ISRAEL STANDARD

SI 413

THE STANDARDS INSTITUTION OF ISRAEL

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The Israel Standard SI 413
from November 1975
Corrigendum from January 1977
Amendment No. 1 from December 1980
Amendment No. 2 including Appendix C
from February 1989
Amendment No. 3 from September 1990
Amendment No. 4 from July 1991

DESIGN PROVISIONS FOR EARTHQUAKE RESISTANCE OF STRUCTURES

(TRANSLATION)

Descriptors: structures design, earthquakes , design response spectra, ductility level.

INTRODUCTION

Earthquakes are characterized by ground shakings that endanger structures stability.
This Standard describes the structural design requirements to withstand such an event. The requirements are based on updated knowledge. The resistance of ductile structures is reflected by their ability to absorb energy while undergoing plastic deformations. Complying with the requirements of the Standard shall provide the appropriate structural resistance:

- to an earthquake, without causing instability of the structural elements - in the case of a moderate earthquake;
- to an earthquake without causing failure or endangering human life - in the case of a severe earthquake.

CHAPTER A - General information

.101 Scope of Standard

This Standard details the design of seismic resistant structures.

The requirements of this Standard apply to all types of structures listed in Section 105.1

The requirements of this Standard do not apply to structures listed in Section 105.2. The requirements apply to these structures are more severe.

.102 Reference

Standards and documents mentioned in this Standard:

Israeli Standards

SI 412	- Loads on structures : Characteristic loads
SI 414	- Characteristic loads in buildings : Wind loads
SI 466 Part 1	- Concrete code : General principles
SI 466 Part 2	- Concrete code : Reinforced and unreinforced concrete structures
SI 466 Part 3	- Concrete code : Prestressed concrete
SI 466 Part 4	- Concrete code : Precast concrete elements and structures
SI 466 Part 5	- Concrete code : Precast prestressed hollow core slab floors

SI 739	- Steel for reinforcement of concrete : Ribbed bars
SI 893	- Rolled plain steel bars for concrete reinforcement
SI 940	- Foundations for buildings
SI 1225 Part 1	- Steel structures code
SI 1227 Part 1	- Loads on bridges : Highway bridges
SI 1227 Part 2	- Loads and geometrical requirements for bridges : Railway bridges
SI 1378	- Pile foundations in rock by percussion drilling
SI 1523(1)	- Masonry walling

Foreign documents

Comite Euro-International du Beton - Bulletin d'Information No. 165, 1985: " CEB Model Code for Seismic Design of Concrete Structures"

SEAOC, Dec. 1988: "Recommended Lateral Force Requirements", Seismology Committee, Structural Engineering Association of California

prENV 1998-1-1: October 1993: Eurocode 8 - Design provisions for earthquake resistance structures - Part 1-1:General rules - Seismic actions and general requirements for structures

prENV 1998-1-2: October 1993: Eurocode 8 - Design provisions for earthquake resistance structures - Part 1-1:General rules - General rules for buildings

prENV 1998-1-3: October 1993; Eurocode 8 - Design provisions for earthquake resistance structures - Part 1-1:General rules - Specific rules for various materials & elements

UBC 1994 - Structural Engineering Design Provisions, Ch. 16, Div. III - Earthquake design

(1) On the publishing day of this Standard the SI 1523 is under preparation

.103 Definitions

The following definitions apply to this Standard:

103.1 Accelerogram

Ground accelerations list during an earthquake as a function of time.

103.2 Base of structure

A level, assumed by the engineer, that transmit most of the seismic effects to the structure.

103.3 Story shear strength

The total shear strength, in the examined direction, of all columns and walls in a horizontal cross section above a discussed story floor, i, (section 204.6).

103.4 Story shear force

The sum of all lateral seismic forces acting on the structure, above a discussed story floor, i

103.5 Collector

A member or element provided to transfer lateral forces from a portion of a structure to vertical elements of the lateral force-resisting system.

103.6 Low structure

One of the following types of structures:

- A one or two story, reinforced concrete or steel, dwelling structure with an occupancy area less than 400 m^2 located in a zone where $Z \leq 0.075$, and not constructed with an open column story.
- One story storage structure with a roof span less than 10 m and with no overhead crane;
- One story agricultural structure used for agricultural crops or animals grouth.
- A temporary or mobile structure.

103.7 Regular structure

A structure that complies with all the conditions of section .203.1

103.8 Irregular structure

A structure that violates any one of the conditions of a regular structure

103.9 Story stiffness ratio

The ratio between the calculated story stiffness of a discussed story, i, and the calculated story stiffness of the story above, or the average calculated story stiffness of the three stories above.

103.10 Moment -resisting space frames

A frame system that transfers the effects of lateral forces mainly by bending moments.

103.11 Braced space frames

A vertical truss system that transfers the effects of lateral forces mainly by axial forces.

103.12 Frame system

A system of space frames, without shear walls carrying all the loads (vertical and lateral) according to paragraphs 103.10 or 103.11

103.13 Bearing wall system

A system of single bearing walls or coupled walls carrying all the loads (vertical and lateral)

103.14 Dual system

A system carrying all the loads (vertical and lateral), by a moment resisting space frames combined with either single bearing wall, or coupled walls, or braced frames

103.15 Force reduction factor

A factor that depends on the type of structure and the ductility level of the structure.

103.16 Site coefficient

A coefficient that represents the local ground conditions, and is used to determine the design response spectrum.

103.17 Importance factor

A factor that represents the social - economical importance of the structure, and the level of protection that it provides.

103.18 Stiffness center

A point on a discussed floor i, where the resultant of the lateral forces crossing it does not create a floor rotation around a vertical axis relative to the story floor.

103.19 Ductility

The capacity of a structure or an element to absorb energy by plastic strains before failure.

103.20 Story drift

The maximum difference in displacements between conformed points on the floor and the ceiling on a discussed story, after displacements occurred.

103.21 Response spectrum

The maximum response envelop of a single degree of freedom oscillator with a given damping, to ground motions, as a function of the oscillator frequency.

103.22 Column

Compression member with flexure, complies with the requirements in section 403.3.2.

103.23 Plastic joint

A critical zone in an element, acting under a moment equivalent to the flexural capacity of the section, and can form a plastic rotation, while maintaining its capacity.

103.24 Fundamental mode

The mode corresponding to the fundamental period (definition 103.35)

103.25 Coupling

Formation of internal forces in direction perpendicuar to a principal direction in which the external lateral forces act.

103.26 Flexible story

A story that is one of the following:

- a story that its lateral stiffness is smaller than the stiffness of the above story times 0.7, or the average stiffness of the three above stories, times 0.8.
- a story, that at least in one of its principal directions, there is less than half the length of concrete walls or masonry walls (with a thickness of 15 cm or more) between columns, compared to the above story.

comments:

A story with foundation columns, or sheet pile (including walls from adjoining piles), is considered to be above ground story, and is included in the above criteria, and definition 103.27 (Section 203.1).

In compressed soil, the ground resistance can be considered, according to its modulus of subgrade reaction, starting with a depth of at least 1 m.

103.27 Weak story

A story that its shear capacity to lateral forces is less, in one of the directions, than the shear capacity of the story above (in the same direction) times 0.8 (Section 203.1).

103.28 Coupled shear wall

A couple of walls in the same plane, connected by lintels or coupled beams in the floor levels.

103.29 Torsional stiffness

The moment required for a one radian rotation around the center of stiffness of the ceiling, conformed to the floor, of the same story.

103.30 Story stiffness

The lateral force required for obtaining a unit dispacement, in the same direction of the force (story drift); equals to the reciprocal of the story drift from a unit force acting in the same direction and crossing the stiffness center.

103.31 Stiffness radius

The square root of the ratio between the torsional stiffness of a story and its story stiffness, to a directional displacement.

103.32 Beam

A flexural member, that in the most severe load combination, including the seismic action, carries an axial force, according to the requirements in section 403.3.1.1.

103.33 Ductility level

The capability given to a whole structure and its elements, by the appropriate design of concrete sections and reinforcement, to develop plastic hinges (Definition 103.23), and to absorbe energy under seismic conditions, without failure. This capability is given in three different levels, to reinforced concrete structures.

103.34 Occurrence

A time period, defined in years, during which an earthquake stronger than the expected, shall not occur (in a given probability).

103.35 Fundamental period

The longest structural period of vibration.

.104 List of symbols

A_a - Total area of tension reinforcement, in beam of a joint cross-section, that surrounds the joint, bent vertically, and anchored at the tension face of the column.

