STRUCTURAL CONSIDERATIONS IN EARTHQUAKE-RESISTANT DESIGN

by

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It is indeed with distinct pleasure that I find myself about to talk to you on a subject which is of primary interest to civil engineers. Earthquakes, as they affect structures, have collectively always posed as an active challenge to designers, but it is only recently that more scientific methods have greatly contributed to the better understanding of this phenomenom. Ordinarily, undergraduate students in civil engineering are exposed only to the Dynamics of Rigid Bodies—but even then, the First Law of Newton is oftentimes haphazardly explained, much less sufficiently applied. After all, the nature of live loads on most civil engineering structures is such that they are assumed to be applied "very slowly", and as such, may be considered static in effect. It is only when loads are applied in truly dynamic fashion that the interest of the civil engineer is aroused as if to tell himself that this is something different! Earthquakes loads are good manifestations of these dynamic actions; other examples are wind and blast loadings.

In our schools, dynamics of structures as a formal subject is offered at the post-graduate level, and to the best of my knowledge, only the U.P. presently offers such a course.

The purpose of this lecture is to give a fair overview of the structural considerations as they relate directly to the art of earthquake-resistant design.

The Philosophy of Earthquake-Resistant Design

If the ground motion due to an earthquake were defined by one accelerogram, the seismic forces may be readily determined by analysis. Thus, we are able to define the dynamic history in order to study the behavior and safety of the structure under seismic action. By the use of many accelerograms, records have been obtained of various earthquakes, and the responses of structures were derived as functions of the important parameters of seismic action, which

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are: earthquake intensities, time durations of the earthquake motions, soil conditions, and frequencies of the impulses.

The structural characteristics, in turn, which directly affect dynamic response are: magnitudes and distribution of the masses, damping coefficients and stiffness. In the case of a one-degree-of-freedom oscillator, the maximum values of dynamic response can be obtained for various periods of vibration in the form of graphical response spectra, both for linear as well as for non-linear behavior. These response spectra show that if damping were small, or when the system enters the post-elastic range, the resonance effect greatly influences the graphical shape. This simply means that the soil conditions have a strong influence on the response.

In seismic analysis of structures, two approaches have been successfully used: The first method adopts the total shear force at the base of a multi-storey building as equal to the force of a simple oscillator having an equal period. The force is then distributed along the height of the structure. The second method calculates the seismic forces directly and the lateral forces at various heights are proportioned. It has been observed that the shear force and overturning moment for the lower part of the structure are largest for the fundamental period, whereas for the upper part of the structure, the quantities obtained for the higher mode shapes are sometimes larger compared to these of the fundamental mode at these higher levels. The actual value at a particular level of course is the super-position of all the modal values.

For structures which can withstand deformations larger than those caused by elastic action, the seismic forces decrease and at the same time the maximum displacements exceed the deformations within the elastic limit. The lower the yield point, the larger is this reduction. Experience has shown that structures capable of withstanding significant deformations can survive even stronger earthquakes.

At present, the energy concept provides the most reasonable explanation of structural behavior during earthquakes. Structures must possess some capacity to absorb energy and this energy accumulation depends upon the ability to deform in the elastic and, much more so, in the inelastic ranges. Consequently it may be concluded that safety depends not only on strength and resistance but to a greater extent upon ductility, which is one of the most significant factors in earthquake-resistant design. It follows that the very important, and possibly the most difficult, part of the analysis is to find the most advantageous balance between strength and ductility.

The theory and method of calculation of the direct dynamic response and also the response spectra give the best approximation to a more accurate analysis of structures subjected to seismic action. The degree of approximation however depends upon many factors the more significant of which are the soil properties and the nature and characteristics of the earthquakes themselves.

Objectives and Methods of Aseismic Structural Design

The aims of aseismic structural design is to provide civil engineering structures with features which will enable them to resist satisfactorily earthquake forces. In their order of importance I would rate these objectives as follows:

1. To attain reasonable safety against collapse when subjected to the effects of a strong earthquake.
2. To confine and limit material damage in the event of a moderate earthquake.
3. To minimize, if not entirely eliminate, panic among occupants of buildings where people congregate during earthquake occurrences.
4. To prevent harm and injury to the populace.
5. To avoid unnecessary damage to neighboring constructions.

It is not easy to meet these objectives merely by observing a set of rules and recommendations. Every structural design presents features which obligate the engineer to exercise judgment. On the other hand, because of the many variables involved in earthquake design, specific recommendations are not feasible and we have to satisfy ourselves with sound criteria in order to exercise more rationally our judgment.

