ALGERIAN EARTHQUAKE RESISTANT REGULATIONS « R P A 99/Version 2003»

CHAPTER I – GENERAL

1.1 SCOPE

The present technical regulations set the rules for the conception and the earthquake resistant design of constructions in seismic prone areas.

1.2. OBJECTIVES

The present regulations aim at giving an acceptable protection for human lives and constructions against the adverse effects of seismic actions through an appropriate design and detailing.

- For current constructions, the aimed objectives are to provide the structure with :

- - a sufficient strength and stiffness in order to limit the non structural damages and to avoid the structural ones through an essentially elastic behavior of the structure while facing a relatively frequent moderate seismic event.

- - an adequate ductility and capacity of energy dissipation to allow the structure to undergo inelastic displacements with limited damages and no collapse nor loss of stability while facing a rare major seismic event.

- For certain important constructions, the aimed protection is even more severe since the construction should stay in operation immediately after a major seismic event.

1.3. APPLICATION FIELD

The present regulations are applicable to all current constructions. On the other hand, they are not directly applicable to constructions such as:

- constructions and facilities for which the consequences of an even light damage might be of an exceptionnal gravity : nuclear power plants, LNG facilities, installations for manufacturing and stocking flammables, explosive, toxic or polluting products.

-civil engineering works (dams, marine works, bridges, tunnels,...).

-buried networks and constructions.

-plates and thin shells structures.

For these types of constructions, it is necessary to use specific rules and recommandations.

On the other hand, the provisions of the present regulations are not applicable in the zone of neglected seismicity of the seismic zoning classification system (cf 3.1).

1.4. APPLICATION CONDITIONS

The constructions for which the present regulations are applicable should satisfy at the same time the other relevant provisions in force for conception, design and execution.

When wind load effects are more severe than the seismic ones, they have to be used for strength and stability design but seismic detailing requirements have to be observed too.

The rational and the efficient application of these provisions suppose a close cooperation and coordination between the different concerned parties at every step of the conception and execution of the project.

1.5. DEFINITIONS AND NOTATIONS

1.5.1. Definitions

1.5.2. Notations:

CHAPTER II - GENERAL RULES FOR CONCEPTION

2.1. SELECTION OF THE SITE

For the selection of the site, a special attention should be paid to the following unfavourable or penalizing conditions:

- presence of known active faults
- suspected zones of liquefaction potential
- unstable soils
  - unstable slopes, edge of cliffs, banks and shores subjected to erosion
  - saturated poorly drained soils subjected to settlement or flooding
  - presence of underground cavities
  - presence of non compacted fills
- Uneven surface topography
  - ridges, peaks
  - banks of deep valleys
  - surrounding of important slope changes
- Presence of alluvial deposits of variable thickness at the toe of a slope or of important thickness in the middle of valleys (possibility of amplification).
- Presence of different geological formations.

The final choice of the site will be made on the basis of the investigations the importance of which will be in accordance with the planned project.
The type and importance of these investigations can be oriented by the results of the seismic microzonation studies where they have been made.

2.2. SOIL INVESTIGATIONS AND STUDIES

Except for the constructions having a basement with 3 stories at most or having an average height of 11m (as for individual housing or assimilated buildings) with a total floor area less than 400m^2, the soil investigations are mandatory for the constructions classified as of middle importance and more, sited in zones having a seismicity ranging from moderate to high.

These studies are in principle the same as in the case of non seismic situations but they should in addition permit to classify the site and to detect the zones of liquefaction and / or other instabilities

Additional investigations can be necessary especially in the presence of liquefiable or instable zones and also to take into account the dynamic properties of the soils in design process.

2.3. SITING OF THE CONSTRUCTIONS

While siting the constructions it would be necessary:

- to absolutely avoid the immediate proximity to a known active fault in case of constructions classified as of medium importance or more. If the lineament of the fault has been located during a previous site investigation study, the constructions of a medium

importance should be designed for a higher protection level and sited outside a band having a minimal width of 100 meters on each side of the lineament of the fault.
For constructions having a lesser importance, the width of the band to avoid is reduced to 50 meters on each side of the lineament of the fault.

- to avoid as much as possible the unstable soils, those with an uneven topography *and sites near the cliffs' edges*.
- to avoid the liquefiable soils, heavily fractured or poorly cemented soils and the zones of fills.

On the other hand, it is recommended to:

- give the preference to rocky sites, to firm soils sites rather than to the soft soils sites that have a poor bearing capacity and excessive differential settlements
- check if the foundation bearing layer is thick enough and is not lying on an unstable layer.
- Site, as far as possible, tall buildings on rock or firm soils sites having a small thickness, and short buildings on either firm or soft soils sites relatively thick in order to avoid the resonance phenomena.
- give the preference to many building blocks on horizontal platforms while siting a large construction program on a sloping ground. The slope whose stability has still to be checked should not exceed 2/3.
- site a construction on the same side of a discontinuity such as a fracture, a contact between different geological formations, an abrupt change of a slope, otherwise split it by joints into distinct blocks sited on each side of the discontinuity.

2.4. INFRASTRUCTURE AND FOUNDATIONS

The infrastructure composed of the structural elements of the basements and the foundation system should form a resistant and rigid unit that rests if possible at a minimum depth on in situ compact and homogeneous formations, preferably out of water.
In addition, this unit should be capable of transmitting both the horizontal seismic forces and the vertical ones, limiting the differential settlements and preventing the relative horizontal displacements of the support points by tying grade beams or other equivalent system.
Foundations on fills or restored soils are not accepted, unless special justifications are given.
The foundation system should be homogeneous (isolated footings, mats, piles) with only one mode of foundation by construction block limited by joints. It should, as far as possible, form a .unique horizontal basis overall the ground of the block.

2.5. SUPERSTRUCTURE

2.5.1. Regularity

To offer a better resistance to earthquakes, the constructions should preferably have simple forms on one hand, and a distribution of the masses and rigidities as regular as possible in plan and in elevation on the other hand.
The purpose is to ensure the best possible distribution of the effects through the structure in order to bring all the structural elements to participate to the absorption and dissipation of the energy developed by the seismic action.

2.5.2. Joints

The laying out of the seismic joints might coincide with the thermal or construction joint.
They should ensure the complete independence of the blocks they limit and prevent the pounding effect.
In the case of homogeneous foundation soil conditions, it is not necessary to carry the joints down to the foundation level.
The joints should be flat, without setbacks and free from any material or odd object.
They are layed out in a manner to:

- limit the lengths of buildings
- separate the blocks of coupled buildings having unequal geometry and / or rigidities and masses.
- simplify the in-plan forms of buildings having complex configurations (forms in T, U, L, H,...)

2.5.3.Materials and building technologies

The present rules concern essentially structures achieved with the following materials :
- Construction steel
- Reinforced concrete
- Various masonries (bricks, concrete blocks, stone) suitably confined horizontally and vertically by cast-in place reinforced concrete elements.

The seismic behavior of materials cannot be separated from the type of structure they constitute:
- materials having a strength/density ratio as that of steel permit to achieve light resistant and economical structures.
- the materials rigidity permits to limit stability problems
- ductility is the capacity of materials to undergo plastic deformations under large loads without significant resistance decrease during many loading cycles. Steel and appropriately reinforced concrete have a good ductility.

- the use of brittle materials whose tension and shear strengths are weak (plain concrete, traditional masonry) is not permitted for the realisation of the bracing system elements.
On the other hand, they can be used for certain non structural elements after having checked if their behavior is compatible with the deformations of the structure or after combining them with other materials to improve their resistance.

- the connections between the structural elements should be realised in steel or cast-in place reinforced concrete to ensure the mechanical continuity of the structure.

- the use of prestress for the bracing elements is not permitted in seismic zones. But, the use of secondary isostatic elements in prestressed concrete such as purlins, floor beams and forming-slabs is allowed.

* The prefabricated structures should:
    - satisfy the general conditions of conception, design and construction
    - be approved with specified conditions to use in seismic zones

2.5.4. Structural systems

In general, the constructions should have lateral load resisting systems at least in two horizontal directions. These systems should be arranged in order to:

- take up a sufficient vertical load enough to ensure their stability.
- ensure a direct transmission of the forces to the foundations.
- minimise the torsion action effects

The lateral load resisting systems should have a regular configuration and form a continuous and coherent structural system as monolithic as possible. On the other hand, this system should be sufficiently redundant in order to ensure an important margin between the elastic limit and the rupture threshold of the structure.
A particular attention should be given to the design and execution of all the connections, keeping in mind the effects of any failure at this level on the behavior of the structure.

