CODE OF TECHNICAL REGULATIONS FOR THE DESIGN AND CONSTRUCTION OF BUILDINGS IN SEISMIC REGION

SECTION ONE: GENERAL

Article 1

This code prescribes the technical regulations for the design and construction of buildings in seismic zones of maximum intensity VII, VIII and IX on the MCS-64 Scale. Conditions for the design and construction of buildings in seismic zones with a maximum intensity of X on the MCS Scale are determined on the basis of special studies, as is required for sites where out-of-category buildings are to be constructed.

All buildings within the S.F.R. of Yugoslavia are located in seismic regions as defined by the Seismological Maps of the S.F.R. of Yugoslavia, which have been prepared taking into account earthquakes with return periods of 50, 100, 200, 500, 1000 and 10000 years, and which form a constituent part of this code.

Article 2

According to the provisions of this Code, buildings in seismic regions shall be designed so that earthquakes of the highest (expected) intensity may cause damage to the load-bearing structure, but, in no case, collapse of the building.

Article 3

The symbols used in this Code have the following meanings:

K_o	-	coefficient of building category;
f_{max} (cm)	-	maximum permitted horizontal deflection of the building;
H (m)	-	height of the building above ground level;
G (10 kN)	-	total weight of the building;
S (10 kN)	-	total horizontally or vertically acting seismic load, or seismic load acting on an element of the structure;
K	-	total seismic coefficient for the horizontal direction;
K_s	-	coefficient of seismic intensity;
K_d	-	coefficient of dynamic response;
K_p	-	coefficient of ductility and damping;
T (sec)	-	period of fundamental mode of structural vibration;
S_i (10 kN)	-	horizontal seismic force acting at the height of the "i"-th storey;
G_i (10 kN)	-	weight of the "i"-th storey;
H_i (m)	-	height of the "i"-th storey, measured from the top of the foundation;
K_v	-	total seismic coefficient for the vertical direction;
Q_i (10 kN)	-	transverse seismic force acting at the height of the "i"-th storey;
$M_{t,i}$ (10 kN)	-	torsional moment acting in the "i"-th storey;
e_i (m)	-	distance between the centre of rigidity and the centre of mass in the "i"-th storey;
K_e	-	coefficient for the calculation of seismic effects upon structural elements;
G_e (10 kN)	-	weight of structural elements;
μ (%)	-	percentage of tensile reinforcement;
μ' (%)		percentage of compressive reinforcement;
σ (10^2 KPa)	-	average stress in a structural element due to vertical loading;

β_B (10 KPa) - strength of concrete prism;

β_K (10 KPa) - strength of concrete cube;

h_i (cm) - height of "i"-th storey;

γ - safety factor;

d (cm) - wall thickness;

$\sigma_{n\text{-}perm}$ (10 KPa) - permissible principal tensile stress;

σ_n (10 KPa) - principal tensile stress in a wall element;

τ_o (10 KPa) - average shear stress in a wall element due to seismic load;

$\sigma_{n\text{-}ult.}$ (10 KPa) - principal tensile stress in a wall at ultimate load;

K_t - coefficient defining the increase of eccentricity due to coupling;

P (10 kN) - axial force due to the vertical loading of a column;

F (cm^2) - cross-sectional area;

SECTION TWO: CLASSIFICATION OF BUILDINGS

Article 4

According to this Code, buildings and structures shall be classified into one of the following categories:

Building category	Type of building or structure	Building category coefficient, K_o
Out-of-category	Buildings forming part of nuclear power stations; buildings for the transport and storage of inflammable liquids and gases; buildings for the storage of toxic materials; more important telecommunications buildings and structures; buildings with more than 25 storeys, and other buildings upon whose unimpaired functioning depends the operation of other technical-technological systems, faults in which could have disastrous effects on the environment and/or cause great material losses to the wider community;	
Category I	Buildings which contain rooms for assembly use (cinemas, theatres, gymnasiums, exhibition-halls, etc.); university faculty buildings; schools; hospitals and health centres; fire stations; telecommunications buildings and structures not classified as out-of-category buildings (post-office, radio and television broadcasting, etc.); industrial buildings containing particularly valuable equipment; all energy-production buildings with an output of up to 40 MW; buildings containing objects of exceptional cultural and artistic value, and other buildings in which activities of particular importance to socio-political communities are carried out.	1.5
Category II	Residential buildings; hotels; restaurants; public buildings not classified into Category I, industrial buildings not classified into Category I.	1.0
Category III	Auxiliary industrial buildings; agrotechnical buildings.	0.75
Category IV	Temporary buildings and structures whose collapse cannot endanger human lives.	

