:

a) the building should be of importance Class I or II (see Table 3);

b) the building should be of max 3 storey height;

c) the plan configuration of the building should fulfil the following conditions:

i) the plan should be approximately regular, but

ii) the ratio of the overall length of the smaller to the larger plan dimension should not be less than 0,25;

iii) the area of projections or recesses from the rectangular plan shape must not be greater than 15 % of the total floor area above the level being considered;

d) the shear walls of the building should fulfill all the following conditions:

i) the building must be stiffened by shear walls arranged almost symmetrically in plan in two orthogonal directions;

ii) at least for the walls in one direction, the distance between these walls must be greater than 75 % of the length of the building in the other direction;

iii) at least 75 % of the vertical loads must be supported by the shear walls;

iv) shear walls must be continuous from foundations to the top of the building and

v) between adjacent storey heights, the difference in mass and in horizontal shear wall cross-section in both orthogonal directions should be limited to 20 %

e) The minimum sum of cross sectional area of horizontal shear walls (length of wall × $t_{eff}$ ), in each direction, as a percentage of the total floor area per storey must be 2,5 % for 2 storey buildings and 5 % for 3 storey buildings.

**Figure C.1 — Seismic hazard map of South Africa**
**10% in 50 years nominal peak ground acceleration in *g* (9,81 m/s$^2$)**



## Bibliography

SANS 10164-1 *The structural use of masonry Part 1: Unreinforced masonry walling*

Council for Geoscience, *Probabilistic Seismic-Hazard Maps for South Africa*, Version 1, 2003, Pretoria.

EN 1998-1: *Design of structures for earthquake resistance Part 1: general rules, seismic actions, and rules for buildings*. December 2004, European Committee for Standardization.

SANS 10164-1, *The structural use of masonry Part 1: Unreinforced masonry walling.*