2.5.5. Ductility

The structure and its elements should have a ductility sufficient enough to be able to dissipate an important part of the energy induced by the seismic motions while keeping constant their design strength under the imposed deformations.
The development of plastic hinges should take place outside the nodal zone, preferably in the horizontal elements (beams, lintels) rather than in the vertical ones (columns, shear walls) in order not to disturb the vertical load path, nor the structure stability and/or that of its bearing elements. As for the bearing elements that are not part of the lateral load resisting system, they should be able to keep their bearing capacity under the effects of the imposed deformations.

2.5.6. Non-structural elements

In addition to the design of the structural system, it is necessary to take into account the presence of non-structural elements which can significantly modify the behavior of the structure and give rise to important damages.

2.6. MODELING AND ANALYSIS

The choice of the analysis method and the structural modeling should aim at reproducing to the best the actual behavior of the structure.
In the case of the constructions concerned by the present regulations, it is accepted that the structures, subject to a seismic ground motion can undergo deformations in the post-elastic domain. It is then necessary to use equivalent linear analysis methods, using an elastic model of the structure where the seismic action is represented by a response spectrum. A unique behavior coefficient associated to the structure permits then to:

- determine the structural design loads
- assess the inelastic deformations of the structure for the verification of the damage criteria.

Otherwise, more sophisticated analysis methods can eventually be used, provided appropriate scientific justification is given.

CHAPTER III . CLASSIFICATION CRITERIA

The present chapter describes a set of classifications needed in the definition of the studied seismic situation and in the choice of the design method and the design values of the parameters for the determination of the seismic forces.

3.1. CLASSIFICATION OF THE SEISMIC ZONES

The national territory is subdivided into five *(05) zones* of increasing sismicity, defined on the seismic zoning map and the attached table which details this repartition at the wilaya and commune levels, that is :

Zone 0	: neglected seismicity
Zone I	: low seismicity
Zones IIa and IIb	*: moderate seismicity*
Zone III	: high seismicity

Figure 3.1 shows the seismic zoning map of Algeria and the global zoning of the different wilayas. Annex I presents seismic classification by wilaya and by commune in the case where the wilaya is subdivided between two different seismic zones.

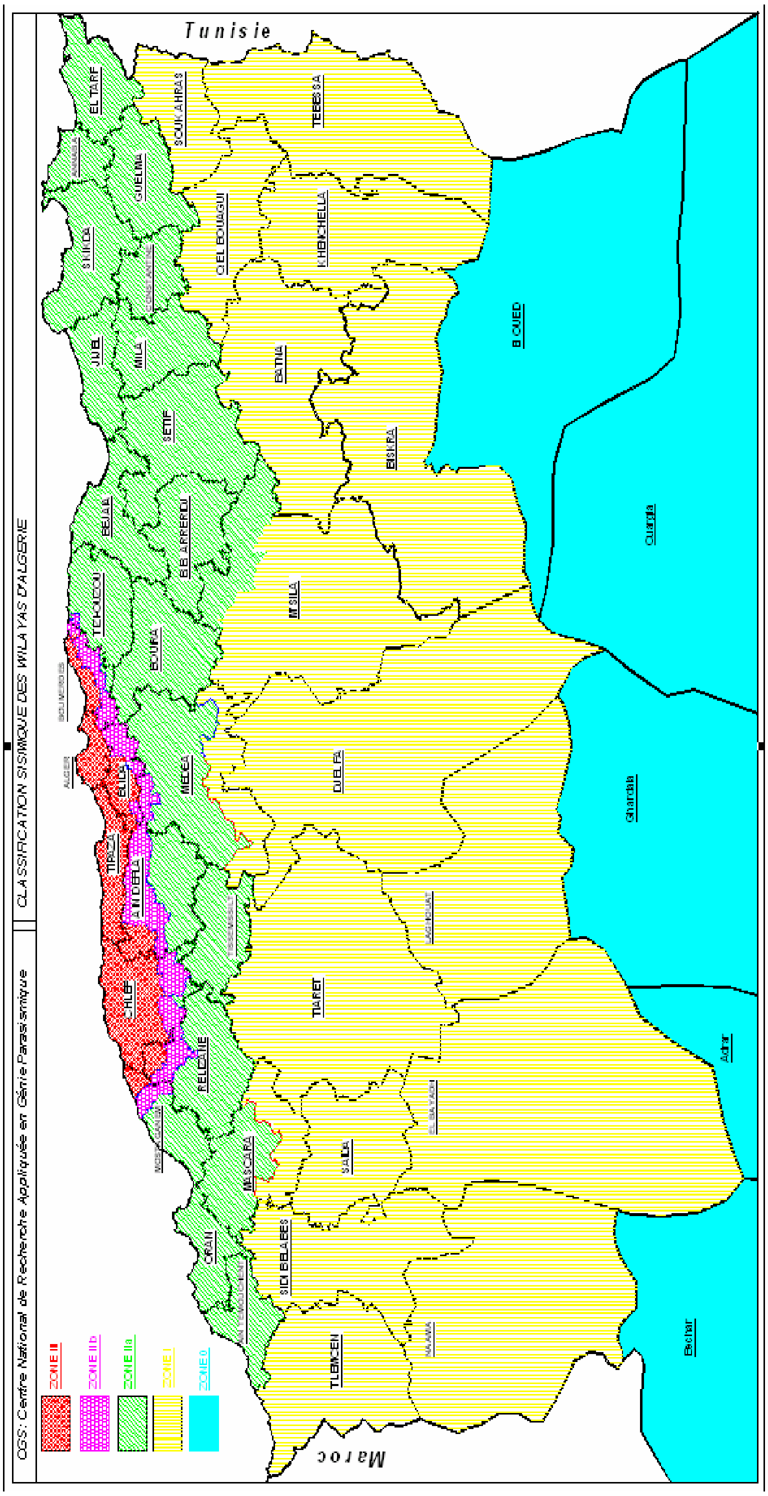


Fig. 3.1 : Seismic Macrozoning Map of Algeria

3.2. CLASSIFICATION OF THE CONSTRUCTIONS ACCORDING TO THEIR IMPORTANCE

The minimum seismic protection level accepted for a building depends on its destination and importance in regard to the protection objectives set by the community.

The lists described below are necessarily incomplete. However, they illustrate this classification which aims at protecting the human lives and the economical and cultural assets of the community.

This classification sets minimum protection thresholds that can be modified by a building owner only by over classifying the building for a higher protection level taking into account its nature and destination in regard to the aimed objectives.

Any building treated by the present rules should be classified in one of the four (04) groups defined hereafter:

Group 1A : Construction of vital importance
Vital constructions should stay operational after major earthquake for the needs of the survival of the region, the public safety and the national defense, that is:

- buildings housing strategic decision making centers.
- buildings housing staff and equipment for rescue and/or national defense having an operational role such as civil defence centres, police or military barracks, parking lots for emergency and rescue equipment and vehicles
- public health department buildings such as hospitals and centres equipped with emergency, surgical and obstretrics services
- public communication department buildings such as centers of telecommunication, broad cating and reception of information (radio and television), radio relays, airport and air-traffic control
- drinking water production and storage facilities of vital importance
- historical and cultural public buildings of national importance
- energy production and distribution facilities of national importance
- administrative or any other buildings that should stay operational in case of an earthquake occurence

Groupe 1B: Construction of high importance

Constructions housing frequently large groups of persons

- public buildings occupied by more than 300 people at the same time such as large mosques, office buildings, commercial and industrial buildings, schools, universities sport and cultural buildings, jails, great hotels
- buildings for collective housing or office services with height exceeding 48 m.

Public buildings of national importance or having a great social, cultural and economical importance

- library or depository buildings of regional importance, museum, etc,...
- health department buildings other than those in group 1A
- energy production or distribution facilities other than those in group 1A
- water towers and water tanks with high to moderate importance

Groupe 2 : Current constructions or those of moderate importance
Constructions non classified in the other groups 1A, 1B or 3 such as :

- buildings for collective housing or office services with height not exceeding 48 m
- other buildings occupied by less than 300 persons at the same time such as office buildings, industrial buildings,...
- public parking lots

Groupe 3 : Constructions of low importance

- industrial or agricultural buildings sheltering low value goods
- buildings with limited risk for people
- temporary constructions

3.3. CLASSIFICATION OF SITES

3.3.1. Categories and classification criteria

The sites are classified into four (04) categories according to the mechanical properties of the constituting soils.

Category S_1 : (rocky site)
Rock or other geological formation characterized by an average shear wave velocity $V_s \geq 800$ m/s

Category S_2 : (firm site)
Very dense gravel or sand and/or over consolidated clay deposits with a thickness of 10 to 20 meters and $V_s \geq 400$ m/s from a depth of 10 meters.