Apparently, safety against collapse seems to be a simple problem of resistance and strength. However, because of the aleatory nature of earthquakes, it is appreciated that the problem is rather much more complex. Whereas under static loads, safety against collapse is assured by the load carrying capacity of the structure, in the case of earthquake forces, attention must be paid to making the structure strong, ductile, preferrably with high damping characteristics and with periods quite different from that of the ground.

During the last decade, the scientific basis of aseismic design has improved fundamentally, but the greatest impact is still the energy concept. The development of these methods leads to the following:

1. The modal method of dynamic analysis which utilizes the elastic theory.

2. The application of probabilistic and statistical approaches by taking into account the random nature of the input.
3. The ultimate strength design procedures, especially in the acceptance of the concept of the plastic hinge.
4. The plastic theories which establish the post-elastic properties of these plastic hinges, such as deformability, ductility, and energy dissipation by yielding.
5. The methods of direct dynamic response and energy response in addition to the equivalent static load.

The method by direct dynamic response is of the deterministic type, but it is also possible to use non-deterministic methods using probability theory. Plastic methods can be used either directly, or indirectly as check on the elastic design.

To determine the earthquake response, the use of a computer has hastened the development of the analysis. The development of models invariably expresses the structure dynamic properties in mathematical form. For a building, the dynamic equations of motion are usually expressed for each storey. There is usually no problem with respect to mass, but there are difficulties with regards to stiffness and damping. The problems in determining stiffness arise when the members transform into the post-elastic range, while damping is conveniently assumed as viscous.

The energy response is considered an advanced development which offers better understanding of the behavior of the structure. It offers theoretical explanations of the failure mechanisms. The energy forms are: kinetic, which the vibrating masses possess; potential, which is stored in the elements due to their deformations; that dissipated due to internal friction at the joints, and; that generated by plastic deformation. The energy concept explains how a weak storey acts as a barrier to the propagation of energy waves causing a weak energy feed to the storeys above the weak one.

The basic energy response relation is:

$$E_f = E_k + E_p + E_v + E_y$$

which simply states that the energy feed is the sum of the kinetic energy, the potential energy, the energy absorbed due to viscous damping and the energy dissipated due to yielding.

A closer examination of accelerogram records of an actual earthquake would indicate that the seismic forces exceed the values given by most codes by 2 to 6 times. Because the structures have not been designed to resist these high magnitudes of forces, the members invariably enter the inelastic range. Since the structure may now vibrate both in the elastic and inelastic ranges, the structure is said to possess the property of "dynamic adaptation".

Earthquakes are characterized by their magnitudes. A popular scale is the one proposed by Richter. This magnitude characterizes the energy released at the focus, and an increase in M of one degree increases the energy almost a hundred times. This fact implies that the energy feed to the structure also increases tremendously. Studies show that energy response is greatly influenced by the type and duration of the earthquake, but the fact remains that seismic intensity scales neglect entirely the energy character of the earthquake. For example, the longer the earthquake duration, the more is the energy feed to the structure. This is true because the long duration requires that the structure work much stronger in the post-elastic range.

With the increasing importance of plastic hinge formations, it may also be concluded that indeterminate structures are more advantageous. They do not easily lose their stability by forming immediately into collapse mechanism. With the common materials used in construction: concrete, steel and timber, the desired ductility can only be attained after a suitable design has been made. It is easy to accept ductility of steel, but even for reinforced concrete this concept has been well accepted and applied.

The psychological effect of the "large" horizontal movements called "drifts", of a flexible structure must not be overlooked. Past experiences have indicated that damage due to panic can be extremely high. The choice of designing a rigid or flexible structure will defend upon many factors, such as the local geology and economic considerations.

One of the most common examples of damage to neighboring constructions is perhaps the case of two buildings erected adjacent to each other. It will be a rare coincidence if the periods of the buildings happen to be nearby equal; if not, the collision of the two structures will cause damage to both. A separation is strongly recommended particularly for tall, slender and flexible constructions. The size of this separation depends upon the dynamic properties of the adjacent buildings.

The basic conditions which must be carried out to provide better aseismic design must take into consideration three points of view: The structural, the architectural and the materials used. These are inter-related and certainly are not independent. Among these, the third is oftentimes taken for granted. A case may arise where the design is excellent for reinforced concrete, but the same design may yield poor performance if constructed out of structural steel.