Article 5

Buildings and structures classified as Category I buildings, but not located in a seismic zone, shall be designed to resist a loading corresponsing to intensity VII. In this case a building category coefficient of $K_0 = 1.0$ shall be adopted.

Buildings and structures classified as Category IV buildings need not be designed to resist seismic loading.

SECTION THREE: SEISMICITY AND SEISMIC PARAMETERS

Article 6

The seismic hazard associated with a particular seismic region shall be estimated on the basis of the Seismological Maps of the S.F.R. Yugoslavia.

When designing buildings which belong to Category II or Category III, the seismological map of the S.F.R. of Yugoslavia which corresponds to a return period of 500 years shall be used.

Seismic hazard and the parameters needed to design buildings against earthquakes may also be determined by means of additional research within the framework of detailed seismic zoning studies or seismic microzoning.

Article 7

When designing buildings classified into Category I, the coefficient of seismic intensity, as well as other parameters, shall be defined beforehand by means of special studies - with the seismic micro-zoning of building areas.

Article 8

When designing buildings classified as out-of-category according to Article 4 of this Code, it is necessary to carry out first a detailed investigation of the seismicity of sites upon which construction is foreseen. The design and maximum expected earthquake shall be determined on the basis of seismic hazard investigations.

SECTION FOUR: LOCAL GROUND CONDITIONS

Article 9

The influence of local ground conditions shall be taken into account, when detemining seismic effects on buildings of Category II and III, by means of the dynamic response coefficient as defined in Article 25 and depending on the category of the ground upon which the building is to be constructed. The category of ground shall be determined according to the classification given in Table 1, on the basis of the results of geotechnical investigations of the site, of engineering-geological and hydro-geological data, and of geophysical and other investigations of the ground.

Table 1

Category of ground	Characteristic soil profile
I	Rock or rock-like ground (crystalline rocks, shales, carbonate rock, limestone, marlstone, well-cemented conglomerate and similar, very dense and hard soils, of thickness less than 60.0 m, consisting of stable layers of gravel, sand and stiff clay on top of a firm geological formation.
II	Dense and medium-dense soils, as well as very dense hard soils, with a thickness of over 60.0 m, consisting of stable layers of gravel, sand and stiff clay on top of a firm geological formation.

III	Soils of low density and soft soils, with a thickness of greater than 10.0 m, consisting of loose gravel, medium-dense sand and clay, with layers of sand or other cohesionless soils or without such layers.

Construction sites for buildings belonging to Category II or III, whose ground conditions are not known with sufficient certainty, may be classified into ground Category II.

Article 10

In the case of ground where, during earthquakes, dynamics instability may occur as a result of the liquefaction of loose sandy soils and other water-saturated materials, as well as a result of severe settlement, landslides, rockslides, soil slips, or similar phenomena, the feasibility and conditions for the construction of buildings on such sites shall be determined by means of special on-site and laboratory investigations.

Unless so dictated by the purpose of the building, buildings and structures shall not be built on ground where dynamic instability may be expected to occur (arreas of quicksand or silty soil, landslide-prone areas, unstable slopes, ground where liquefaction and severe settlement may occur).

Article 11

In the case of ground where it has been proved by means of standard geotechnical investigations that the possibility of occurence of dynamic instability phenomena exists, the feasibility and conditions of design and construction for buildings to be erected on such ground shall be determined by means of special on-site and laboratory investigations.