Category S_3 : (soft site)
Thick deposits of moderately dense gravel and sand or moderately stiff clay with $V_s \geq 200$ m/s from a depth of 10 meters.

Category S_4 : (very soft site)
-Loose sands deposits with or without soft clay with $V_s < 200$ m/s within the 20 first meters.
-Soft to moderately stiff clay with $V_s < 200$ m/s within the 20 first meters.

On the other hand, besides the average values of the shear wave velocities, the harmonic average values of other test results (CPT, SPT, pressiometer,...) can be used in order to classify a site according to the following table :

Table 3.2. : Classification of sites

Category	Description	$\overline{q_c}$ (MPa) (c)	$\overline{N}$ (d)	$\overline{p_l}$ (MPa) (e)	$\overline{Ep}$ (MPa) (f)	$\overline{q_u}$ (MPa) (g)	$\overline{V_s}$ (m/s) (h)
S_1	Rocky(a)	-	-	>5	>100	>10	≥800
S_2	Firm	>15	>50	>2	>20	>0.4	≥400-<800
S_3	Soft	1.5 - 15	10 - 50	1 - 2	5 - 20	0.1 – 0.4	≥200-<400
S_4	Very soft or presence of more than 3m of soft clay (b)	<1.5	<10	<1	<5	<0.1	≥100-<200

a) The value of the wave velocity of the rock should be measured in-situ or estimated in the case of a weakly altered rock. The soft or very altered rocks could be classified in S2 category in the case where Vs was not measured in-situ. The site could not be classified in S1 category it there exists 3 m of soils between the bed - rock surface and the lower level of the isolated footings.

b) The soft clay is characterized by a plasticity index Ip > 20, a natural water content Wn ≥ 40%, an undrained strength Cu < 25 kPa and a shear wave velocity Vs < 150 m/s.

c) CPT

$$\overline{q_c} = \frac{\sum_{1}^{n} h_i}{\sum_{1}^{n} \left(\frac{h_i}{q_{ci}} \right)}$$

h_i: thickness of the soil layer (i)

q_{ci}: CPT value through the soil layer (i)

d) SPT

e) Pressiometer

f)compression strength

$$\overline{q_u} = \frac{h_c}{\sum_1^n \left(\frac{h_i}{q_{ui}}\right)}$$

h_c : total thickness of cohesive soil layers (clay and /or marl)

q_{ui} : unconfined compressio n strengh across the soil layer (i) of thickness h_i

g) Shear wave velocity

$$\overline{Vs} = \frac{\sum_1^n h_i}{\sum_1^n \left(\frac{h_i}{V_{si}}\right)}$$

V_{si} : shear wave velocity across the soil layer (i) of thickness h_i

3.3.2. Classification of the site according to the available tests

According to the availability and reliability of the results of the different types of tests, the site will be classified in the most appropriate category. In the case of some doubt, use the next immediately unfavorable category.

3.3.3. Case of test results not available

This article has been suppressed in the current version of 2003.

3.3.4. Site conditions needing detailed investigations

The site conditions that need detailed investigations are the following:

- presence of unstable soils under the seismic actions such as liquefiable soils, weakly cemented soils, old fills.
- presence of soft soils or clay with very high organic matter content over 3 m depth.
- presence of very plastic clay (plasticity index $I_p > 75$) with a thickness of more than 6 meters.
- presence of soft to moderately stiff clay over 30 m depth (q_c=1,5 to 5 Mpa, p_l=0,5 to 2 Mpa, E_p=5 to 25 Mpa, q_u=0,1 to 0,4 Mpa).....

3.4. CLASSIFICATION OF THE LATERAL LOAD RESISTING STRUCTURAL SYSTEMS

The aim of the classification of the structural systems gives rise in these rules and design methods to the assignment for each category of this classification of a numerical value of the behavior coefficient R (see table 4.3)
The classification of the structural systems is made according to their reliability and their capacity of energy dissipation in regard to the seismic action, and the corresponding behavior coefficient is assigned according to the constitutive materials, the type of construction, the possibilities of load redistribution in the structure and capacities of deformation of the elements in the post elastic domain.

The lateral load resisting structural systems retained in these regulations are classified according to the following categories:

A) Reinforced concrete structures

1.a : Moment resisting space frames without rigid masonry infill walls

It is a structure composed uniquely by frames capable of carrying all the forces due to the vertical and horizontal loads. For this category, the partition walls or elements should not prevent the deformations of the frames (desolidarised or light infill or separation walls with connections not preventing the displacements of the frames).
On the other hand, the concerned buildings should not exceed 5 stories or 17m in height in zone I, 4 stories or 14m in height in zone IIa, and 3 stories or 11m in height in zones IIb and III.

1.b : Moment resisting space frames with rigid masonry infill walls

It is a structure composed uniquely by frames capable of carrying all the forces due to the vertical and horizontal loads. For this category, the infills are composed by small unit masonry walls, inserted into the frames, with a thickness (without coating) not exceeding 10 cm, except for the exterior masonry infill panels or for separating walls between two apartments or two premises situated at the same floor, where a second wall of 5 cm is accepted on the interior side. This latter may eventually be of 10 cm thick, providing that it is not inserted into the frames in order not to increase the “masonry-structure interaction”
Besides, the concerned infill walls should be arranged in plan as symetrically as possible with regard to the center of mass of each floor in order not to enhance a possible asymetry of the reinforced concrete lateral load resistant system of the story (space frames).

On the other hand, the concerned building should not exceed 5 stories or 17m in height in zone I, 4 stories or 14m in height in zone IIa, 3 stories or 11m in height in zones IIb and 2 stories or 8m in height in zone III.

IMPORTANT REMARKS FOR STRUCTURAL SYSTEMS 1a AND 1b

In the case, where a ground floor is programmed for a commercial use or other services and then, at the initial stage of the conception, contains a low density of partition walls and/or story's height is larger than for other stories, leading to a"soft story", it is required that the building lateral resistance should be ensured by an other system containing shear walls in both orthogonal (or equivalent) directions (with a combined frame-shear walls system or with a reinforced concrete core for example).
It is reminded that the soft story is the one which has a lateral rigidity less than 70% compared to that of the immediate above story or less than 80% of the average lateral rigidity of the immediate three above stories.

2. Structural lateral load resistant system composed by vertical load carrying shear walls in reinforced concrete (box system)

The system is composed uniquely by walls or walls and frames. In the last case, walls carry more than 20% of vertical loads. The lateral loads are carried by the walls alone.

3. Reinforced concrete structure entirely braced by reinforced concrete core

The building is completely braced in this case by a reinforced concrete rigid core that carries all the horizontal loads.

4.a. Dual bracing system composed by walls and frames with justification of frame-wall interaction

The shear walls carry less than 20% of vertical loads. The horizontal loads are jointly carried by the shear walls and the frames in accordance to their relative rigidities and the effects of the interaction between the shear walls and the frames must be considered. The frames shall have the capacity to resist not less than 25% of the story shear force in addition to the forces due to the vertical loads.

4.b. Moment resisting frames system braced by reinforced concrete shear walls

In this case, the shear walls carry less than 20% of the vertical loads and the total forces due to lateral loads. The frames are considered as resisting only vertical loads, but in seismic zone III, the frames should be checked for a horizontal force of 25% of the global lateral loads.
With this bracing system, the building is limited to 10 stories or 33m in maximum height

5. Vertical cantilever with predominant distributed masses system

It is for example the case of a cylindrical tank, silos and cylindrical smokestacks and others.

6. Inverse pendulum system

It is a system where 50% or more of the mass are concentrated in the third upper part of the structure. It is for example the case of water tank on piles or on cylindrical or cone-shaped wall.

.B . Steel structures

7. Ductile moment resisting space frame system

The complete structure (frames included) carries the total vertical loads. The ductile moment resisting space frames should resist alone the total horizontal loads. These frames should be designed and executed according to the requirements given in the paragraph 8.2.

8. Structures braced with ordinary moment resisting space frames

The complete structure carries the total vertical loads. The moment resisting space frames, resist alone the total horizontal loads and should satisfy to the requirements given in paragraph 8.3.
The height of all the buildings using this bracing system should be limited to 5 stories or 17m in height.
Note: The bracing systems 7 and 8 suppose the use of light infill elements compatible with the considered structural systems and that do not prevent the displacements of the structure.

9. Structures braced by concentric braced frames

The complete structure carries the total vertical loads and the braced frames carry the total horizontal ones
The concentric braced frames should satisfy the requirements given in the paragraph 8.4.
The height of the buildings using this braced system should be limited to 10 stories or 33 m in height.
For this bracing system category, we hare two (02) subcategories, that are X and V bracing systems (the K bracing system category is not accepted).