ΣA_{cx} ; ΣA_{cy} - Total area of a horizontal cross-section, of reinforced concrete columns and walls in the examined direction.

A_g - Gross area of a concrete section in an element, either a column or a beam or a wall..

A_i - Area on a discussed floor, i, loaded with a live load, q.

A_{jh} - Area of horizontal shear reinforcement in a beam - column joint.

A_{jv} - Area of vertical shear reinforcement in a beam - column joint.

A_k - Cross -sectional area of a column or wall core enclosed by an external hoop (stirrup).

A_L - Area of longitudinal reinforcement in a beam (upper and lower).

ΣA_{mx} ;ΣA_{my} - Total horizontal cross-sectional area of infill walls in a discussed direction.

A_s - Area of longitudinal reinforcement, in a beam, located at the outer tension half of the cross-section; total vertical reinforcement in a shear wall segment or in a column.

A_s' - Area of longitudinal reinforcement, in a beam, located at the outer compression half of the cross-section.

A_{s1} ; A_{s2} - Area of longitudinal reinforcement in a beam section, at both sides of a beam - column joint.

A_{sc} - Area of longitudinal tension reinforcement in a column section(in the case of asymmetrical reinforcement, the larger area)

A_{sc} - Area of longitudinal compression reinforcement in a column section(in the case of asymmetrical reinforcement, the smaller area)

A_{sh} - Area of all tie and hoop (stirrup) legs(parallel to a discussed axis) in a column section; area of horizontal reinforcement in a wall section; area of one leg of a stirrup in a beam section

$A_{s, min}$ - Minimum reinforcement area of one leg of a stirrup.

ΣA_{sx} ; ΣA_{sy} - Horizontal cross sectional area of all sides of steel columns, in a discussed direction

A_T - Torsional amplification factor (section 302.6)

a - Spacing of longitudinal reinforcement in a column (figure 10, 19)

$a_{h, max}$ - Maximum expected horizontal ground acceleration (absolute value of maximum acceleration, m/sec^2)

a' ; b' - Edge dimensions of a thickened shear wall section (Figures 15, 22, 23)

B - The horizontal plan dimension of a structure, perpendicular to the direction of the seismic action.

B_x ; B_y - The width of the structure, in the x and y direction, respectively, on a discussed floor.

b - Thickness of wall.

b_c - Width of column.

b_j - Effective width of column at joint (for shear calculations).

b_w - Width of a beam.

C_d - Seismic design factor.

C_{dm} - Lateral mode seismic design coefficient of mode shape, m.

C_{gi} - Mass center at story, i.

C_{ki} - Stiffness center at story, i.

d - Distance between mass center and the stiffness center perpendicular to the direction of the seismic action (Figure 4); the allowable horizontal displacement at the top of the retaining wall (cm); the active depth of a concrete cross-section.

E - Maximum active force acting on a retaining wall.

E_{AE} - Active earth pressure on a retaining wall.

E_{PE} - Passive earth pressure at the base of a retaining wall.

E_{WE} - Dynamic force from pore water pressure on a retaining wall.

e - Eccentricity of load F_i relative to the mass center, perpendicular to the direction of the seismic action; beam eccentricity relative to column.

e_{Mx} ; e_{My} - Distance of the area centers, ΣA_{Mx} or ΣA_{my}, from the stiffness center of the structure, at the discussed story.

F_H - Total lateral design load (resultant).

F_{hm} - Total lateral modal design load of mode shape, m.

F_i - Resultant lateral design load of seismic force at story, i.

F_{im} - Lateral design load at story, i, of mode shape, m.

F_p - Seismic design load on a non-structural element.

F_T - Lateral design load, from the seismic effects, concentrated at the top of a structure.

F_v - Vertical design load, from the seismic effects.

f_{cd} - Design strength of concrete in compression = f_{ck} / γ_c .

f_{ck} - Characteristic strength of concrete in compression.

f_{ctm} - Average tensile strength of concrete in a shear wall or a frame.

f_{mk} - Characteristic strength of masonry walls in shear.

f_{sd} - Design strength of steel reinforcement or steel structures.

$f_{sd,L}$ - Design tensile strength of longitudinal steel reinforcement, = f_{sk} / γ_s

$f_{sd,h}$ - Design tensile strength of stirrups (hoops) or horizontal (transversal) steel reinforcement.

f_{sk} - Characteristic yield strength (nominal yield point) of steel reinforcement.

f_{vd} - Design strength of concrete in shear.

G_i - Characteristic dead load on story, i.

g - Acceleration of gravity (9.81 m / sec^2)

H - Total height of structure; height of a retaining wall above its base.

H_i - Height of floor story, i, above base level.

H_p - Part of the retaining wall height subjected to a passive force.

h_b - Depth of beam cross -section (m).

h_c - The horizontal dimension in a column cross-section perpendicular to b_c .

h_i - Height of story, i (m).

h_s - Floor thickness (figure 6).

h_w - Height of a wall in the structure.

h_x' ; h_y' - Distance between the axes of the extreme longitudinal reinforcement bars in a column, in the principal axis (figure 20).

I - Importance factor of a structure.

i - The number of the discussed story; slope of the soil behind a retaining wall relative to the horizon.

K - Force reduction factor of a structure, as specified in tables 5, 6, and 7.

K_{AE} - Active earth pressure coefficient on a retaining wall under earthquake conditions.

K_{PE} - Passive earth pressure coefficient at the base of a retaining wall under earthquake conditions.

k_h - Lateral seismic pressure coefficient. Its value depends on the allowable displacement of the retaining wall.

k_q - Live load frequency factor (Table 8).

l - Length of beam to center of joint, or length of column above center of joint.

l_a - Anchorage length of diagonal bars in coupled beam.

l_b - Clear length of a coupled beam.

l_1 ; l_2 - Span length of beams on both sides of the beam - column joint (center to center of joints).

l_{1n} ; l_{2n}	- Clear span length of beams on both sides of the beam - column joint (edge to edge of columns).
l_c	- Length of critical region in a column or a beam or a wall.
l_{c1} ; l_{c2}	- Length of columns in a beam - column joint (center to center of joints, above and below the joint).
l_n	- Length of column (clear length).
l_p	- Length of plastic joint region in a wall.
l_w	- Length of a wall (in the horizontal direction).
M	- Seismic participating mass in a mode shape, according to its location in the building.
M_0	- The moment that causes 0 (zero) compression stress on the edge of a column or a wall cross-section, under the same N_d (linear strain distribution).
M_1 ; M_2	- Moment capacity at both ends of the beam span (with the addition of upper sign, + or -).
M_d	- Calculated design moment (includes amplification factors) relative to the center of the cross section, at the analyzed direction.
M_u	- Flexural moment capacity of a wall cross section, according to its reinforcement.
M_{uc1} ; M_{uc2}	- Flexural moment capacity of a column, at a beam - column joint (above and below the joint).
M_{ul}	- Flexural moment capacity of a beam, left to the joint.
M_{ur}	- Flexural moment capacity of a beam, right to the joint.
N_d	- Design axial force (negative in compression).
n	- Number of stirrup legs; number of stories in a building.
P_{cs}	- Prestressed force that is caused by the tendons located at the central third of the beam depth, after losses.
Q	- Combined response value (Section 303.5).
Q_i	- Characteristic live load, concentrated or linear, at story, i.
Q_m	- Response value at mode shape, m.
q_i	- Characteristic live load distributed over an area, at story, i.
R_a	- Spectral amplification factor.
R_p	- Seismic amplification factor for non-structural elements.
S	- Site coefficient.

s - Spacing between vertical reinforcement in a shear wall.

s_h - Spacing between adjacent stirrups (or ties or hoops) along a beam or a column; spacing between horizontal reinforcement in a wall.

T - Fundamental period of vibration of a structure.

V_{cd} - Part of the shear force in a column carried by the concrete.

V_{ch} - Part of the horizontal shear force carried by the concrete at the joint.

V_{col} - Horizontal shear force in a column.

V_{cv} - Part of the vertical shear force carried by the concrete at the joint.

V_{cw} - Part of the shear force carried by the concrete in a shear wall.

V_d - Maximum design shear force in a shear wall or a coupled beam in a coupling shear wall.

V_i - Total horizontal shear force at story, i.

V_{id} - Maximum design shear force in a beam.

V_{im} - Total shear force at story, i, of mode shape, m.

V_{jh} - Horizontal design shear force at a joint.

V_{jv} - Vertical design shear force at a joint.

V_{max} - Maximum shear force in a beam.