In addition, the seismic resistance of a building may be greatly increased if rigid diaphragms on each floor level are able to distribute the seismic thrusts more adequately to the resisting frame, and if the structure has properly designed foundations to be able to withstand the base shears generated between the structure and its foundation. Local experience also has taught us that a basic condition for good aseismic design is symmetry and uniformity such that the center of mass and the center of rigidity almost coincide. It is important to point out that static eccentricity does not define by itself the full effect of torsion since the effect of dynamic torsion may exceed that of the static condition. Nonetheless, it is undoubtedly advantageous to reduce this static eccentricity to a minimum. For the purpose of resisting the effects of amplification of dynamic torsion, the elements resisting the horizontal thrusts must have the required resistances. Structural symmetry is indeed more important in the case of tall buildings and also for low buildings which are elongated in plan.

Building Codes as Preventive Measures in Earthquake-Resistant Constructions

The philosophy of design expounded by various Codes is based on the elastic concept. More appropriate parameters and factors, such as inelastic action, the energy concept, ductility, the actual dynamic response, and the influence of the foundation are all neglected. In this context, Codes are considered inadequate as there stems an automatic tendency for the engineer to aim only at the strength criterion. Refinements in design, however, may lead to decisions on energy localization and many structures designed on the basis of the Codes have in fact performed poorly.

For practical purposes, it is possible to generate simplified response spectra and to derive simple design formulas. The parameters involved are: seismic intensity and duration, dynamic characteristics of the soil, structural damping and ductility. Using this simplified view, expressions for the calculation of the base shear is written in the form which gives the shear as a function of several factors. Some of the provisions of selected codes are outlined in Appendix A. It is seen that the general forms are basically similar, although certain refinements are attributable to local conditions and to some degree of sophistication. The Uniform Buliding Code of U.S.A. and the New Zealand Code both take into account the "whiplash" effect, although the latter further classifies buildings into "ordinary" and "important". The format of the U.S.S.R. Code implies that the method used is the modal analysis since formulas are based on individual modes. It is readily seen however that almost all popular Codes at present consider the period of vibration of the structure as a very important parameter. The Yugoslav Code, in addition to the rule-of-thumb nature of getting seismic coefficients, suggests spectral analyses, not only for the building, but also for the ground. Since 1960, many other countries have adopted the spectral method, which is generally connsidered the most progressive method proposed as yet.

The methodology given in Codes may be considered adequate to meet the level of present scientific knowledge. The Codes must also correspond to the professional level and economic capabilities of the country. But it must be emphasized that the recommendations are intended for typical designs only. It is difficult to give a qualitative evaluation, and only continuous and long experience in the study of actual earthquakes will show whether or not the applications are for proper application of the Codes are necessary. Presently, new principles and concepts are being investigated and tremendous progress has been made in the post-elastic range. This probably suggests that revisions of existing Codes, inevitably, will follow.

A new idea which will surely catch attention is the concept of structural leveling. When a well-studied structural method is used, and when the structure satisfies all the requirements of the Code, the structure can be built which will be resistant to earthquake forces. However, when an engineer attempts to try new methods based on the latest researches, he most probably cannot attain his objectives if he does his work only within the spirit of the Code. Here is where the concept of structural leveling may be used because a very detailed analysis is required in order to compensate for the lack of experience. A proposal for such a project is outlined in Appendix B.

Seismic Microzoning

The aims of a detailed seismic zoning and microzoning of the ground are to examine the factors affecting earthquake motions and how the influences vary from site to site. This is especially important in planning future urban areas in order to offer greater safety and protection to the expected large concentration of material and people. As a matter of fact, seismic microzoning must be on all populated areas where seismic activity is know to exist.

The effect on particular areas is evaluated by examining the physical and dynamic characteristics of the ground and correlated to the influence of earthquake intensity on the responses of the structures. The study will be valuable not only in laying out a completely new town but also in deciding the type and characteristics of new buildings and structures to be put up in the future. An ambitious recommendation states the limits of the number of stories which a structure may have knowing the type of structure and the location where it is planned.

Seismic microzoning evolved because of the observation that damage is categorized into various degrees even if they happen to be observed near each other. Its methodology developed with the aid of other sciences such as geology, geophysics, instrumental seismology and quite recently, the theories of structural dynamics. Today, engineers are familiar with three of these methods; namely, the geologic method, the method of seismic impedance, and the method of dynamic response of the ground.