9.a. Structure braced by X braced frames

In this system, for a braced frame node, the axes of the diagonal, the beam and the columun are convergent to one point located in the center of the node.
Besides, in this system, among all the diagonals of a braced frame, only those in tension contribute to the resistance and the dissipative behavior of this braced frame in regard to the seismic action.

9.b. Structure braced by V braced frames

In this system, the beams of each braced frame are continuous and the point of intersection of the diagonal axes of the braced frame is located on the axis of the beam.
The resistance and the capacity of dissipation of the braced frame in regard to the seismic action are provided by the joint participation of both the in-tension and in-compression diagonals.

10 Dual bracing systems

In this case, the braced frames should not carry more than 20% of the vertical loads.
A dual bracing system is a combination of two (02) types of bracing systems, chosen among those previously defined.
It is composed by ductile moment resisting space frames coupled with X or V braced frames or closer to the V type (double brackets system).
The complete structure carries the total vertical loads while the dual bracings (moment resisting frames and braced frames) carry the total horizontal loads.
The moment resisting frames and the braced frames should be designed to resist horizontal load according to their relative rigidities considering the interaction at all levels.
The ductile moment resisting frames should have the capacity to resist alone not less than 25% of the global horizontal loads.
The requirements concerning these bracing system categories are specified in the paragraph 8.5.

10.a. Structural system braced with ductile frames and X braced frames

In this system, the dual bracing system is a combination of ductile moment resisting space frames and concentric X braced frames.

10.b. Structural system braced with ductile frames and V braced frames

In this system, the dual bracing system is a combination of ductile moment resisting space frames and concentric V braced frames.

11. Vertical cantilever frame system

This category of structural system with small degree of redundancy concerns essentially classical one story frames with a rigid transversal beam and slender structures of « tube » type where the resistant structural elements are essentially the columns located on the periphery of the structure.
These particular structures have a dissipative behavior located uniquely at the ends of the columns.

C) Masonry structures

The constructions in traditional bearing masonry are not accepted in seismic zone. The tied (confined) bearing masonry is the only one permitted.

12. Tied (confined) bearing masonry structures

This structural system concerns bearing structures achieved in rubble masonry or small manufactured elements and including strengthening reinforced concrete bands cast-in place after execution of the masonry. These structures resist both the vertical and horizontal loads.
The buildings concerned by this structural system category are limited to 5 stories or 17m in height in seismic zone I, 4 stories or 14m in height in seismic zone IIa and 3 stories of 11m in seismic zones IIb and III.

D. **Other structures**

13. Steel frame structure braced by diaphragm

These structures resist the seismic action by the diaphragm effect of vertical elements (walls) and horizontal elements (floors). The level of dissipative behavior of these structures depends on the capacity of ductile shear resistance of these walls and floors that can be achieved with various materials and technologies (cold formed ribbed sheet, reinforced masonry wall, plain concrete or reinforced concrete wall, etc...)
The walls should be fixed to the steel frame in order to consider the connections as.rigid.

14. Steel frame structure braced by a reinforced concrete core

Same definition as for reinforced concrete structural system (cf. system 3.)

15. Steel frame structure braced by reinforced concrete shear walls

Same definition as for reinforced concrete frames structural system (cf. system 4.b.)

16. Steel frame structure braced with dual system composed by a reinforced concrete core and braced steel frames and/or steel moment resisting frames in periphery

17. System including transparencies (soft stories)

The most illustrative examples are given by the reception levels or lobbies of hotels (rare separation walls or story height more important than for the current stories,...) or absence of separation walls at some stories for some specified reasons (computer rooms, special equipment, etc..).
In general, these systems should be avoided. Otherwise, besides the procedures previously recommended for the systems 1a and 1b for the specific case of the ground floor (change of dual systems), all the arrangements to decrease the unfavorable effects should be taken.
In this respect, the procedure to increase the rigidity should be adopted in order to decrease or attenuate the phenomena (see the definition of the soft story given previously as remarks for systems 1a and 1b).

3.5 CLASSIFICATION OF THE CONSTRUCTIONS ACCORDING TO THEIR CONFIGURATION

3.5.1. Each building (and its structure) should be classified according to its configuration in plan and in elevation as a regular building or not, in regard to the criteria hereafter mentioned :

a) Regularity in plan

a_1. The building should present a quite symmetrical configuration in regard to two orthogonal directions as well as for the distribution of the rigidities and for that of the masses.

a_2. At each level and for each design direction, the distance between the center of gravity of the masses and that of the rigidities should not be more than 15% of the building dimension perpendicular to the considered direction of the seismic action.

a_3. The shape of the building should be compact with a length to width ratio of the floor less than or equal to four (4) (cf.fig.3.2). The sum of the dimensions of the re-entrant parts and setbacks in a given direction should not exceed 25% of the global dimension of the building in that direction (cf.fig.3.3).

a_4. The floors should have sufficient in plane rigidity in regard to that of the vertical bracing elements to be considered as rigid in their plane. In this case, the total area of the floor openings should be less than 15% of that of the floor.

b) Regularity in elevation

b_1. The bracing system should not present vertical discontinuous bearing element the load of which is not transmitted directly to the foundation.

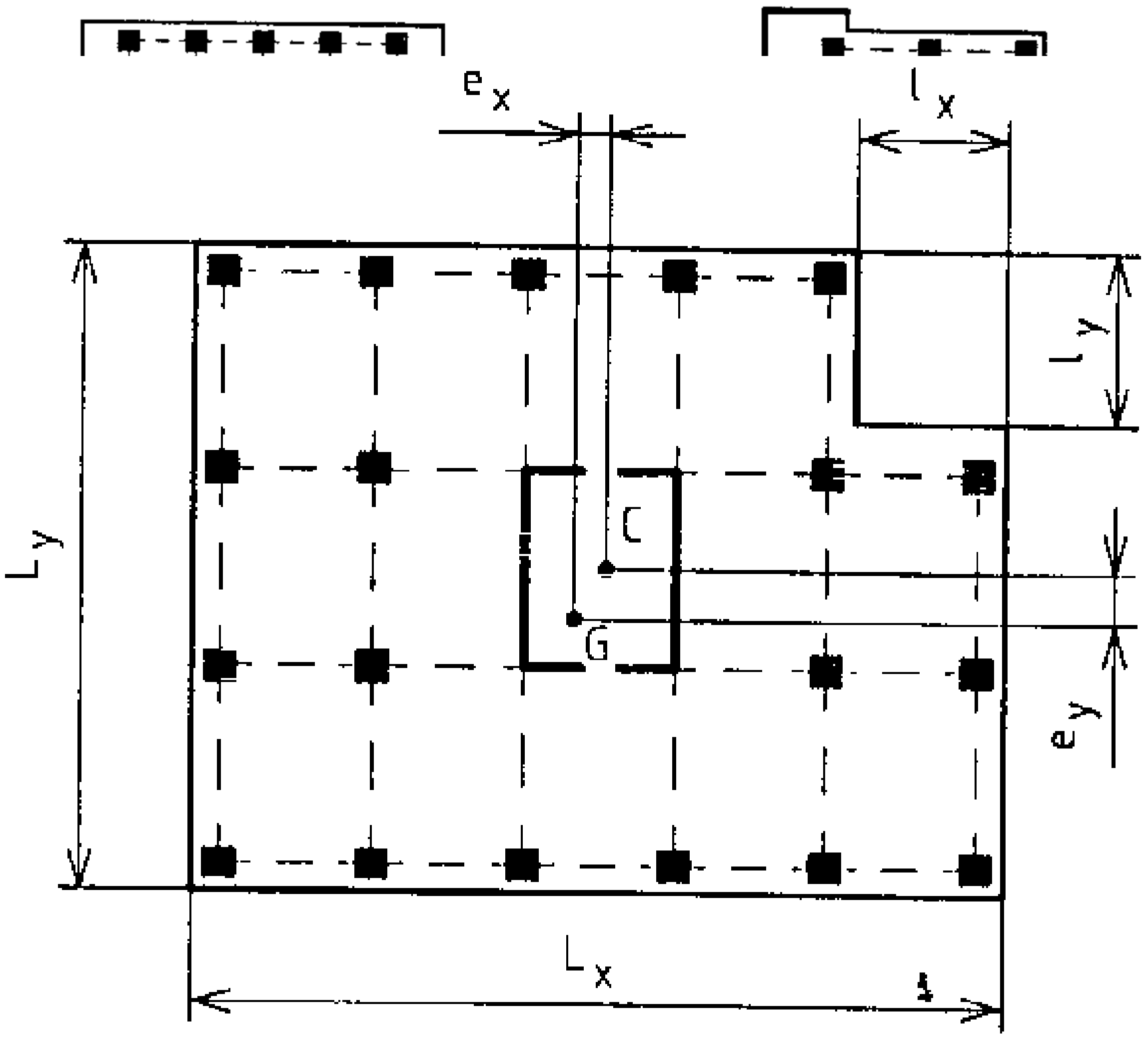
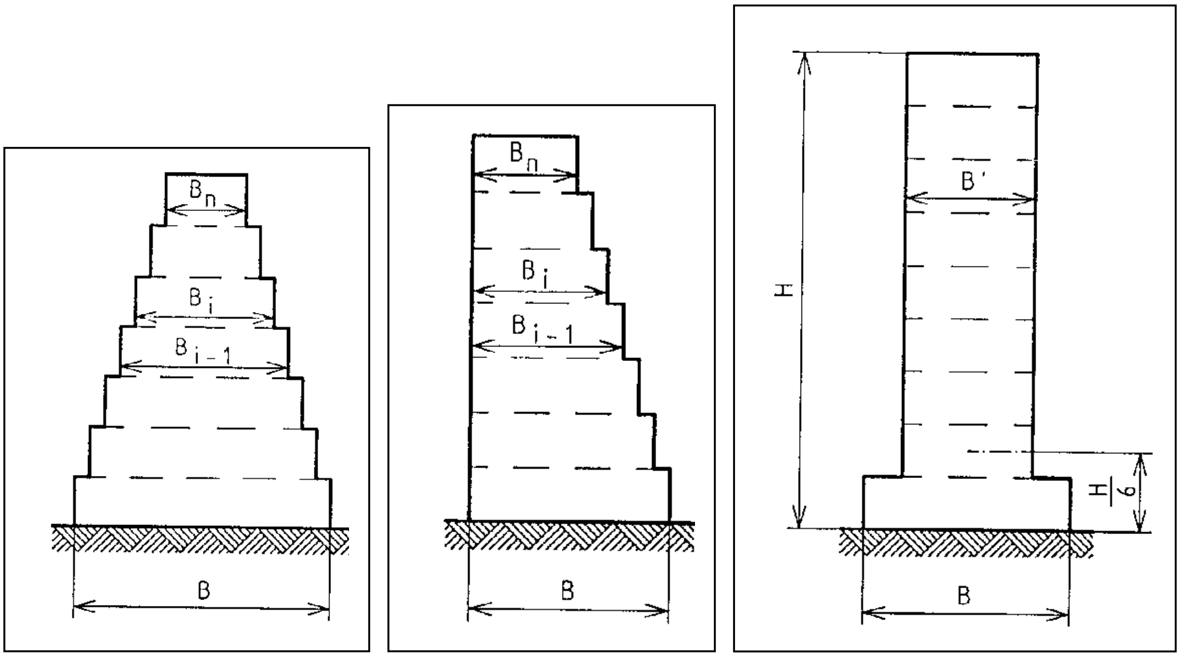