V_{min} - Minimum shear force in a beam.

V_{rx} ; V_{ry} - Total story shear strength in the analyzed direction.

W - Total weight of structure above story discussed; weight loaded on an element ; total weight of element.

W_i - Total weight of story, i (in force units).

W_{im} - Active mode weight on story, i, of mode shape, m.

W_m - Total active mode weight of mode shape, m.

W_{min} - Minimum weight on an element at the serviceability limit state.

W_w - Weight of a retaining wall.

x - Distance from the neutral axis to the compressed edge in a wall.

$\bar{x}$ - Critical location to the neutral axis.

y - Distance of an element from the stiffness center, measured perpendicular to the direction of the seismic action.

Z - Expected horizontal ground acceleration coefficient (relative to acceleration of gravity, g).

z	- Moment arm of internal forces in a reinforced concrete element, at the ultimate limit state.
α	- Coefficient in equations (66) - (69).
α_h	- Slope angle of inclined stirrup, relative to axis of element.
β	- Inclination of a retaining wall relative to the vertical axis.
β_1	- Axial force coefficient, according to equation (76).
γ	- Unsaturated unit weight of soil.
γ_f	- Partial load safety factor.
γ_m	- Partial material safety factor (γ_c for concrete and γ_s for steel).
γ_n	- Performance coefficient.
γ_{sub}	- Saturated unit weight of soil.
γ_w	- Unit weight of water.
Δ	- Clearance between two adjacent structures or between two blocks in a specific structure.
$\Delta_{el,i}$	- Maximum story drift (of story, i), based on an elastic seismic analysis.
$\Delta_{i,lim}$	- Horizontal limit story drift of story,i.
$\Delta_{i,max}$	- Maximum expected real displacement at floor level, i, including torsional effects.
δ	- Friction angle between the wall and the backfill soil.
$\delta_{i,calc}$	- Maximum calculated displacement at floor level, i.
δ_{id}	- Horizontal design drift of story, i.
δ_{max}	- Maximum calculated displacement at floor level, i, including torsional effects, and excluding coefficient, A_T.
δ_{min}	- Minimum calculated displacement at floor level, i, including torsional effects, and excluding coefficient, A_T - simultaneous with δ_{max} (at opposite end).
ε_c ; ε_{cu}	- Maximum compression strain of concrete in a shear wall; compression strain of concrete.
λ ; λ_1 ; λ_2	- Coefficients to determine the hoop reinforcement ratio in a column, or the horizontal reinforcement in a shear wall.
μ ; ν	- Coefficients in equations (26), (27).

ρ - Tension reinforcement ratio in a cross-section.

ρ' - Compression reinforcement ratio in a cross-section.

ρ_c - Total longitudinal reinforcement ratio in a column.

ρ_h - Volumetric ratio in a column, or horizontal reinforcement ratio in a shear wall.

ρ_{max} - Maximum reinforcement ratio.

ρ_{min} - Minimum reinforcement ratio.

ρ_v - Vertical reinforcement ratio in a shear wall.

ϕ - Diameter of plain steel bar; internal friction angle of soil.

ϕ_b - Friction angle between the base of a retaining wall and the soil.

ϕ_h - Diameter of stirrup (or hoop or tie) bar.

ϕ_{im} - Mode displacement at story, i, of mode shape, m.

ϕ_L - Diameter of longitudinal reinforcement bar.

θ - Obtained angle, according to equation (87), for the stability of a retaining wall.

θ_i - Deformability index of story, i.

θ_{im} - Deformability index of story, i, at mode shape, m.

ξ - Ratio between minimum shear force and maximum shear force; Eccentricity effect coefficient.

Σ - Sum, of all stories in a structure, or of all its mode shapes.

τ_d - Design shear stress in a beam or column.

τ_{d1} - Design strength of concrete in shear.

ω - Dynamic amplification factor for moment capacity in walls.

$\bar{\Phi}$ - Diameter of a deformed steel bar.

.105 Classification of structures

105.1 This Standard applies to the following types of structures:

105.1.1 Residential buildings, except a "low structure" (section 103.6);

105.1.2 Public buildings;

105.1.3 Industrial and storage structures, except a "low structure";

105.1.4 Chimneys;

105.1.5 Silos [(2)];

105.1.6 Reservoirs [(2)];

105.1.7 Bridges[(3)];

105.2 This Standard does not apply to the following types of structures (The requirements on these structures are more severe);

105.2.1 Nuclear plants;

105.2.2 Pressure vessels;

105.2.3 Security installations and other structures that their demolition could endanger a large population.

105.3 Types of structures, materials, and construction methods that are not detailed sufficiently in this Standard, shall be designed according to the appropriate requirements that appear in the foreign documents mentioned in section .102

.106 Documentation

106.1 The documents of the designer shall detail the basic parameters for the seismic design:

- This Standard;
- The ground acceleration and ductility level that have been considered in the seismic design calculations, or in the calculation of the coefficient, C_d ;
- A description of the lateral forces resisting system;
- Whether the calculations were performed manually or by a digital computer.

(2) Silos and reservoirs calculations shall include their contents response to the motion of the structure, at different filling levels (information is available in the technical literature).

(3) Bridges design shall be performed according to the Israeli Standard SI 1227. The chapter on seismic design is under preparation on the publishing day of this Standard. Meanwhile, bridges shall be designed for seismic resistance according to this Standard.

106.2 In the case of manual calculations, partial or full, all manual calculations of the seismic design of the engineer shall be kept, as part of the duty to keep all calculations concerning the stability of the structure.

In the case that the calculations were performed using a computer, the following items, signed personally by the engineer, shall be added to the documents:

- A drawing of the computational models used to represent the structure in the computer-generated analysis;
- Names and editions of computer program used, and their manuals (including all necessary material to determine the nature and extent of the analysis, verify the input data, and interpret and analyze the results).

106.3 The designer shall also keep, as part of the duty to keep all calculations concerning the stability of the structure, the following documents:

- A complete printout of input information, as was provided to the computer, with the signature of the designer, his/her full name, and the date of processing .
- The output results in the form of computer printout, and magnetic tape or a diskette.

.107 Design control and construction

For structures of groups A, B (Section 204.3), and high rise structures of groups C, in all parts of the country, the following design control and construction shall be required:

- Design control - Performed by an independent professional civil engineer, who is an expert in earthquake design of structures. This requirement shall apply after the formal publication of the Israeli design and construction specifications.
- Preparation of a specification, for the control of materials and their tests (in addition to the regular control) - by an experienced engineer, that shall check the laboratory test reports ,and shall periodically visit the construction site, in order to harmonize the construction to the specifications and the plans.

.108 Extensions to existing structures

An extension to existing structure shall be designed considering the resistance of the whole structure (including the extension) to an earthquake, as a function of the area of the existing structure. The following minimum requirements shall be fulfilled:

- 25% extension to existing structure area - resistance of 2/3 the load required in this Standard
- 50% extension or more to existing structure area - resistance as required by this Standard
- 25 % to 50% extension to existing structure area - resistance calculated by linear interpolation between the above cases.

CHAPTER B - Characteristics of the Seismic Action

.201 General

201.1 Seismic action for the design of structures

201.1.1 The seismic action

The seismic action is an action that its effects are combined with the effects of all dead loads and live loads (Israeli Standard SI 412), in order for the structure to fulfill all the static and dynamic requirements described in this Standard and the Israeli Standards SI 466 with in its parts, and SI 1225 part 1.

In case of discrepancies, the requirements of this Standard shall be governed.

Wind loads shall not to be combined with earthquake loads[(4)].

The characteristic effects of the concrete and the reinforcement steel of the elements in the bearing stiffening systems shall comply with requirements in Section 402 (for example: columns, beams, flat slabs, shear walls, shafts, ans stiffening cores)

(4) If the wind load, according to the Israeli Standard SI 414, has a greater effect on the structure than the seismic loads - the wind effects shall determine the strength of the structural elements and their cross-sections, but the structural detailing and the reinforcement shall also comply with the requirements of this Standard (Israeli Standard SI 413).

201.1.2 Principal parameters

The principal parameters for determining the size of the forces for the seismic calculation of the structure are the following:

Z - Expected horizontal ground acceleration coefficient (Section 202.1);

S - Site coefficient (Section 202.2);

T - Fundamental period of vibration of the structure (Section 203.4);

R_a - Spectral amplification factor (Section 203.5);

I - Importance factor of the structure;

K - Force reduction factor of the structure;

All these parameters affect the value of the seismic design coefficient, C_d (Section 204.2)

.202 Site characteristics

202.1 Expected ground acceleration

The expected ground acceleration is a forecast of the maximum expected horizontal ground acceleration, $a_{h,max}$, for which there is a 90% probability that a stronger earthquake shall not occur at the studied site, for a return period of 50 years (measurements to assist updating of the forecast are described in Appendix A).