The geologic method came earliest and during that time structures were stiff and basically fragile and it became difficult to find reasons why damages varied, except to correlate this directly with the geologic conditions. Besides the constitution of the ground, other geological factors which decreased or increased seismic intensities were studied. This method is cheap and can even be initiated by countries which do not have many specialists on engineering seismology.

The method of seismic impedance was proposed in Russia but the results still carried some supplementary suggestions based on the findings by the first method. According to this approach, the most important property of the ground is its seismic impedance which is defined as the product of the speed of longitudinal wave propagation and the density of the ground. It was found that the amplitudes of vibration varied as the square root of the corresponding seismic impedance. A table has been prepared showing typical foundation materials with their corresponding comparative impedances. This method is considered more improved than the geological one; for one thing the basis is scientific. However, the method includes only the physical properties of the ground and the results are expressed as increases in intensities and it has the deficiency in that intensities in themselves are not scientifically defined values.

The method of dynamic response was first developed in Japan. It is a semi-theoretical approach using the spectra of the earthquake and includes most of the known parameters. The results can be directly used for evaluating structure configurations, as for example, the number of stories. Microzoned maps of a town in Yugoslavia show divisions which indicate the areas of specific predominant periods and the recommended seismic coefficients corresponding to expected seismic intensities in the area. The greatest advantage of this method perhaps is the fact that it not only utilizes the latest concepts of structural dynamics, it also tries to include the influences of more parameters.

Education, Training and Research

The need for further studies in order to design earthquake-resistant structures cannot be overemphasized. For example in education, the Institute of Earthquake Engineering and Engineering Seismology at Skopje, Yugoslavia, plays an important role in that part of Eastern Europe. After the disastrous earthquake which struck the area in July, 1963, Skopje immediately became a "natural laboratory" for scientific investigations in the field of seismology, earthquake engineering and urban planning. The United Nations, after considering a proposal from the Yugoslav government decided to establish the Institute in 1964. At first, practically all lectures were conducted by eminent international experts recruited thru the United Nations. In addition, the Institute acquired an IBM computer which is utilized not only by the Institute's needs but also by all the reconstruction projects in the damaged city. After only 7 years, the Institute has grown very rapidly, that presently about 80 percent of the teaching and research staff are from Yugoslavia and particularly products of the Institute itself.

Two years ago, a post-graduate course of study was officially started with the details of the new curriculum shown in Appendix C. Essentially, there are two types of training — that for the populace so that they will be better prepared to meet the grim effects of an earthquake disaster and the second, which is more concerning the engineering field, the training of experts, specialists and technicians. It is a fact that basic training of the engineer is attributed to his undergraduate education. Civil Engineering curricula in some countries now incorporate disaster prevention as an ingredient part of earthquake engineering. An international training center for the second category mentioned above is the Institutes of Seismology and Earthquake at Tokyo, Japan. This Center was also established thru U.N. aid and has accepted engineers from all over the world.

There is indeed a great need for further research in the field and the extent of this need is unlimited, except for available funds for the purpose. An extensive research on the dynamic properties and responses of civil engineering structures nowadays utilizes full-scale models. Two cases describe a multi-story symmetrical building and a rock-filled dam, both of which were subjected to vibrations induced by eccentric mass exciters. Results show that the theoretical and experimental mode shapes are in fair agreement.

Study on soil-structure phenomenon is now popular among earthquake engineers. The sway, rocking and rolling motions of the structure due to the deformation of the surrounding soil decrease the accumulation of strain energy within the structure although this action generally generates stress concentration problems. Besides, the non-linear nature of soils literally shields the structure from the impact-type earthquake loads. Although analytical studies show these actions, experimental investigations have not clearly attested to these phenomena as yet.

In the case of moderate earthquakes, the calculated responses of the structure to the observed input earthquake record at the base show close agreement with actual earthquake records. When the structure is low and rigid, the vibration is not so much affected by the eigenvalues and eigenvectors as the ground motion itself. The modal method may be most applicable to the dynamic analysis of high-rise buildings provided that assumed input earthquake has a time-amplitude record which is suitable to the actual earthquake.

Any constructive measure for the protection of structures against earthquakes increases its cost. In order to achieve the minimum increase in cost with the corresponding level of safety, structures have been classified in accordance with an "Importance Scale." It was noted that recommendations cite a doubled coefficient for the most important category of structures while for the least important ones, some degree of damage is tolerable.

General Conclusions

Earthquake-resistant design Codes must be elaborated as a focal part in the general measures of preventing disasters due to earthquake. These Codes must conform to the professional level and economic considerations of the country.