SECTION FIVE: METHODS OF CALCULATION, PERMISSIBLE STRESSES AND DISPLACEMENTS

Article 12

For the structural analysis of the load-bearing structure of buildings either limit-state theory or elastic theory may be used.

Article 13

If calculations are to be based on the elastic theory, then the allowable stresses may be increased by 50 %, but must not exceed the yield point. In the case of metals without a distinct yield point, the allowable stress may not exceed 80 % of the ultimate strength of the material.

Article 14

The maximum permissible loading of the sub-soil shall be determined, for the most unfavourable combination of seismic and other effects, by taking into account a safety-factor against soil failure of 1.5.

Article 15

If calculations of the seismic resistance of the load-bearing structure are to be based on limit-state theory, then the following safety-factors shall be used:

- for reinforced and prestressed concrete structures 1.30,
- for steel structures 1.15,
- for masonry structures 1.50.

Article 16

The maximum horizontal deflection of a building for the given seismic loading, as determined on the basis of elastic theory without taking into account the influence of soil-structure interaction, shall not exceed a value of

$$f_{max} = \frac{H}{600}$$

where H is the height of the building.

When determining the size of maximum deflections, the influence of soil-structure interaction shall be taken into account separately, if this is essential.

In the case of industrial buildings, as well as other special buildings and structures, larger deflections than the above are permitted if, at the same time, the stability of these buildings can be proved.

SECTION SIX: CALCULATION OF SEISMIC LOADS

1. Fundamental Principles of Calculation

Article 17

When analysing the effect of horizontal seismic loads on the load-bearing structure of a building, the action of these loads on at least two orthogonally-orientated planes shall be considered.

Article 18

In the case of cantilevered structures, as well as other structures where the influence of vertically-acting seismic loads may be of major importance, calculations of the effect of vertically-acting seismic loads shall be carried out separately.

Article 19

The total weight of a building, G, shall be defined as the sum of all dead loads, probable live loads and snow loading.

Probable live loading shall be considered to be equal to 50 % of the loading specified in the loading regulations. If live loading is a significant factor (e.g. in the case of warehouses, silos, libraries, archives, etc.), then the seismic loads shall be determined for the most unfavourable case of maximum or minimum actual loading.

Loads caused by the wind, as well as the live load carried by cranes, need not be taken into account when calculating the seismic resistance of buildings.

The full weight of permanently-installed equipment shall be taken into account.

Article 20

The seismic analysis of structures may be carried out either by the equivalent static load method or by the dynamic analysis method.

2. The Equivalent Static Load Method

Article 21

The total horizontal seismic force acting on a building, S, shall be determining according to the formula:

$$S = K * G ,$$

where K is the total seismic coefficient for the horizontal direction and G is the total weight of the building and its equipment as defined in Article 19 of this Code.

Article 22

The weight of a building shall be defined as the weight above the upper edge of its foundation. In the case of rigid basement structures, however, it shall be defined as the weight above the upper edge of these structures.

Article 23

The total seismic coefficient K shall be calculated from the expression:

$$K = K_o * K_s * K_d * K_p ,$$

where:

κ_o is the coefficient of building category,

κ_s is the coefficient of seismic intensity,

κ_d is the coefficient of dynamic response, and

κ_p is the coefficient of ductility and damping.

The total seismic coefficient κ shall have a minimum value of 0.02.

Article 24

Depending upon zone seismicity, the coefficient of seismic intensity, κ_s, shall have one of the following values:

Zone seismicity on the MCS Scale	κ_s
VII	0.025
VIII	0.050
IX	0.100

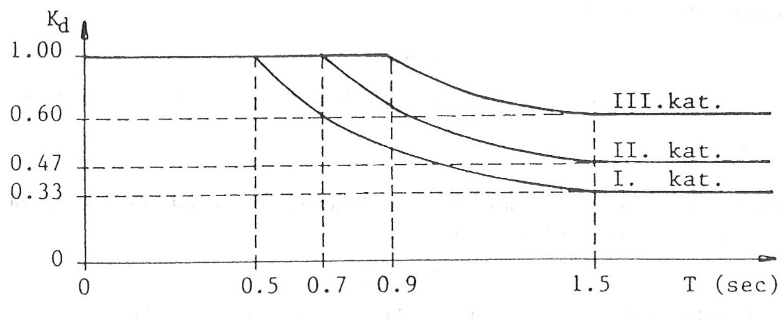
Article 25

The coefficient of dynamic response, κ_d, shall be determined according to Table 2 or according to Diagram M, depending on the category of ground:

Table 2

Category of ground	Coefficient	Limit values of the coefficient κ_d
I.	$\kappa_d = \frac{0.50}{T}$	$0.33 < \kappa_d < 1.0$
II.	$\kappa_d = \frac{0.70}{T}$	$0.47 < \kappa_d < 1.0$
III.	$\kappa_d = \frac{0.90}{T}$	$0.60 < \kappa_d < 1.0$

Diagram M



Article 26

Calculation of the natural periods of free vibration of structures shall be carried out using the methods of structural dynamics, or by means of approximate formulae which are based on the principles of structural dynamics.

If, in the case of stiff reinforced-concrete or masonry buildings, up to 5 storeys high, the natural periods of free vibration are not calculated, then the maximum value of the coefficient K_d according to Table 2 shall be assumed, for the corresponding sub-soil conditions.

Article 27

The coefficient of ductility and damping, K_p, depends on the type of structure under consideration:

1) For all modern reiforced-concrete structures, for all steel structures except those mentioned in section 2 of this article, and for all modern wooden structures, except structures listed in section 3 of this article, $K_p = 1.0$;
2) For structures built of reinforced masonry, and for braced steel structures, $K_p = 1.3$;
3) For masonry structures, strengthened by means of vertical reinforced-concrete tie-beams; for reinforced-concrete shear-wall structures which do not satisfy the requirements of Article 68 of this Code; for very high and slender structures with low damping, such as high industrial chimneys, aerials and masts, water-towers and other structures with a fundamental natural period of free vibration of $T \geq 2.0$ sec., $K_p = 1.6$;
4) For structures with a particularly flexible ground-floor or any other storey, or with a sudden change in stiffness, as well as for ordinary masonry structures, $K_p = 2.0$.

Article 28

Analysis of structures with a particularly flexible ground-floor or any other storey may be carried out, instead of according to Article 23 of this Code, by the dynamic analysis method, taking into account the effect of the design and maximum expected earthquake.

Article 29

The total seismic force acting on a structure shall be distributed over the height of the latter either:

1) by the method of structural dynamics, or
2) according to the approximate formula given in Article 30 of this Code.

Article 30

For buildings up to 5 storeys high, the seismic force shall be considered to be distributed according to the approximate formula:

$$S_i = S * \frac{G_i * H_i}{\sum_{i=1}^{n} G_i * H_i}$$

where

- S_i is the horizontally-acting seismic load in the "i"-th storey,
- G_i is the weight of the "i"-th storey, and
- H_i is the height of the "i"-th storey, measured from the upper edge of the foundation.

Article 31

For all other buildings, except for buildings for which calculations based on the methods of structural dynamics are obligatory, the total seismic force shall be distributed over the height of the structure as follows: a force amounting to 85 % of S shall be distributed according to the formula given in Article 30 of this Code, whereas the remainder, 15 % of S, shall be assumed to act as a concentrated load at the top of the building.

Article 32

The total vertical seismic force acting on a building shall be determined in accordance with the formula:

$$S = K_v * G$$

where K_v is the total seismic coefficient for the vertical direction, and G is the total weight of the building (see Article 19).

Article 33

The total seismic coefficient for the vertical direction shall be calculated from the expression:

$$K_v = 0.7 * K = 0.7 * K_o * K_s * K_d * K_p ,$$

where K is the total seismic coefficient for the horizontal direction.

When determining values of the coefficient K, the expression given in Article 23 of this Code shall be used, taking into account, for the natural period of vibration, the natural period for the vertical direction of the structure or structural element under consideration.