Fig. 3.2 : Limits of the plan setbacks

b_2. Both the lateral stiffness and the mass of the individual stories remain constant or reduce gradually, without abrupt changes, from the base to the top of the building.



$\frac{B_n}{B} \geq 0.67$ $\frac{B_i}{B_{i-1}} \geq 0.80$

$\frac{B_n}{B} \geq 0.67$ $\frac{B_i}{B_{i-1}} \geq 0.80$

$\frac{B'}{B} \geq 0.67$

Fig. 3.3 : Limits of elevation setbacks

b_3. In the case of setbacks in elevation, the variation of the horizontal dimensions of the building between two successive levels should not be more than 20% in the two design directions, decreasing along the height. The largest horizontal dimension of the building should not exceed 1,5 times its smallest dimension.

Otherwise, at the last level, the building elements such as laundry, elevator machine room, etc…, can be designed, without reference to the point b_2, as secondary elements.

In general, refer to illustrative figures hereafter (fig.3.3)

3.5.2. A building is classified regular in plan if all the plan regularity criteria (a_1 to a_4) are satisfied. But, it will be classified as irregular in plan if one of these criteria is not satisfied.

3.5.3. A building is classified as regular in elevation if all the elevation regularity criteria (b_1 to b_3) are satisfied. But it will be classified as irregular in elevation if one of these criteria is not satisfied.

3.5.4. A building is classified as regular if it is regular both in plan and in elevation.

CHAPTER IV: ANALYSIS METHODS

4.1. CHOICE OF THE DESIGN METHOD

4.1.1. usable methods

The seismic loads calculation can be performed according to three methods :

- the equivalent static method
- the modal response spectrum analysis method
- the time history dynamic analysis method

4.1.2. conditions of application of the equivalent static method

The equivalent static method can be used in the following conditions:

a) The building or the studied block comply with the conditions of regularity in plan and in elevation prescribed in the chapter III, paragraph 3.5 with a height to most equal to 65m in zones *I* and *IIa* and to 30m in zone *IIb* and *III*.

b) The building or studied block presents an irregular configuration but satisfying, in addition to the conditions of height expressed in a), the following complementary conditions:

Zone I : all groups

Zone II : using group 3
using group 2, if the height is lower or equal to 7 stories or 23m.
using group 1B, if the height is lower or equal to 5 stories or 17m.
using group 1A, if the height is lower or equal to 3 stories or 10m.

Zone III : using groups 3 and 2, if the height is lower or equal to 5 stories or 17m.
using group 1B, if the height is lower or equal to 3 stories or 10m.
using group 1A, if the height is lower or equal to 2 stories or 08m.

4.1.3. dynamic methods

a) The modal response spectrum analysis method can be used in all cases, and in particular, in the case where the equivalent static method is not permitted.

b) The time history dynamic analysis method can be used in specific cases by a qualified personnel which must justify the choice of the seismic inputs (accelerograms) to be used, the behavior relationships of materials, the method of results interpretation and safety criteria to comply with.

4.2. EQUIVALENT STATIC METHOD

4.2.1. principle

The dynamic real loads developed in the construction are replaced by a system of nominal static loads the effects of which are considered equivalent to those of the seismic action.
The soil motion can be in any direction in the horizontal plan. The equivalent horizontal seismic loads will be considered successively applied in two successive orthogonal directions chosen by the designer. In general, these two directions are the principal axes of the horizontal plan of the structure.
However, the loads and deformations for a given element obtained from the static analysis methods for recommended design loads are lower than those that would be observed on the

structure under effects of a major earthquake for which the loads have been specified. This excess of loads is balanced by the ductile behavior that is provided by detailing of the element. It is why the use of this method can not be dissociated from the rigorous application of the detailing requirements being able to give to the structure :

- a sufficient ductility
- a capacity to dissipate the vibration energy transmitted to the structure by major earthquakes

4.2.2. Modelling

a) The building model to be used in each of the two directions for analysis is plane, with masses concentrated at the gravity center of the floor and only one degree of freedom by floor in horizontal translation is considered.
b) The lateral stiffness of supporting elements of the bracing system is calculated from non cracked sections for reinforced concrete structures or masonry structures.
c) Only the fundamental vibration mode of the structure is considered in the calculation of the total seismic load.

4.2.3. Total seismic load

The total seismic load **V**, applied to the basement of the structure, must be calculated successively in two orthogonal and horizontal directions, according to the following formula:

$$\mathbf{V} = \frac{\mathbf{A.D.Q}}{\mathbf{R}}\mathbf{W} \qquad (4.1)$$

- **A : zone acceleration coefficient**, given by table 4.1, according to the seismic zone and the using group of the building.

Table 4.1.: coefficient of zone acceleration

	Zone			
Group	***I***	***IIa***	***IIb***	***III***
1A	*0,15*	*0,25*	*0,30*	*0,40*
1B	*0,12*	*0,20*	*0,25*	*0,30*
2	*0,10*	*0,15*	*0,20*	*0,25*
3	*0,07*	*0,10*	*0,14*	*0,18*

- D : average dynamic amplification factor, depending on the site category, on the damping correction factor (η) and on the fundamental period of the structure (T). The factor D is given in chart forms in figure 4.1 for a damping coefficient ξ = 5%.

(4.2)

T_2: characteristic period, associated to the category of the site and given in the table 4.7
η: is the damping correction factor given by the following formula :

≥ 0.7 **4.3**

where ζ (%) is the critical damping ratio depending on constitutive material, structure type and importance of infills.
When ζ=5%, we have η =1.