Continuous effort must be made for further scientific research in the field of earthquake engineering and with this goes also the training of specialists, researchers and technicians.

Analysis of structures should not be confined within the elastic range. A more realistic and meaningful approach involves the ultimate strength concepts and the plastic theories of structural analysis.

The energy concept explains satisfactorily the behavior of structures during earthquakes. The criteria for aseismic design includes not only satisfying the strength criterion, but more so the ductility characteristics.

At present, the spectral method of analysis seems to be the most reasonable in so far as agreement with full-scale tests are concerned. The method also includes parameters which are not ordinarily covered by many Codes.

A more refined seismic zoning must be undertaken at locations where damage to property and/or injury to people are likely to be extensive if an earthquake strikes.

APPENDIX A

General Forms of Earthquake Loads for Structural Design

Two types of earthquake design forces (or their combination) are usually provided in many current design Codes:

A. Equivalent Static Load

B. Standard dynamic excitation input

A. The Equipment Static load may be written as follows:

$$F = C(Z, I, S, K, T).\ W = \sum f_i$$

$$\text{or } f_i = K_i(Z, I, S, K, T).\ W_i$$

where F is the total lateral earthquake force (or the total base shear)

f_i is the portion of F "tributary" to level i

C is the seismic coefficient, which is a function of Z, I, S, K and T

K_i Seismic coefficient for level i

Z is the Seismic Zoning factor

I is the importance factor (or the importance of the structure as related to its use)

S is the Subsoil conditions factor

K is the construction factor, including effects of damping ductility and energy-absorbing qualities
W is the total vertical load for Seismic calculations

W_i is that portion of W "tributary" to level i
and T is the natural period of vibration of the structure.

Typical examples of the above are:

1. The Uniform Building Code, U.S.A.

$$F = C\ (Z,\ K,\ T).\ W = Z.K \frac{0.05}{\sqrt[3]{T}} W$$

where $Z = 1,\ 0.5,\ 0.25$

$K = 1.33,\ 1.00,\ 0.8,\ 0.67$

$$f_i = \frac{(F-F_t)W_i h_i}{\sum_{i=1}^{n} W_i h_i}$$

$$F = \sum f_i + F_t$$

F_t = concentrated load at top of structure

and $F_t = 0.15F$ for slender structures

2. New Zealand

$F = C\ (Z,\ I,\ T).\ W$

For important buildings:

$C = 0.16,\ T \leq 0.44$ sec.
$= 0.80,\ T \geq 1.20$ sec.
= linear interpolation for $0.44 < T < 1.20$

$Z = 1,\ 3/4,\ 1/2$

For ordinary buildings

$C = 0.12,\ T \leq 0.44$
$= 0.06,\ T \geq 1.2$
= linear interpolation for $0.44 < T < 1.2$

$Z = 1,\ 5/6,\ 1/2$

f_i same as UBC except
$F_t \leq 0.1\ F$ for slender structures

3. U.S.S.R.

$$f_{iK} = K_{iK}(Z, I, T_K) \cdot W_i$$

$$= Z.I.\beta_K\ \alpha_{Ki}\ .W_i$$

where f_{iK} = design seismic force acting at level i in the Kth vibrational mode

T_K = natural period of vibration in the Kth mode

$\beta_K = \frac{1}{T_K}$ $0.8 \leq \beta \leq 3$ but may be increased for tall and slender structures

α_{Ki} = normal function at level i

4. Japanese Building Code

$$f_i = K_i\ (Z, S, K) \cdot W_i$$

$$Z = 1,\ 0.9,\ 0.8$$

$$S.\ K = 0.6,\ 0.8,\ 1.0,\ 1.5$$

The formula above is usually applied to buildings up to 45 meters tall.

5. Yugoslavia

The formula for the calculation of the earthquake force is determined as the product of 5 factors.

$$Q_B = C_{BX} P_T$$

$$C_{BX} = Z\ .\ \alpha\ .\ \delta . u$$

C_B = Total seismic coefficient
Z = Seismic intensity coefficient of the zones
α = Spectral factor — Dynamic earthquake effect coefficient
δ = Influence factor of damping and ductility
u = Reduced mass factor

These factors take into account the influence of a group of parameters which characterize the seismic ground motion as well as those which pertain to the dynamic and mechanical properties of the structure. The zone coefficient Z is taken as an empirical quantity based on the accelerations of the SK Scale (after Medvedev, Spudheuer and Karnik, 1964)