In Appendix B, a map with the values of Z is presented:

$$Z = a_{h,max} / g$$

202.2 Influence of soil profiles

The effects of the ground conditions at the site on the structural response shall be determined by the soil profile, as listed in Table 1, and detailed in the Israeli Standard SI 940. Sites that do not have enough information on soil properties, or that the existing profile does not match to any of the eight profiles detailed in the table, the more similar of the described profiles shall be used. In sites, where not enough information on the soil properties is available, the site coefficient shall be taken as: $S = 1.5$

Table 1- Site coefficient by description of soil profile

(applies to stable soil conditions)

Description of soil profile		Type of soil	Site Coefficient
A B C	A rock-like material; Soil (rock or soil) characterized by a shear - wave velocity greater than 800 m/sec; Stiff soil where the soil depth is less than 60 m, located above a rock layer, and includes a stable sand layer	S_1	S = 1.0
D	Noncohesive deep layers (thickness greater than 60 m), located on a rock layer	S_2	S = 1.2
E F G	Layers of soft clay or dry sand, with a thickness greater than 10m, with a low or average stiffness, characterized by clearly defined layers, with no intermediate layers of other materials; Same as above section, but includes intermediate layers of sand or any other noncohesive soils; All soils that have not been analyzed, or are not included in the other descriptions.	S_3	S = 1.5
H	A soil profile containing soft clay layers of 12 m or more.	S_4.	S = 2.0

.203 Structural characteristics

Structures shall be designated as being regular or irregular.

203.1 Regular structure

A structure that has all the following characteristics:

A. Horizontal configuration:

- The structure has an approximately symmetric layout. In the case of reentrants features, the dimensions of each reentrant shall not be greater than a quarter of the smallest external dimension of the structure (Figure 1), if their depth is greater than, the smaller between 2.5m or 1/10 the horizontal dimension of the structure in the direction of the depth of the reentrant;

- The total floor area that serves as a diaphragm shall not be less than half the inner area (in the convex polygon) of the discussed story;
- In every story, the distance, d, that is perpendicular to the direction of the seismic action (Figure 4), between the mass and stiffness centers (definition 103.18) shall not exceed 15 % of the rigidity radius (definition 103.31) calculated in this direction (as detailed in the Commentary [(5)])
- There shall be no horizontal discontinuities in the lateral force resisting systems;
- The maximum calculated story drift, including the torsional effect, shall not be greater than 50 % of the drift at the opposite end of the same story;

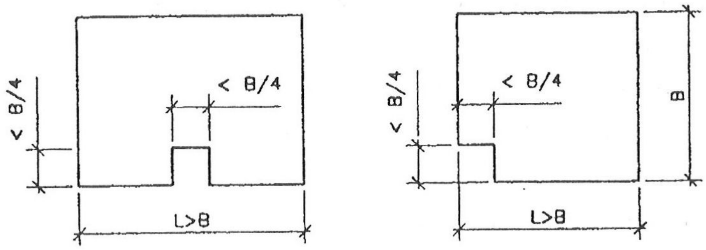


Figure 1 - Structures with reentrants

B. Vertical configuration:

- There is no restriction on the vertical configuration, in one story structure, or a two story structure with a height that is less than 11 m;
- There shall be no flexible story in the structure (definition 103.26)
- There shall be no soft story in the structure (definition 103.27);
- For framed structures, the ratio between story shear capacity and the design shear force shall not differ by more than 20% from story to story. This requirement does not apply to the uppermost story in all structures, or the two uppermost stories in structures with seven stories or more;

(5) The Commentary is currently being prepared.

- There shall be no vertical discontinuity in the lateral force resisting system.
- There shall be no story that its total mass is 50 % larger than that of any story below;
- In a structure that its horizontal dimensions gradually decrease along the height of the structure (figure 2), there shall be no reduction in the dimensions at the lower part of the structure(15 % of the total height), and the dimension reduction in every floor above this part shall be less than 10 % of the horizontal dimension in the direction of the reduction..

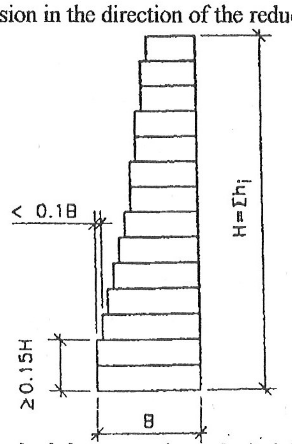


Figure 2 - Gradual decrease along the height of the structure

203.2 Irregular structure

A structure that violates any of the above conditions.

203.3 Design limitations

- The design of regular structures can be performed using the equivalent static analysis (section 302) in all seismic zones, except in the case of structures that are taller than 80 m, or structures that their fundamental period is longer than two seconds.
- The design of the following structures shall be done only using the modal or the dynamic analysis (section 303): structures taller than 80 m, or structures that their fundamental period is longer than 2 sec, and irregular structures to which, according to Table 9 (section 301.3), the equivalent static analysis does not apply.
- A structure with an especially weak story (definition 103.27), that has a shear resistance to lateral forces smaller than 0.65 times the shear resistance of the above story, can be constructed, only if the following two conditions are fulfilled:

- The structure shall not have more than two stories;
- The height of the structure from the base, shall be less than 9 m.

These two requirements shall not apply provided that the shear capacity of the weak story, the shear capacity of the story above, and the shear capacity of the story below, are sufficient to carry a resultant lateral seismic load equals to 0.75K times the design load mentioned in section 302.1 (K is the force reduction factor according to Section 204.4).

203.4 Fundamental period of vibration of structure

The fundamental period, T, of structure is calculated using an accepted method in dynamics (the period calculation is required for determining the spectral amplification factor R_a and the seismic design coefficient, C_d), considering the properties of the structure (elastic, and uncracked), and all those elements which contribute to the stiffness of the structure. In the equivalent static analysis it is allowed to determine the fundamental period by experimental results or by approximation methods. For the determination of R_a only, T can be calculated using the following approximation formulas (1):

for reinforced-concrete moment resisting space frames

$$T = 0.073\, H^{3/4} \qquad (1A)$$

for steel moment resisting space frames

$$T = 0.085\, H^{3/4} \qquad (1B)$$

for all other structures

$$T = 0.049\, H^{3/4} \qquad (1C)$$

Alternatively, the fundamental period of vibration, T, shall be calculated by one of the dynamic methods, with the restriction that the period shall not be longer than the time calculated according to the following formulas (2) (these formulas ensure that at least 80% of the total lateral load calculated using formulas (1)is included):

for reinforced-concrete moment resisting space frames

$$T = 0.102\, H^{3/4} \qquad (1A)$$

for steel moment resisting space frames

$$T = 0.119\, H^{3/4} \qquad (1B)$$

for all other structures

$$T = 0.068\, H^{3/4} \qquad (1C)$$

where:

H - total height of structure, m

T - fundamental period of vibration of a structure, sec.

203.5 Spectral amplification factor

This factor is obtained from the average spectrum, which is constructed from the response spectra data of various earthquakes, obtained from accelerograms, and normalized to a peak acceleration of 1.0g, and a damping coefficient of 5%.

The ordinates, R_a, of the spectral amplification factor (for horizontal seismic action),are described by the four curves in figure 3. This coefficient depends on the type of soil, the fundamental period, T, and the method of analysis.

The values of R_a are determined by formula (3) and the formulas in table 2, and are restricted to the conditions in equations (4):

$$R_a\,(T) = 1.25\ S\,/\,T^{2/3} \qquad (3)$$

in equivalent static analysis,

$$2.75 \geq R_a \geq 0.20\ K \qquad (4A)$$

in modal analysis,

$$2.50 \geq R_a \geq 0.20\ K \qquad (4B)$$

where:

K - Force reduction factor of a structure, as listed in either tables: 5, 6, 7

T - Fundamental period of vibration of the structure, sec.