Tableau 4.3 : Values of ξ (%)

	Frames		Shear walls or walls
Infill	**Reinforced concrete**	**metal**	**reinforced concrete/masonry**
light	6	4	10
heavy	7	5	

- R: **global behavior coefficient of the structure**, given in table 4.4 according to the lateral force resisting system as defined in 3.4
In case of different lateral force resisting systems in the two considered directions, the smallest value of R must be used.

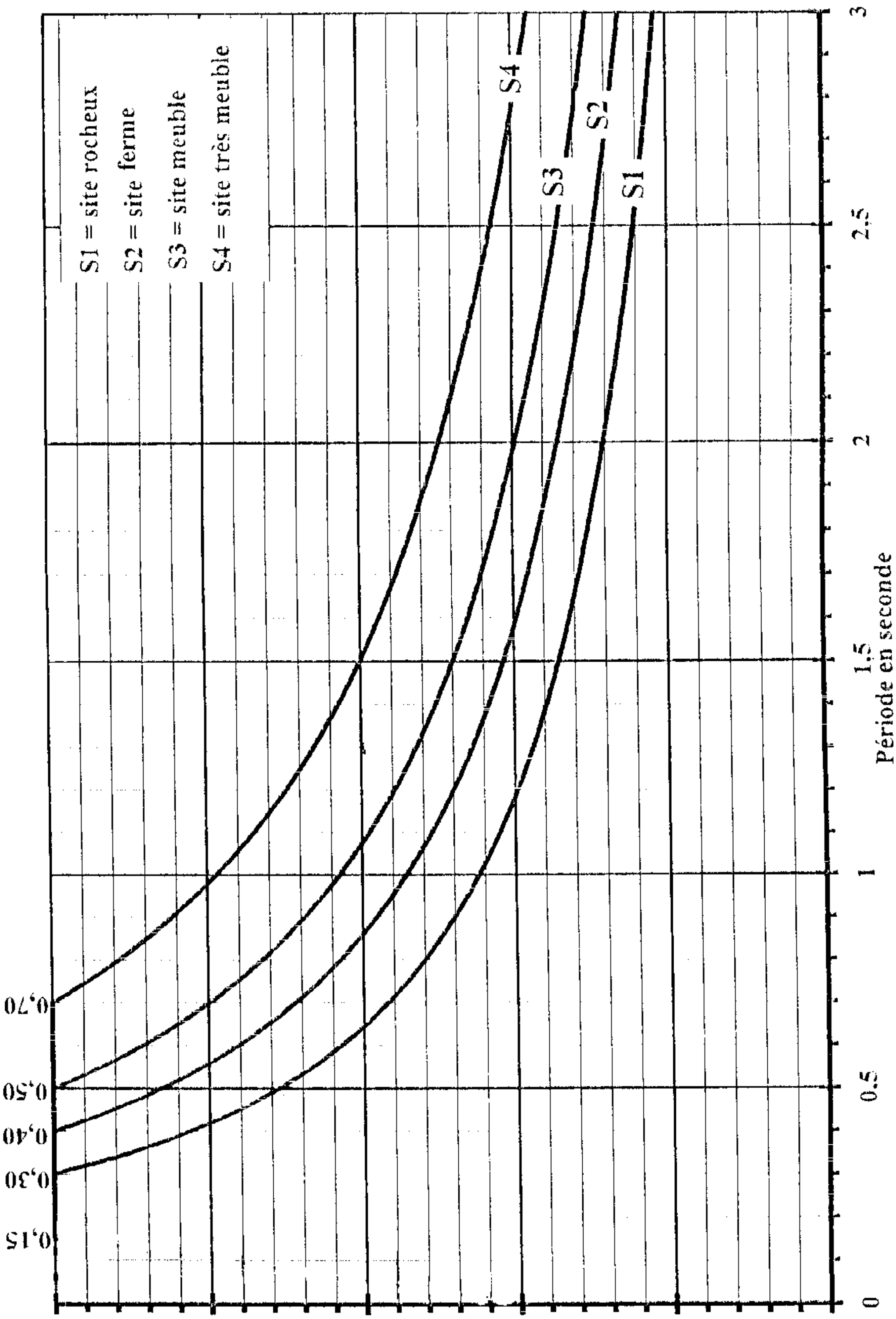
- Q: Quality factor
The quality factor of the structure depends on :
- the redundancy and the geometry of the constituent elements.
- the regularity in plan and in elevation.
- the quality of the control of construction.

The value of Q is determined by the formula :

(4.4)

P_q is the penalty to be applied depending on whether the criteria of quality q " is satisfied or not". Its value is given in table 4.4

Criteria of quality "q" to verify are:
1. minimal conditions on bracing plans.
- *frames system* : every plan of frames must include at all floors, at least three (03) bays and the ratio of two adjacent spans must not exceed 1.5. The frame bay can be constituted of shear walls


S1 = site rocheux
S2 = site ferme
S3 = site meuble
S4 = site très meuble
S1
S2
S3
S4
0,15
0,30
0,40
0,50
0,70
Facteur D
0
0.5
1
1,5
2
2.5
Période en seconde
0
0.5
1
1.5
2
2.5
3

- *shear walls system* : every plan of shear walls must include at all floors, at least one (01) pier having a ratio "story height on width" less or equal to 0.67 or two (02) piers having a ratio "story height on width" less or equal to 1. These piers must rise on all the height of the floor and must not have any opening or perforation that can reduce significantly their strength or their stiffness.

2. redundancy in plan

Every story should have, in plan, at least, four (04) plans of frames and/or shear walls in the considered direction.
These bracing plans should be arranged as much as possible symmetrically with a ratio between maximal and minimal values of spacing less than 1.5.

3. regularity in plan
The structure is classified regular in plan. (cf. 3.5 1a)

4. regularity in elevation
The structure is classified regular in elevation. (cf. 3.5 1b)

5. control of material quality
Systematic tests on used materials must be achieved by the enterprise.

6. control of the quality of construction
A control mission to follow-up the works on yard is contractually foreseen. This mission must include a supervision of tests done on materials.

Table 4.3 : values of behavior factor R

Cat	Description of lat. Force res. systems (see chapter III § 3.4)	Value of **R**
<u>A</u>	**<u>Reinforced concrete</u>**	
1a	Moment resistant frames without stiff masonry infill	5
1b	Moment resistant frames with stiff masonry infill	3,5
2	Bearing shear walls	3,5
3	central core	3,5
4a	Mixed moment resistant frames/shear walls with interaction	5
4b	Frames braced by shear walls	4
5	Vertical cantilever with distributed masses	2
6	Inverted pendulum	2

B	**Steel**	
7	Ductile moment resistant frames	6
8	Ordinary moment resistant frames	4
9a	Structure braced by X triangulated elements	4
9b	Structure braced by V triangulated elements	3
10a	Mixed moment resisting frames/ X triangulated braces	5
10b	Mixed moment resisting frames/ V triangulated braces	4
11	Vertical cantilever frames	2
C	**Masonry**	
12	Bearing tied masonry	2,5
D	**Other systems**	
13	Steel structure braced by diaphragm	2
14	Steel structure braced by reinforced concrete core	3
15	Steel structure braced by reinforced concrete shear walls	3,5
16	Steel structure with mixed bracing including a reinforced concrete core and steel braces or frames in façade	4
17	Systems including transparencies (soft stories)	2

Table 4.4.: values of the penalties P_q

	P_q	
Criteria Q	**Observed**	**n/observed**
1. Minimal conditions on bracing lines	0	0,05
2. Redundancy in plan	0	0,05
3. Regularity in plan	0	0,05
4. Regularity in elevation	0	0,05
5. Control of material quality	0	0,05
6. Control of construction quality	0	0,10

- W: total weight of the structure

W is equal to the sum of the weights W_i, calculated at every floor (i):

$$\mathbf{W = \sum_{i=1}^{n} W_i \qquad with \qquad W_i = W_{Gi} + \beta\, W_{Qi}} \qquad \mathbf{4.5}$$

- W_{Gi}: weight due to the dead loads and loads of the eventual fixed equipment attached to the structure.
- W_{Qi}: live loads
- β : weighting coefficient, depending on the nature and the duration of the live load, given in table 4.5.

Table 4.5. weighting coefficient

Case	Building type	β
1	Residential use building, offices and assimilated	0,20
2	Buildings receiving the public temporarily :	
	- Rooms of exhibition, of sport, places of cult, meeting rooms with stand up places	0,30
	- classrooms, restaurants, dormitories, meeting rooms with sitting seats	0,40
3	Warehouses, hangars	0,50
4	Archives, libraries, tanks and assimilated buildings	1,00
5	Other buildings no aimed above	0,60

4.2.4 Estimation of the fundamental period of the structure

1. The value of the fundamental period (T) of the structure can be estimated from empirical formulae or can be calculated by numerical or analytic methods.