Article 34

Torsional moments shall be calculated, for each storey of the structure, from the expression:

$$M_{t,i} = Q_i * e_i * K_t ,$$

where:

- Q_i is equal to the greater of the calculated values of storey shear, in the "i"-th storey, corresponding to the directions chosen for analysis,
- e_i is the eccentricity of the centre of stiffness with respect to the centre of mass, in the "i"-th storey, and
- K_t is the coefficient defining the increase of eccentricity due to coupling between lateral and torsional vibrations, and due to non-uniform movement of the foundations. If no value of the coefficient K_t is calculated, then a value of $K_t = 1.5$ shal be assumed.

In the calculations, all masses situated above the storey being analysed for torsional moments shall be taken into account.

Article 35

The seismic forces acting on the elements of a structure shall be calculated according to the formula:

$$S = K_s * K_e * G_e ,$$

where:

- K_s is the coefficient of seismic intensity, according to Article 24 of this Code,
- K_e is the coefficient defined in Article 36 of this Code, and
- G_e is the weight of the element of the structure for which the seismic force is being calculated.

Article 36

The values of the coefficient K_e are given in Table 3:

Table 3:

Elements of the structure	Ke	Direction of action of seismic force
- partition walls, non load-bearing walls	2.5	perpendicular to the flat surface of the wall
- balconies	6.0	perpendicular to the flat surface of the balcony
- chimneys, tanks connected to the building	6.0	in any direction
- masonry parapet walls and fences	10.0	perpendicular to the flat surface of the wall
- ornamentations	10.0	in any direction

Article 37

In the case of equipment fixed inside buildings whose movement or overturning might endanger human lives or cause damage, the anchoring of such equipment shall be designed according to the formula given in

Article 35 of this Code, assuming a value of $K_e = 10.0$, in order to prevent the movement or overturning of such equipment.

Article 38

The design of anchorages for particularly valuable equipment, whose operation is vital, shall be carried out by applying the methods of dynamic analysis to the structure and the equipment.

3. The Dynamic Analysis Method

Article 39

The aim of dynamic analysis is to determine, in both the elastic and post-elastic range, the structural behaviour of buildings when subjected to the ground-acceleration time-histories of earthquakes which bay be expected at the construction site. By means of such an analysis the stresses and deformations occuring in the structure for the design and maximum expected earthquake can be determined, as well as the acceptable level of damage which may occur to the structural and non-structural elements of the building in the case of the maximum expected earthquake.

Calculation of seismic resistance by means of the dynamic analysis method is obligatory for the following types of buildings:

1) all out-of-category buildings
2) prototypes of prefabricated buildings or structures which are produced industrially in large series (except for wooden structures).

Article 40

The seismic parameters defining the action of earthquakes upon the buildings listed in Article 39 of this Code shall be determined according to the local site conditions.

The parameters mentioned in the first paragraph of this Article shall be determined on the basis of the return-period of earthquakes occuring at the site in question, taking into account the expected life-span of the building and its purpose. In this way the level of acceptable seismic risk shall be determined.

The seismic parameters shall be determined for both the design earthquake and the maximum expected earthquake at the construction site in question.

The seismic parameters shall be determined on the basis of the findings of existing theoretical an/or experimental studies, or by means of specially performed investigations.

Article 41

If the structural parameters of linear and non-linear behaviour of the buildings listed in Article 39 of this Code are not determined by means of specially performed theoretical or experimental studies, then it shall be assumed in the calculations:

1) That the maximum relative displacement of storeys for linear behaviour of the structure shall amount to not more than:

$$\frac{h_i}{350}, \text{ and}$$

2) that the maximum relative displacement of storeys for the design level of earthquake, i.e. for a modest level of nonlinear deformation of the structure, shall amount to not more than:

$$\frac{h_i}{150},$$

where h_i is the height of the "i"-th storey in cm.

Article 42

The total horizontal seismic forces s obtained by means of the dynamic analysis method shall not be less than 75 % of the force obtained by calculations using the equivalent static load method, and not less than 0.02 G.