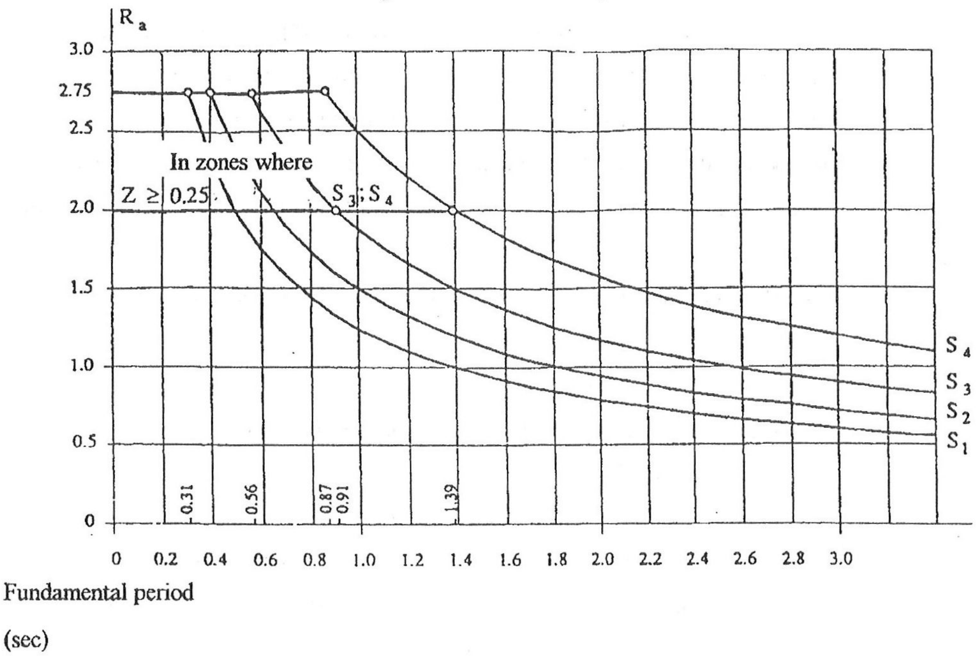
S - Site coefficient

R_a - Spectral amplification factor

Table 2 - Values of spectral amplification factors for lateral seismic action

Z	$R_a(T)$	Range of period T (sec) for soil type			
		Limitation of Z values		For all Z	
		S_4	S_3	S_2	S_1
EQUIVALENT STATIC ANALYSIS					
< 0.25	$R_a(T) = 2.75$	≤ 0.87	≤ 0.56	≤ 0.40	≤ 0.31
≥ 0.25	$R_a(T) = 2.00$	≤ 1.39	≤ 0.91	-	-
<0.25 ≥0.25	eq. (3), (4A) eq. (3), (4A)	> 0.87 > 1.39	> 0.56 > 0.91	> 0.40 > 0.40	> 0.31 > 0.31
MODAL ANALYSIS					
< 0.25 ≥0.25	$R_a(T) = 1+10T$ $R_a(T) = 1+10T$	< 0.15 < 0.10	< 0.15 < 0.10	< 0.15 < 0.15	< 0.15 < 0.15
< 0.25 ≥ 0.25	$R_a(T) = 2.50$ $R_a(T) = 2.00$	0.15 - 1.00 0.10 - 1.39	0.15 - 0.65 0.10 - 0.91	0.15 - 0.46 -	0.15 - 0.35 -
< 0.25 ≥ 0.25	eq. (3), (4A) eq. (3), (4A)	> 1.00 > 1.39	> 0.65 > 0.91	> 0.46 > 0.46	> 0.35 > 0.35

For equivalent static analysis



For modal analysis

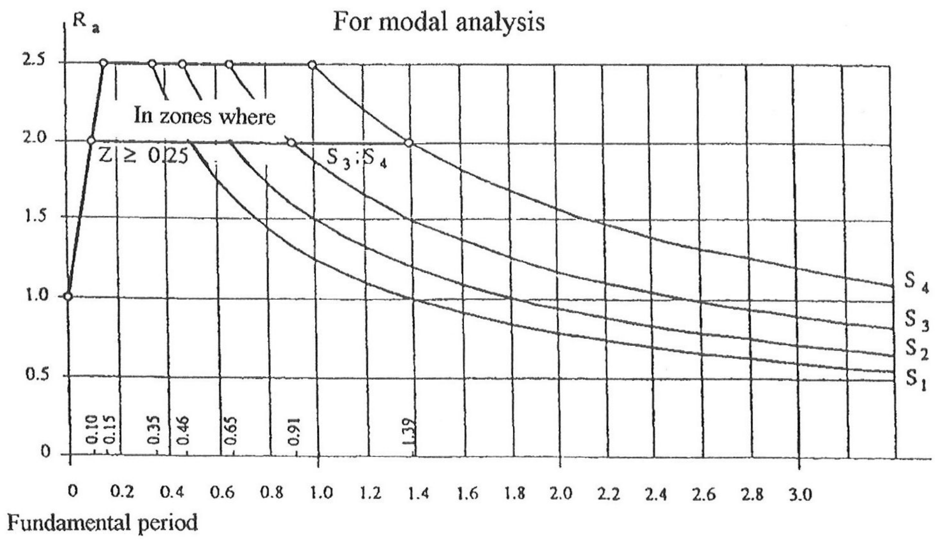


Figure 3 - Spectral amplification factor for lateral seismic action

In the case that the fundamental period of vibration of the structure is not determined in the analysis, the following value is inserted in equation (5), for all types of soils:

the value	$R_a = 2.75$	in equivalent static analysis
the value	$R_a = 2.50$	in modal analysis

In modal analysis, when the period of mode, m, is shorter than 0.15 sec - R_a decreases linearly from a value of 2.5 for 0.15 seconds, to a value of 1.00 for 0 seconds (bottom of Figure 3).

In both types of structural analysis, in a zone where $Z \geq 0.25$ and the soil is of type S_3 or S_4, the following limitation applies:

$$R_a \leq 2.0$$

The instruction of this section are also described in Table 2 and Figure 3.

Amplification factor for the vertical action:

The spectral amplification factor for the vertical action is calculated by multiplying the ordinates of the spectral amplification factor for the horizontal action by 2/3 (that is, the values for calculating vertical accelerations are determined by multiplying by 2/3 the values obtained from equation (3) and the equations in table (2)).

.204 Design loads

204.1 Directions of the seismic action

204.1.1 Horizontal action

A general assumption, that the effect of the horizontal seismic action causes the most dangerous damage to all elements, is assumed.

For a regular structures, it is sufficient to analyze the structure, separately, in each of its principal axis (the approximated axis). The conditions for combining the two directions shall be specified in the following sections.

204.1.2 Vertical action

The effect of the vertical seismic action shall be considered in the design of cantilevers, prestressed concrete beams (SI 466, part 3), and beams which support columns (Section 302.4).

204.2 Seismic design factor

The value of the seismic design factor, C_d, is obtained from the spectral amplification factor, R_a (section 203.5), and it shall be the larger of the values calculated by the following formulas, (5) and (6) :

$$C_d \geq R_a I Z / K = R_a I a_{h,max} / (g K) \quad (5)$$

$$C_d \geq SIZ / \sqrt{(3K)} \quad (6)$$

where:

I - Importance factor of the structure (Table 4)

$Z = a_{h,max} / g$ - Expected horizontal ground acceleration coefficient (according to the map in Appendix B), but not less than 0.075

g - Acceleration of gravity (9.81 m/sec^2)

$a_{h,max}$- Maximum expected horizontal ground acceleration (absolute value of maximum acceleration)

K- Force reduction factor of the structure (table 5, 6, or 7)

S - Site coefficient

The value of C_d in a reinforced concrete structure, is not required to be higher than the values listed in Table 3, for all possible combinations of conditions

Table 3 - Maximum values for the seismic design factor for reinforced concrete structures

Ductility level	Low	Medium	High
max value of C_d	0.30 I	0.20 I	0.15I

204.3 Importance factor

The protection level from a seismic action, that is to be granted to a specific structure, is related to its social - economical importance. Structures will be classified into three groups as listed in Table 4.

Table 4 - Importance factor of a structure

Group	Type of structure	Importance Factor
A	Essential facilities, required to be usable during and after an earthquake: communication facilities, power stations, hospitals, fire stations, police stations, first aid stations (including service buildings and water tanks that serve them)	I = 1.4
B	Public structures, specified by the authorities, that can be escapable, such as: schools, cinemas, synagogues, public facilities where a large concentration of people is expected	I = 1.2
C	All structures not included in Groups A, or B	I = 1.0

204.4 Force reduction factor

Force reduction factors, K, for reinforced concrete structures, are listed in Table 5.
Force reduction factors, K, for steel structures, are listed in Table 6.
Force reduction factors, K, for special structures, are listed in Table 7.