2. The empirical formula recommended is the following:

(4.6)

h_N: height measured in meters from the basis of the structure to the top of the last level (N).
C_T: coefficient, function of the lateral force resisting system and of the type of infill It is given by the table 4.6.

Tableau 4.6: values of the coefficient C_T

Case n°	Resisting System	C_T
1	Reinforced Concrete Moment Resisting Frames without infilled masonry	0.075
2	Steel Moment Resisting Frames without infilled masonry	0.085
3	Steel or Reinforced Concrete Moment Resisting Frames with infilled masonry	0.050
4	Partially or totally RC Shear walls, Braced Frames and Masonry Walls	0.050

In cases n° 3 and 4, the following formula can be used also:

(4.7)

Where **D** is the dimension of the building measured at its basis in the direction of calculation. In this case the smaller value between the values given by the formulae 4.6 and 4.7 is considered.

3. The value of T can be calculated using the Rayleigh formula or a simplified version of this formula:

***a*)**

$$\mathbf{T = 2\pi\sqrt{\left(\sum W_i\delta_i^2\right)\Big/\left(g\sum_i^n f_i\delta_i\right)}} \qquad (4.8)$$

$\mathbf{f_i}$: horizontal forces system, distributed according to formulae of V distribution following the vertical line.
δ_i: horizontal displacements due to $\mathbf{f_i}$ forces calculated following a linear elastic model of the structure that takes into account all elements which contribute to its rigidity

***b)* Simplified version of Rayleigh formula:**

$$\mathbf{T = 2}\sqrt{\delta_N} \qquad (4.9)$$

δ_N: horizontal displacement at to the top of the building, measured in meters, due to the vertical dead loads applied horizontally.

4. The Values of T, calculated using Rayleigh formulae or numerical methods must not exceed those estimated by appropriate empirical formulae of more than 30%.

4.2.5 Distribution of the global seismic force in the building height

The global seismic force **V** at the base of the building should be distributed following the height of the structure according to the following formulae:

$$\mathbf{V = F_t + \sum F_i} \qquad (4.10)$$

The concentrated force $\mathbf{F_t}$ at the top of the structure allows to take into account the influence of the high vibration modes of the structure. It is determined by the formula: $\mathbf{F_t = 0.07\ TV}$ Where **T** is the fundamental period of the structure (in second). The value of $\mathbf{F_t}$ should not exceed **0,25 V** and should be taken equal to 0 when T is smaller or equal to 0.7 seconds

The differential part of **V, i.e., (V - $\mathbf{F_t}$)** should be distributed following the height of the structure following the formula:

$$\mathbf{F_i = \frac{(V - F_t)\ Wh_i}{\sum_{j=1}^{n} W_j h_j}} \qquad (4.11)$$

4.2.6 Horizontal distribution of the seismic forces

The shear force at the level k: $\mathbf{V_k = F_t + \sum_{i=k}^{n} F_i}$ (4.12)

in the case of structures comprising rigid floors in their plan, is distributed to vertical elements of the resisting system proportionally to their relative stiffness.

4.2.7 Torsion Effect

The increasing of the shear force provoked by the horizontal torsion due to the eccentricity between the center of gravity and the center of rigidity should be taken into account.
The negative shear forces due to the horizontal torsion should be neglected.
For all structures having rigid floors or diaphragms in their plan, it is supposed that at each level and in each direction, the global horizontal force has an eccentricity in comparison with the torsion center equals to the greater of the two values:

-5% of the greatest dimension of the building at this level (this eccentricity should be considered on either side of the center of torsion)

-Theoretical eccentricity given by the schemes.

4.3. MODAL RESPONSE SPECTRUM ANALYSIS METHOD

4.3.1. Principle

By this method, the objective is to assess for each vibration mode, the maximum effects generated in the structure by the seismic forces represented by a design response spectrum. These effects are thereafter combined to obtain the response of the structure.

4.3.2. Modelling

a) For regular structures in plan with rigid floors, the analysis is made separately in each of the two main directions of the building. The building is then represented in each of the two directions of calculation by a plan model, embeded at the basis and where masses are concentrated in the gravity centers of the floors and considering only one DOF in horizontal displacement.
b) For irregular structures in plan, subject to horizontal torsion and having rigid floors, they are represented by a tridimensional model, embeded at the base and where masses are

concentrated in the gravity centers of floors considering three (03) DOF (2 horizontal motions and a rotational motion)

c) For structures, regular or not, comprising flexible floors, they are represented by the tridimensional modals embeded at the base and considering several DOF by floor.

d) The deformability of the soil of foundation should be taken into account in the model in all the cases where the response of the structure depends significantly on it.

e) The model of building to use should represent to the better the distribution of rigidities and masses so that to take into account all significant deformation modes in the calculation of the seismic forces (ex: contribution of the nodal zones and non-structural elements to the rigidity of the building).

f) In case of Reinforced Concrete or Masonry Buildings, the rigidity of vertical resisting elements should be calculated taking into account non-cracked transversal sections. If displacement is critical particularly in the case of structures associated with high values of the behavior coefficient, a more precise estimation of the rigidity becomes necessary and cracked transversal sections must be accounted for.

g) To take into account uncertainties on the position of masses and the spatial variation of the seismic motion, an accidental eccentricity (0.05 L, L being the dimension of the perpendicular direction to the seismic action) should be applied in the same direction in addition to structural eccentricity.

4.3.3 Design Response Spectrum

The seismic action is represented by the following Design Response Spectrum

$$
\frac{S_a}{g} = \begin{cases}
1.25A\left(1+\frac{T1}{T}\left(2.5\eta\frac{Q}{R}-1\right)\right) & 0 \le T \le T_1 \\
2.5\eta\left(1.25A\frac{Q}{R}\right) & T_1 \le T \le T_2 \\
2.5\eta\left(1.25A\frac{Q}{R}\right)\left(\frac{T_2}{T}\right)^{2/3} & T_2 \le T \le 3.0s \\
2.5\eta\left(1.25A\frac{Q}{R}\left(\frac{T_2}{3}\right)^{2/3}\left(\frac{3}{T}\right)^{5/3}\right) & T \ge 3s
\end{cases} \qquad (4.13)
$$

A: Zone acceleration coefficient (table 4.1)
η: factor of correction of damping (when the damping is different of 5%)

$$\eta = \qquad (4.3)$$

ξ: percentage of critical damping (table 4.2)
R: behavior coefficient of the structure (table 4.3)
T1, T2: characteristic periods associated with the site category (table 4.7)
Q: factor of quality (table 4.4)

table 4.7: Values of T_1 an T_2

Site	**S_1**	**S_2**	**S_3**	**S_4**
T_1 (sec)	0.15	0.15	0.15	0.15
T_2 (sec)	0.30	0.40	0.50	0.70

In the determination of the value of **Q**, it should be taking into account that the irregularities in plan and in elevation have already been considered in the model. Otherwise, in case of tridimensional analysis, the most penalizing value of **Q** between the two values determined in the two directions has to be considered.
The seismic action should be applied in all directions which are determinant for the calculation of seismic forces as well as directions that are perpendicular to them, considering the configuration in plan of the structure. For structures having their resisting elements distributed along two orthogonal directions, these two directions are considered as directions of the seismic excitations.

4.3.4 Number of modes to be considered

a) For structures represented by plan models in two orthogonal directions, the number of modes of vibration to be considered in each of the two directions of the seismic excitation should be such as:

- the sum of the effective modal masses for considered modes is at least equal to 90% of the total mass of the structure.
- or that all modes having an effective modal mass larger than 5% of the total mass of the structure are considered for determination of the total response of the structure.

The minimum of modes to be considered is three (03) in each direction

b) In the case where the above described conditions can not be satisfied because of the important influence of the torsion modes, the minimal number of modes (K) to be considered should be such as:

$$\mathbf{K \geq 3\sqrt{N}} \quad \textbf{and} \quad \mathbf{T_K \leq 0.20}\ \text{sec} \qquad (4.14)$$

where: **N** is the number of levels over the ground and $\mathbf{T_k}$ is the period of the mode K.