SECTION SEVEN: TESTING OF STRUCTURES

Article 43

The dynamic characteristics of buildings, constructed in zones of seismic intensity VIII and IX on the MCS scale, shall, in the case of out-of-category buildings or prototypes of industrially-produced prefabricated buildings, be verified experimentally, without exception.

Article 44

The behaviour of structural elements of buildings for which calculations of seismic resistance by means of the dynamic analysis method are obligatory, and which are to be constructed in zones of seismic intensity VIII or IX on the MCS scale, shall be checked experimentally.

SECTION EIGHT: DESIGN OF EARTHQUAKE-RESISTANT STRUCTURES

Article 45

When choosing sites for the construction of buildings, unless special reasons exist, non-homogeneous, embanked or generally unstable ground shall be avoided.

Article 46

Suitable layout of the load-bearing structures of buildings shall be achieved by means of a regular and simple floor-plan arrangement, with a uniform distribution of masses.

If buildings are heavily loaded, then all masses shall be kept as low as possible above ground level.

Article 47

Aseismic joints shall be provided in the case of:

1) building with irregular floor-plans,

2) buildings or parts of buildings of unequal height.

The minimum width of the aseismic joint shall be 3.0 cm. The width of the aseismic joint shall be increased by 1.0 cm for every increase of 3.0 metres of height above 5.0 metres.

In the case of buildings higher than 15.0 m, as well as in the case of flexible structures of lesser height, such as unbraced frames, the necessary width of the seismic joint shall be determined by calculation. This width shall not be less than the sum of the maximum deflections of adjacent parts of the building, nor shall it be less than the value following from the first paragraph of this Article.

Article 48

Floor structures shall be designed to form stiff horizontal diaphragms, which, monolithically jointed onto the vertical load-bearing system, can transfer compressive and tension loads onto the latter. Floor structures which do not fulfill this requirement shall be treated in the design procedure as flexible elements.

Article 49

The structural system of a building shall be chosen taking into account the following criteria:

1) The structural elements of the basic system shall be made out of strong and ductile material; lighter material shall be used for the non-structural elements.

2) The structural system, and its structural elements, must have sufficient strength and capacity for large deformations, and for the accumulation and dissipation of energy.

3) Abrupt changes in rigidity and strength over the height of the building are not, as a rule, permitted. If the structural system includes a flexible storey (or storeys), then the building must be analysed taking into account the requirements of Article 27 of this Code.

4) The stiffness of the structural system should be chosen in such a way that severe damage to the non-structural elements of the building will not be caused by an earthquake loading;

5) Structural elements which could, in the case of imperfections during construction or minor damage of any kind, cause instability of the system or progressive failure, shall not be used for the construction of buildings.

Article 50

During strong seismic motion, structural elements must be able to perform adequately in the non-linear range. For this reason the following conditions must be fulfilled:

1) when designing the structural elements of buildings, the cross-sections and zones where non-linear deformations and plastic hinges may occur must be selected;

2) in zones of plastic hinges, a high capability for plastic deformations must be ensured, so that the structure's ductility and capacity for energy-dissipation is increased;

3) the joints, anchorages and supports of structural elements in buildings must be designed so that they are able to transfer the ultimate static loads without being damaged.

Article 51

The foundations of buildings shall be designed in such a way that non-uniform settlements are avoided under design load conditions.

As a rule, the foundations must be built at the same depth. The foundations of individual parts of the building (strip and pad footings) shall be connected together by means of tie-beams in order to achieve adequate rigidity of the foundation structure.

Article 52

The founding of buildings on ground with varying characteristics should be avoided. If this is not possible, then structural joints must be provided in order to separate individual parts of the structure according to the different soil conditions.

Article 53

In the case of unfavourable ground conditions, the optimum design solution for the foundations shall be sought, taking into account especially the influence of groundwater on dynamic seismic effects (non-linear deformation of the soil or liquefaction).

When designing buildings for seismic loads, depending upon the kind of ground and type of foundations the deformation of the foundation structure and the latter's influence upon the whole upper structure of the building shall be verified.