Table 5 - Force reduction factor, K, for reinforced concrete structures

Resisting system	Ductility level			
	Low	Medium	High	
Moment resisting frames	4.0	5.5	7.0	
Braced frames	3.5	4.5	6.0	
Shear walls (A)	4.0	5.5	7.0	A
Dual systems (A)	3.5	5.0	6.0	B

Comments:

(A) The values, K, for shear walls and dual systems, listed in line A, are only valid when the condition that at least 50% of the lateral forces in both directions are resisted by coupled shear walls.

If this condition is not fulfilled, the values, for all ductility levels, of K, are listed in line B.

Table 6 - Force reduction factor, K, for steel structures

Resisting system	K
Flexural moment resisting frames	8
Ductile dual systems[(A)]	7
Regular dual systems[(A)]	4
Braced systems:	
X truss systems	4
V truss systems	2
K truss systems	1
Comment to table: (A) In dual systems the walls can be of reinforced concrete	

Table 7 - Force reduction factor, K, for special structures

Structure	K
Reinforced concrete chimneys and silos cast in situ, their walls starting from the foundation level, cooling towers, signs, shelves in warehouses	3.5
Chimneys and silos (not mentioned above), vertical industrial production facilities, bunkers, antenna towers (cantilevered or anchored by cables), and all other buildings (auto supported) not mentioned	2.8
Tanks, water towers, cantilevered structures with concentrated mass at their top, entretainment facilities, monuments	2.0

204.5 Limitations of the different ductility levels and the reduction factor

204.5.1 A low ductility level shall be permitted only to low structures and structures of Importance Group C and a zone where $Z \leq 0.20$, structures of Importance Group B and a zone where $Z \leq 0.10$, and structures of Importance Group A and a zone where $Z \leq 0.075$. Structures of Importance Group A, located in a zone where $Z \geq 0.10$, shall be designed with the appropriate reduction factor corresponding to medium ductility level. (even if their elements are detailed to a high ductility level).

204.5.2 In the case of a regular structure with infill walls (structural or non-structural) that complys with the condition of a regular structure (both in the vertical and horizontal configuration), it is permitted to increase the value of K by 15%.

204.5.3 In dual system (reinforced concrete or steel), if the shear walls are capable to resist all the lateral loads, and the frames are capable to resist at least 25% of these loads - it is allowed to increase the values of K by 15%.

In systems that fulfill the condition of this section and also the condition in Section 204.5.2, it is allowed to increase the value of K by 25%.

204.6 Story shear resistance

The story shear resistance shall be calculated separately for each of the principal directions, in order to check for the existence of a weak story (definition 103.27), according to Section 203.1.

The calculations of the story shear resistance shall consider all the structural elements (such as: concrete or steel columns, reinforced concrete walls, coupled shear walls, vertical concrete or steel bracing) that resist the story shear force in the direction considered, and masonry walls with a thickness of 15 cm or more, parallel to the considered direction, if they framed by concrete columns or walls, at both their ends - excluding their opening lengths. The total story shear resistance in the direction considered shall be calculated using equations (7) and (8):

for concrete:

$$V_{Rx} = 10\,(\Sigma A_{cx})\,f_{vd} + 0.4\,(\Sigma A_{Mx})\,f_{mk} \qquad (7\ A)$$

$$V_{Ry} = 10\,(\Sigma A_{cy})\,f_{vd} + 0.4\,(\Sigma A_{My})\,f_{mk} \qquad (7\ B)$$

for steel:

$$V_{Rx} = 0.577\,(\Sigma A_{sx})\,f_{sd} + 0.4\,(\Sigma A_{Mx})\,f_{mk} \qquad (8\ A)$$

$$V_{Rx} = 0.577\,(\Sigma A_{sy})\,f_{sd} + 0.4\,(\Sigma A_{My})\,f_{mk} \qquad (8\ B)$$

where:

V_{Rx} ; V_{ry} - total story shear strengths along the considered direction

$\Sigma A_{cx} \Sigma A_{cy}$ - the total cross- section areas of the reinforced concrete columns and walls along the direction considered

ΣA_{mx} ; ΣA_{my} - the total cross-section areas of the masonry walls along the direction considered

ΣA_{sx} ; ΣA_{sy} - total cross-section areas of the steel column webs along the considered direction

f_{vd} - design strength of concrete in shear (6)

f_{sd} - design strength of steel columns

f_{mk} - characteristic shear strength of the masonry walls:

0.2 MPa - for masonry walls with a mortar of at least 10 Mpa compressive strength;

0.1 MPa - for similar walls, with a weaker mortar.

204.7 Limitations on location of masonry walls

In order to avoid the negative effects caused by eccentric distribution of the masonry walls on a discussed floor level, the following conditions (9) shall be obeyed on each floor:

$$e_{Mx} < 0.1\ B_y \quad ; e_{My} < 0.1\ B_x \tag{9}$$

where:

e_{Mx} ; e_{My} - the distances between the structural rigidity center to the centers of the areas, ΣA_{mx} or ΣA_{my}, respectively, at the discussed story (measured perpendicularly to the analyzed wall)

B_x ; B_y - width of the building at the same story along the x and y directions, respectively.

In the case that one of these conditions is not satisfied, the position of the story rigidity center, shall be calculated considering also the stiffness of the masonry walls. For this purpose, hollow concrete walls and sand-lime brick walls are considered with an elastic modules of 2000 MPa; and walls built of Ytong blocks are considered with an elastic modules of 1200 MPa.

(6) Until the publication of the revision to the Israeli Standard SI 466 shall be in action - approximate values shall be used: $f_{vd} = 0.5 \times \tau_{d1}$; $f_{cd} = 0.5 \times f_{ck}$

CHAPTER C - Methods of Structural Analysis

.301 General

301.1 Analytical model

The evaluation of the seismic affect on a structure is based on an analytical model that represents the response of the real structure. The model includes all relevant structural and non-structural elements which influence the response of the structure.

This Standard assumes a linear elastic behavior of the structure, for calculating the design loads.

301.2 Loads

In the calculations of the seismic effects, all the weights, W_i, of the building are considered as the cause and origin of the inertial forces that develop during an earthquake, as follows:

$$W_i = G_i + k_q (Q_i + A_i q_i) \quad (10)$$

$$M = W_i / g \quad (11)$$

where :

W_i - total weight of story, i (in force units)

G_i - characteristic dead load on story, i

Q_i -characteristic live load, concentrated or linear, on story , i

q_i -characteristic live load, distributed over an area, at story, i

A_i - area on a discussed floor, i, loaded with a live load, q.

k_q - live load frequency factor (Table 8)

M - seismic participating mass in a mode shape, according to its location in the building

g -acceleration of gravity (9.81 m/sec^2)

The effect of W_i (multiplied by the partial load factor $\gamma_f = 1.0$) shall always be considered in the seismic calculations.

Table 8 - Live load frequency factor

type of structure	frequency factor
roofs with no access	$k_q = 0$
dwellings and office buildings	$k_q = 0.2$
auditoriums and parking	$k_q = 0.3$
warehouses, libraries, archives	$k_q = 0.5$
silo and reservoirs	$k_q = 1.0$

301.3 Types of analysis

In Table 9, the different types of analysis are detailed according to the characteristics of the structure.

Table 9 - Type of analysis according to the characteristics of the structure

type of analysis	type of structure
equivalent static analysis (section 302)	applicable only to the following structures: A. regular structures of Importance category B or C, up to 80m tall, and with a fundamental period less than 2 sec, located in all zones; B. irregular structures of Importance category C, with the height and fundamental period limitations as above, but located in a seismic zone with $Z \leq 0.075$; C. structures of Importance category C, with a flexible story, and the rest of the stories are considered regular - provided that the structure does not have more than 5 stories above the lowest base level, and it complys with the requirements of section 403.4; D. Regular or irregular structures, in all seismic zones, up to 20 m tall above the base level, which do not have more than 5 stories above the lowest base level - provided that there are no flexible or weak story, and the distance between the mass and rigidity center is less than 15% of the structural plan dimension in the same direction.
modal analysis (Section 303)	applicable to all structures in all seismic zones (the use of other common dynamic analysis methods is also allowed)

301.4 Drifts and displacements

The instructions and requirements described in Sections 403.2.2, 403.2.3, 403.2.5 and its subsections - apply to all types of structures, of all material, and all analysis procedures.