4.3.5 Combination of the modal responses

a) The two responses of vibration modes ***i*** and ***j*** with periods **Ti**, **Tj** and damping ratio ξ_i, ξ_j are considered as independent if the ratio r = Ti/Tj (Ti≤Tj) verifies:

$$r \leq 10 / (10 + \sqrt{\xi_i \; \xi_j}\,) \qquad (4.15)$$

b) In the case where all considered modal responses are independent one of each other, the total response is given by:

$$\mathbf{E} = \pm\sqrt{\sum_{i=1}^{k} \mathbf{E}_i^2} \qquad (4.16)$$

E**: effect of the considered seismic action**

E$_{i:}$ modal value of E according to the mode "i"

K: number of considered modes

c) In the case where two modal responses are not independent; E_1 and E_2 for example, the total response is given by:

$$\mathbf{E} = \sqrt{\left(|\mathbf{E}_1| + |\mathbf{E}_2|\right)^2 + \sum_{i=3}^{K} \mathbf{E}_i^2} \qquad (4.17)$$

4.3.6. Resultant of the design seismic forces

The resultant of the seismic forces $\mathbf{V_t}$ at the base obtained by combination of the modal values should not be less than 80% of the resultant of the seismic forces determined by the equivalent static method V for a value of the fundamental period given by the appropriate empirical formula.
If $\mathbf{V_t < 0.80\ V}$, it will be necessary to increase all parameters of the structural response (forces, displacements, moments,...) by the ratio $\mathbf{0.8V / V_t}$.

4.3.7. Effects of the accidental torsion

When the plan model analysis procedure is used in the two orthogonal directions, the effects of the accidental horizontal torsion are taken into account such as described in the paragraph 4.2.7.
In case when a tridimensional analysis is used, in addition of the computed theoritical eccentricity, an accidental eccentricity equal to ±0.05L (L being the dimension of the perpendicular direction to the seismic action) should be applied at the considered floor and in each direction.

4.4 COMMON REQUIREMENTS TO BOTH STATIC AND DYNAMIC METHODS

4.4.1. Stability to Overturning

The overturning moment that can be caused by the seismic action should be calculated in comparison with the level of ground–foundation contact.
The stabilizing moment will be calculated by taking into account the total weight equals to the sum of the weight of the construction, the weight of foundations and the possible weight of the earth.

4.4.2. Vertical component of the seismic action

The effects of the vertical component of the seismic action should be taken into account in the design of the cantilevers which have length of more than 1,50m in seismic zone III. For this purpose, besides the adequate descendant force, a minimum ascendant seismic force

$$\mathbf{Fv = 0.5\ A\ W_p} \qquad (4.18)$$

should be taken into account.

W_p : weight of the cantilever

A : seismic zone acceleration coefficient

4.4.3 Calculation of the displacements

Le horizontal displacement at each level "k" of the structure is calculated as follows:

$$\boldsymbol{\delta_k = R\ \delta_{ek}} \qquad (4.19)$$

δ_{ek} : displacement due to the seismic force F_i (including torsion effect)

R : behavior coefficient

The relative displacement at level "k" in comparison with level "k-1" is equal to:

$$\boldsymbol{\Delta_k = \delta_k - \delta_{k-1}} \qquad (4.20)$$

CHAPTER V: SAFETY VERIFICATION

5.1. GENERAL

The safety of the structure under seismic effects is considered to be satisfied if the following conditions regarding resistance, ductility, global equilibrium, foundation stability, seismic joints, deformation and « P-Delta » effect are simultaneously met.

5.2. COMBINATIONS OF ACTIONS

The seismic action is considered as « accidental action » in the meaning of limit states design philosophy.
The combinations of actions to be considered for computing the action effects are the following /

$$* \quad \mathbf{G + Q + E} \qquad \mathbf{(5\text{-}1)}$$
$$* \quad \mathbf{0.8\,G \pm E} \qquad \mathbf{(5\text{-}2)}$$

For the columns of « moment resisting frames », the combination (5-1) is replaced by the following combination :

$$* \quad \mathbf{G + Q + 1.2\,E} \qquad \mathbf{(5\text{-}3)}$$

G : permanent loads
Q : non weighted live loads
E : seismic action represented by its horizontal components

Though no mention about vertical acceleration effects has been made, these effects are included as follows :

- The combination (5-1) include total of live load as well as seismic load ; As this live load is quite improbable, a great part of it (about 40 to 60%) may actually represent the effect of seismic vertical accelerations.
- The combination (5-2) account for vertical load reduction that will occur due to vertical acceleration effects.

In the previous combinations, the reversibility of seismic loads must be accounted for.
For columns, the combination G + Q + 1.2 E in (5-3) aims at giving a better resistance against overturning moments effects due to major earthquakes.

5.3. RESISTANCE CONDITION

The following relation shall be satisfied for all structural elements, including connections, and the relevant non-structural elements :

$$S_d \leq R_d \qquad (5\text{-}3)$$

S_d : Design value of the action effect due to the combinations here above defined, including –if necessary- second order effects.
R_d : Corresponding design resistance of the element calculated according to the rules specific to the pertinent material.

5.4. DUCTILITY CONDITION

The ductility condition is deemed to be satisfied if all the detailing requirements for the material and the structural elements as given in the relevant material chapters of the present regulations are satisfied.

5.5. EQUILIBRIUM CONDITION

The building stucture shall be stable under the set of combinations of actions here above defined. Herein are included such effects as global overturning and sliding.

5.6. RESISTANCE OF HORIZONTAL DIAPHRAGMS

Diaphragms and bracings in horizontal planes shall be able to transmit with sufficient strength the effects of the design seismic action to the various lateral load resisting systems to which they are connected.

5.7. RESISTANCE AND STABILITY OF FOUNDATIONS

The foundation system shall be verified according to the relevant requirements of chapter X (Foundations and Retaining Walls)

5.8. SEISMIC JOINT CONDITION

Two adjacent buildings must be separated by seismic joints the minimum width of which must satisfy the following condition :

$$d_{min} = 15 \text{ mm} + (\delta_1 + \delta_2)_{mm} \geq 40 \text{ mm} \qquad (5.6)$$

δ_1 et δ_2 : maximum displacements of the two blocks, calculated at the top of the less high building, including effects of torsion and – if necessary – effects of foundations rotation.

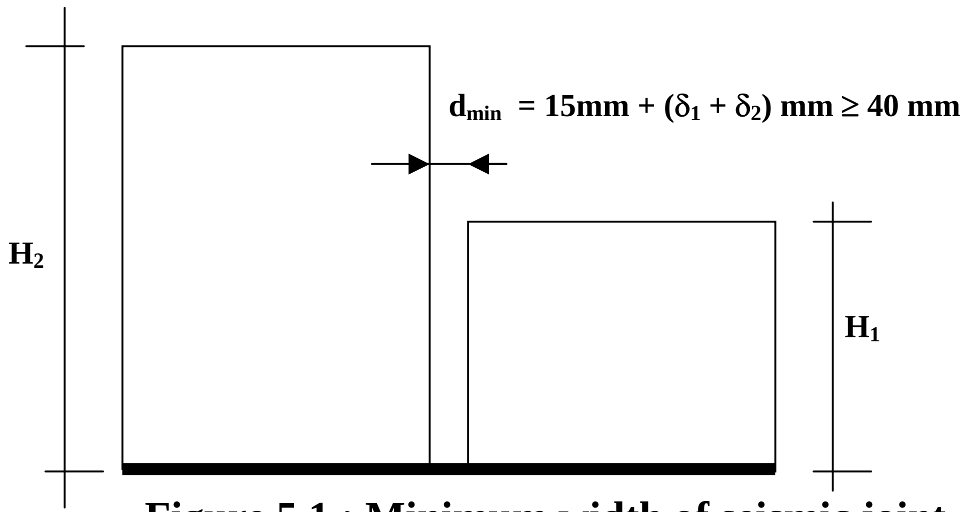


Figure 5.1 : Minimum width of seismic joint

5.9. P-Δ. EFFET

Second order effects (P-Δ effect) need not be considered when the following condition is fulfilled in all storeys :

$\theta = P_k \ \Delta_k \ / \ V_k \ h_k \quad \leq \ 0.10$

P_k : Total gravity load and associated live loads at and above the storey considered.

$P_k = \sum_{i=k}^{n}\left(W_{Gi^+} + \beta W_{qi}\right)$ (see paragraph 4.2.3 for calculation of W)

V_k : Total seismic storey shear

Δ_k : Design interstorey drift (relative displacement between the top and the bottom of the storey under consideration .(see paragraph 4.2.10)

h_k : Storey height

In case when $0,10 < \theta_k \leq 0,20$, P-Δ effets can approximately be taken into account by increasing the relevant seismic action effects by a factor equal to $1/(1- \theta_k)$.

If $\theta_k > 0,20$, the structure is potentially unstable and must be redesigned.

5.10 LIMITATION OF DISPLACEMENTS

The relative displacement between two adjacent storeys (interstorey drift), as calculated using the formulas of paragraph 4.4.3, must not be more than1.0 % of the height of the storey unless it is demonstrated that a bigger displacement could be admitted.