Zone	*Seismic Intensity (MSK Scale)*	*Z-factor*
I	9	1
II	8	1/2
III	7	1/4

The spectral factor α is determined by taking into consideration that structures are ductile with "normal" amount of damping

Soil Group	*Coefficient* α	*Limit of* α
I and II	$\alpha \frac{0.075}{T}$	$0.15 \geq \alpha \geq 0.05$
III	$\alpha \frac{0.120}{T}$	$0.15 \geq \alpha \geq 0.08$

The parameters which have the highest influence on the ductility capacity and degree of damping are the material of which the structure is made and the type of structure. These considerations are reflected by the parameter. Tabulated as follows:

Type of Structure	
Reinforced concrete or steel frame structures	
Industrial one story structures with cantiliver type of columns of reinforced concrete or steel	1.00
Reinforced concrete structures of diaphragms, reinforced concrete structures combined of core and frames	1.33
Structures of bearing walls of reinforced masonry of masonry strengthened by vertical and horizontal belt courses	
Very high reinforced concrete or steel structures as: water towers, antennas, chimneys, high towers and others	
Other types of special structures	1.66
Structures of very low ductility	

Plain bearing masonry strengthened by horizontal belt courses	2.00

The quantity u for "reduced" mass is calculated from a formula in structural dynamics, which take into account the formulation of mode shapes.

By the application of the direct dynamic inelastic analysis, the effective ductility can be improved by correction of the values of the shear forces at different levels without a change in the total base shear. For structures up to 6 stories, a distribution proportional to height is considered reasonable.

The values of the maximum shear forces at different levels as well as the maximum overturning moment at these levels depend upon the influence of the higher vibration modes. In this regard, using the superposition of the modes, only the first three modes are recommended to participate significantly. A probability formula such as

$$N_{max} = \sqrt{N_1^2 + N_2^2 + N_3^2}$$

is proposed, where the N's are the values of the shear force or the overturning moment.

B. Many current practices require dynamic response calculations due to a prescribed excitation only for tall, flexible and very special and important structures. If the calculations are confined within the linear range, the use of the response spectra and the application of stochastic process become more convenient. Since greater earthquake forces than those prescribed in Codes are to be expected, nonlinear analysis must be used.

APPENDIX B

Levels in Structural Design

Level 0

No calculations are require. "'Standard" unimportant buildings, documents are submitted but there is no check.

Level 1

Simple calculations, Small residential houses, Calculations are checked.

Level 2

This is the level of present Building Codes. Seismic coefficient is described with some other design detail requirements. Ordinary structures, calculations are checked.

Level 3

Calculations include natural periods and mode shapes, with few additional limitations such as eccentricity of distribution of mass with respect to the center of rigidity, etc, High-rise buildings with relatively simple configurations, calculations are checked.

Level 4

Detailed calculation including the step-by-step procedures complete data required. Special and new types of structures, calculations are checked by a specially-formed committee.

APPENDIX C

A One-Year Post-Graduate Course in Earthquake Engineering in the Institute of Earthquake Engineering and Engineering Seismology, Skopje, Yugoslavia.

This course may be taken by a graduate Civil Engineering who must attend the Institute on a full-time basis for one year consisting of three terms: Oct. 1 to Jan. 9, Jan. 10 to April 14 and April 15 to July 15. In the following program, the numbers indicate the lecture-computation sessions per week:

Subjects	*Terms*		
	I	II	III
1. Mathematics with Theory of Probability	4 – 2	– – –	– – –
2. Dynamics of Structures	2 – 1	2 – 2	– – –
3. Theory of Stability of Structures	2 – 1	– – –	– – –
4. Applied Elasticity and Plasticity	– – –	– – –	2 – 1
5. Engineering Seismology	3 – 1	2 – 1	– – –
6. Aseismic Structural Design	4 – 2	6 – 4	6 – 4
7. Soil Mechanics and Foundations in Seismic Regions	– – –	2 – 1	– – –
8. Structural Models	2 – 0	2 – 0	0 – 2
9. Urban Planning in Seismic Areas	– – –	– – –	1 – 0
10. Numerical Analysis and Computer Techniques	– – –	– – –	2 – 2
11. Seminar	0 – 2	0 – 4	0 – 4
Totals	17 – 9	14 – 12	11 – 13

In addition, the Candidate starts work or a Master's thesis at the beginning of the Second Term, and must successfully defined this thesis before a Commission of three professors prior to receiving his Diploma.