.302 Equivalent static analysis

302.1 Total lateral design load

Total lateral design load, F_H, acting at the base of the structure in the direction considered (with equivalent value to the total design base shear), is calculated separately in each direction using Equation (12):

$$F_H = C_d \sum_i W_i \qquad (12)$$

where:

C_d - seismic design factor

W_i - total weight of story,i (in force units)

302.2 Concentrated load at top of structure

On a structure, analyzed by the equivalent static analysis, with a fundamental period longer than 0.7 sec, a lateral design load, F_T, from the seismic effects, concentrated at the top of a structure, shall be exerted (in addition to the distributed design load, as specified in Section 302.3). This force is calculated according to Equation (13):

$$F_T = 0.07\,T\,F_H \leq 0.25\,F_H \qquad (13)$$

where:

T - fundamental period of vibration of a structure

A structure that its period is shorter than0.7 sec, and is analyzed by the modal analysis, this concentrated load shall not be applied.

In stability calculations against overturning, the effects of F_T, can be neglected.

302.3 Lateral design load distributed along height of structure

The remaining design lateral load, $F_H - F_T$, is distributed along the height of a regular structure as a sequence of concentrated equivalent forces acting at the floor levels. The lateral load at every floor level, i, along the discussed direction, is calculated according to Formula (14):

$$F_i = (F_H - F_T) W_i H_i / \sum_i (W_i H_i) \qquad (14)$$

where:

F_i - resultant lateral design load of seismic force at story, i

F_H - total lateral design load (Section 302.1)

F_T - lateral design load from the seismic effects,concentrated at the top of the structure (Section 302.2)

W_i - total weight of story, i (in force units)

H_i - height of floor story, i, above base level

the load F_i at the top floor story level is added to the load F_T acting at that level.

302.4 Vertical design loads

In the equivalent static analysis a vertical load, F_v, is applied only on elements that are sensitive to this component of the load (prestressed beams, cantilevers, beam that carrying columns, etc.). The force reduction factor is, K = 1. This force is calculated according to Equations (15), (16), and (17):

on horizontal cantilevers, acting upwards and downwards, without live load -

$$F_v = \pm (2/3)\, Z\, W \quad (15)$$

on prestressed beams, as a combined load with the minimum load, directed downwards-

$$F_v = W_{min} (1 - 1.5\, Z\, I\, S) \geq 0.5\, W_{min} \quad (16)$$

on beams carrying columns within their span -

$$F_v = W\, [\, 1 \pm (2/3)\, Z\, I\, S\,] \quad (17)$$

where:

F_v - vertical design load from the seismic effects

I - importance factor of structure

S - site coefficient

W - weight loaded on an element

W_{min} - minimum weight loaded on an element at serviceability limit state

Z - expected horizontal ground acceleration coefficient (according to the map in Appendix B), but not less than 0.075.

302.5 Horizontal distribution of the design load

The design load F_i at every floor, shall act at the floor level and shall be divided among the different stiffening elements at that floor, by one of the accepted engineering procedures, according to their stiffness and location. It is assumed that the floor is a horizontal diaphragm rigid in its plan (Section 305.1).The floor displacements and rotations are dependent on the size and direction of the resultant (sum) lateral forces above the discussed floor, and its location relative to the center of rigidity of the discussed floor.

All elements resisting the lateral loads, even if they are not part of the system resisting the lateral load of the same direction, are analyzed for their ability to handle their vertical loads, when their horizontal displacement, according to their location, (Section 403.2.3), in every floor, is K times greater than the displacement calculated by the elastic method, considering the design forces mentioned above.

302.6 Torsional effects

It is assumed that in every floor, the total mass contributing to the inertial forces, is moved from its original position, C_{gi}, a distance, $\pm e$ (Figure 4). The displacement that causes the more dangerous condition on the discussed elements, is calculated. The amount of displacement is determined from Equation (18):

$$e = \pm 0.05\ B \qquad (18)$$

where here, and in Figure 4:

- e - eccentricity of load F_i relative to the mass center, perpendicular to the direction of the seismic action
- B - horizontal plan dimension of the structure, perpendicular to the direction of the seismic action
- d - distance between the mass center and the stiffness center, perpendicular to the direction of the seismic action (Figure 4)
- C_{Gi} - mass center at story, i
- C_{Ki} - stiffness center at story, i

If under the torsional effect, the calculation of the more dangerous condition, according to Equation (18), yields that $\delta_{max} > 1.5\ \delta_{min}$, or $\delta_{max} * \delta_{min} \leq 0$, then the torsional effect is increased in the following way:

- In a repeated calculation, the displacement dimension, e, of Equation (18), is multiplied by an amplification factor, A_T, determined from Equation (19):

$$A_T = 2.78\ [\ \delta_{max} / (\delta_{max} + \delta_{min})]^2 \qquad (19)$$

with the following restriction:

$$3.0 \geq A_T \geq 1.0$$

where:

- δ_{max} - the maximum horizontal displacement at floor, i, including the torsional effect of Equation (18), but not amplified by A_T.

δ_{min} - the minimum horizontal displacement at floor, i, including the torsional effect of Equation (18), but not amplified by A_T, calculated at the same time, t, as δ_{max} .

In structures (structures that can be analyzed by two separate models, according to Section 303.2), defined symmetric by their mass and stiffness distribution around an axis parallel to the direction of the seismic action, calculating the effect of torsion distributed along the height, may be accounted for in a simpler way:

The influence of the seismic forces on the stiffening element, calculated without the effects of torsion(only translation), is amplified by multiplying the results by a factor, ξ, determined from Equation (20):

$$\xi = 1 + 0.6\, y / B \qquad (20)$$

where:

ξ - amplification factor

y - the plan distance from the stiffening element to the stiffness center, perpendicular to the seismic action

B - the horizontal plan dimension of the structure perpendicular to the seismic action

The results shall not to be less than the absolute value obtained from the calculation with torsion, according to Equation (18), and with no amplification. In the case that from Equation (20) it is obtained, that $\delta_{max} > 1.5\, \delta_{min}$, Equation (19) shall be used, even in the case of a symmetric structure.

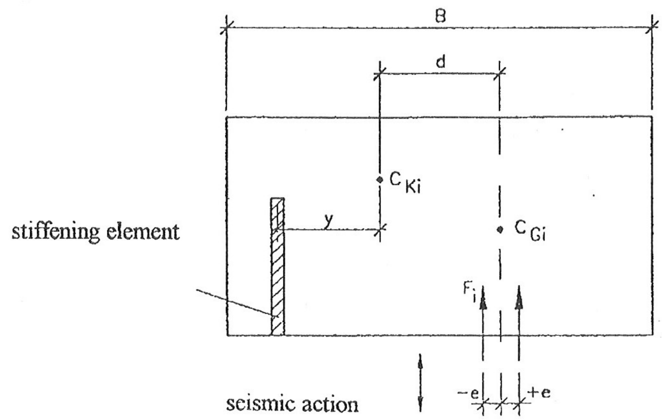


Figure 4 - Effect of torsion

302.7 P - Delta effect

The P - Delta effect on the shear forces and moments at the different floors shall not be considered, when the following condition is satisfied:

$$\theta_i = \frac{W \Delta_{el,i} K}{V_i h_i} \leq 0.10 \qquad (21)$$

where:

θ_i - deformability index of story, i

W - total weight of structure above story discussed, i

$\Delta_{el,i}$ - maximum story drift, based on an elastic seismic analysis, using the design loads obtained from Equations (5), (6), (12)

K - Force reduction factor of a structure (Table (5), (6), or (7))

V_i - total horizontal shear force at story, i

h_i - height of story, i (m)

When the condition $0.10 < \theta_i \leq 0.20$, is satisfied, the P -Delta effect must be considered, using any of the accepted methods of analysis.

The deformability index, θ_i, shall not exceed 0.20, for any story.

302.8 Two-parts analysis of tower structures

Structures, that consist of a flexible multi-story building (flexible tower) located on a wide and stiff structure (together they are called a tower structure), can be analyzed by the two -parts analysis, when the following three conditions are fulfilled:

- each of the two parts of the structure, is regular structure by itself;
- the average stiffness of the stories in the wide and stiff structure, is ten times or more, larger than the average stiffness of the flexible tower;
- the fundamental period of the flexible tower, which is rigidly connected to the wide and stiff structure, is longer than the fundamental period of the tower structure multiplied by a factor of 0.9.

The two-parts analysis shall be carried out as follows:

- the flexible tower is designed as a separate structure which is rigidly connected to the wide and stiff structure at the connecting level, where a K factor, correspond to the characteristics of the flexible structure is chosen;

- the wide and stiff structure shall be designed as a separate structure, where a second K, that corresponds to the characteristics of this structure, is chosen. The seismic loads from the flexible tower, are increased by an amount equivalent to the ratio between the two K values. These loads act at the connecting level between the two structures (in addition to the loads from the weight of the wide and stiff structure that act at the connection level).

.303 Modal analysis

303.1 Design spectrum

The design spectrum for all mode shapes and periods shall be the value of the seismic design factor, according to Section 204.2, normalized with the spectral amplification factor curve, corresponding to the appropriate type of soil, according to Section 203.5.

303.2 Analysis model

The structure, if it vibrates in two perpendicular direction with no significant coupling, is analyzed by two separate - planar analytical models, one for each perpendicular direction. The significant values, for the purpose of design, are combined according to the Square Root of the Sum of Squares method (SRSS) (as detailed in the Commentary) [(5)] in addition to a similar calculation method for the mode shapes combination, in each direction. When significant coupling occurs, the analysis shall include a three-dimensional structural model.

303.3 Mode shapes

Calculations by the modal analysis shall include at least the following mode shapes:

A. **Two-dimensional models**

Every perpendicular direction shall include all mode shapes with a period longer than 0.4 sec. In the case that less than 3 modes are included, at least 3 modes, with the longest periods (including period less than 0.4 sec) shall be considered.

B. **Three-dimensional models**

Every seismic action direction, shall include all mode shapes with a period longer than 0.4 sec. In the case that less than 4 modes are included, at least 4 modes, two of which are mainly circular (including period less than 0.4 sec) shall be considered.

C. When the particitation factor sum (see following comment) of the mode shapes mentioned in A or B is less than 90%, additional modes are added to reach the 90%, in every direction.

comment:

the participation factor is the ratio $W_m / \sum W_i$, according to Equation (23)

303.4 Lateral design loads

The total lateral modal design load, F_{hm}, shall act at the base of the structure in each of the mode shapes included in the model, as follows:

$$F_{Hm} = C_{dm} W_m \qquad (22)$$

$$W_m = \left(\sum_i (W_i \phi_{im})\right)^2 \Big/ \sum_i \left(W_i \phi_{im}^2\right) = \sum_i W_{im} \qquad (23)$$

This design load is divided to lateral design loads, F_{im}, at every story level, i, for each of the mode shapes included in the model - according to the displacement of the discussed story, at the same mode shape and active mode weight, W_{im}, of the same story level and mode shape. The forces are calculated by the Equations (24) and (25):

$$F_{im} = F_{Hm} W_i \phi_{im} \Big/ \sum_i (W_i \phi_{im}) \qquad (24)$$

$$W_{im} = W_i \phi_{im} \sum_i (W_i \phi_{im}) \Big/ \sum_i \left(W_i \phi_{im}^2\right) \qquad (25)$$

In the case that the condition of Equation (26) is fulfilled:

$$\sqrt{\sum_m \left(F_{Hm}^2\right)} < \mu F_H \qquad (26)$$

the response values from the modal analysis shall be multiplied by a factor , ν:

$$\nu = \mu F_H \Big/ \sqrt{\sum_m \left(F_{Hm}^2\right)} \qquad (27)$$

where:

C_{dm} - lateral mode seismic design coefficient of mode shape m, according to Equations (5), (6), (22)

W_m - total active mode weight of mode shape, m

W_i - total weight of story, i(in force units)

ϕ_{im} - mode displacement at story, i, of mode shape,m

F_H - total lateral design load, from equivalent static analysis of Equations (4), (5), (6), (12)

μ - a coefficient with a value of 0.80 - in a regular structure
1.00 - in an irregular structure

303.5 Modal combinations

The modal combinations for each significant value (displacements, axial forces, bending moments, shear forces, etc.) is obtained for each mode of vibration by adding the values using the square root of the sum of squares method (SRSS):

The design values are obtained, using Equation (28)

$$Q = \sqrt{\sum_m \left(Q_m^2\right)} \qquad (28)$$

where:

Q - combined response value(displacement, axial force, bending moment, shear force, etc.)

Q_m - response value at mode shape, m

The mode shapes that must be considered, are those that their participation factor is the greatest in the discussed direction, as long as the conditions in Section 303.3 C are fulfilled.

For periods of vibrations close to each other (the time difference is less than 10%),the combined response value is usually calculated according to the Complete Quadratic Combination method (CQC), as detailed in the Commentary [(5)].

303.6 Effects of torsion

The effects of torsion are calculated according to the instructions in Section 302.6.

303.7 P -Delta effects

The calculations are performed according to the instructions in Section 302.7, except for the deformability index, θ, which shall be calculated according to Equations (29) and (30):

$$\Delta_{e\ell,i} = \sqrt{\sum\left(\Delta_{e\ell,im}^2\right)} \; ; \; V_i = \sqrt{\sum\left(V_{im}^2\right)} \qquad (29)$$

$$\theta_i = \frac{W\,\Delta_{e\ell,i}\,K}{V_i\,h_i} \qquad (30)$$

where:

$\Delta_{el,i}$ - maximum story drift (of story i) based on an elastic seismic analysis

$\Delta_{el,im}$ - same as above, for mode, m

V_i - total horizontal shear force at story, i

V_{im} - same as above for mode shape, m

θ_i - deformability index at story, i

W - total weight of structure above story discussed

K - Force reduction factor, as specified in Tables (5), (6), or (7)

h_i - height of story, i (m)

.304 Other methods

It is allowed to use other accepted dynamic analysis methods, which are based on known analysis principles, such as the time history analysis, by using a number of accelerograms of different earthquakes, and normalizing their acceleration to the value of Z corresponding to the zone where the structure is located (according to the map in Appendix B). It should be emphasized, that in this type of analysis, the maximum values of the forces and moments at different locations in the structure appear at different times for the various earthquakes used - this fact makes it harder to determine the correct design values. Therefore, it is recommended to use this method as a compliment to the modal analysis method, and not as a substitute to it.

.305 Performance of structural elements

All structural elements shall be designed in such a way as to prevent a brittle fracture. These elements shall ensure a continuous path, by having the appropriate strength and stiffness, to all the forces calculated according to this Standard, from their point of action to the structural resisting elements, and from these, to the foundations, and the ground.

305.1 Diaphragms

Horizontal systems shall act as diaphragms that act to transmit the forces in them, to the seismic resisting elements. Their action is mainly in the elastic range - where they serve as rigid surface, or horizontal bracing systems.

The connections of the diaphragm to the structural elements, shall resist the maximum transferred forces (horizontal and vertical). The displacements in the diaphragm plane, shall correspond, and be limited, to the allowed deformations of the adjacent structural elements, in such a way that these elements will not lose their ability to serve as supports to the horizontal and vertical forces. In structures where the diaphragm consists of precast elements, the appropriate interaction of all the elements, must be ensured. The diaphragm shall resist shear forces and bending moments, caused by its behavior as a rigid diaphragm that transfers the seismic forces to the resisting elements, in the horizontal plane. The diaphragm shall also transfer the seismic forces that arise due to stiffness differences between the resisting elements. For this, the precast elements shall be connected by the appropriate means and with the required strength (such as :welding, reinforcement overlapping, supplementary concrete topping at site).

305.2 Shear walls system

Shear walls shall be anchored at the base level. Structural elements in dual systems, as in frames and shear walls (two sub-systems) shall comply (each sub-system separately) with all the requirements, discussed in the appropriate sections.

Structural elements and the connection areas between them shall be of the appropriate strength that shall permit both sub-systems to function according to the requirements they must fulfill.

305.3 Foundations and base story

In the case that the length of the columns in the base story or the piles varies within the area of the structure, their stiffness shall be corrected according to the lateral forces, and the lateral force distribution among the columns in the base story shall also be corrected. The additional eccentricity relative to other floors that may develop, shall be considered (Section 602, 603) (see also the Israeli Standard SI 1378).

.306 A structure with a flexible or soft story

In such a structure (for example, a building with an open story), the columns shall be designed to an amplified design force by the seismic action. The design and reinforcement detailing shall comply with the instructions in Section 403.4.

Chapter D - Design of reinforced concrete structures

.400 Masonry walls with a reinforced concrete lintel or a steel frame

Masonry walls and partitions, constructed from hollow blocks or bricks, or any other material, with a thickness of 15 cm or more, shall include reinforced concrete lintels, as required by the Israeli Standard SI 1523 [(1)]. Until the publication of the Israeli Standard SI 1523, the masonry walls and partitions shall comply with all the requirements in the following subsections.