BULETINUL INSTITUTULUI POLITEHNIC DIN IAŞI
Publicat de
Universitatea Tehnică „Gheorghe Asachi” din Iaşi
Tomul LVII (LXI), Fasc. 1, 2011
Secţia
CONSTRUCŢII. ĂRHITECTURĂ

INFLUENCE OF SOIL CONDITIONS IN COMPUTING THE SEISMIC FORCE IN MISCELLANEOUS DESIGN CODES

BY

CERASELA-PANSELUŢA OLARIU* **and IOAN-PETRU CIONGRADI**

"Gheorghe Asachi" Technical University of Iaşi,
Faculty of Civil Engineering and Building Services

Received: February 16, 2011
Accepted for publication: March 12, 2011

Abstract. In civil engineering the knowledge and control of the seismic action is very important in order to prevent the effects that may occur during an earthquake. The effects of the seismic action may be determined from the linear–elastic behavior of the building. One of the most well-known methods for seismic analysis of structures is the equivalent lateral force procedure associated with the fundamental mode of vibration. The most important aspect of this procedure is to determine the precise seismic shear base. For the seismic force evaluation the influence of the local soil conditions is taken into account through several coefficients that depend on the seismic zonation of the country, the site class, the natural period of vibration and the shear-wave velocity.

The paper highlights different procedures to consider the influence of soil conditions in the seismic analysis of structures in miscellaneous design codes. Therefore, different types of site classifications depending on the seismic zonation, periods of vibration and site coefficients are presented. Also, the relations used to compute the seismic shear force included in the studied design codes are specified. In order to be able to perform comparisons between design codes provisions, the following norms are taken into account: the International Building Code from USA, the Earthquake Resistant Design of Buildings from Chile, the Building Standard Law of Japan, the Romanian seismic design code and the European design codes.

Key words: soil conditions; seismic shear force; seismic zonation.

* Corresponding author: *e-mail*: olariucerasela@yahoo.com

1. Overview on the Seismic Shear Force

Earthquakes are natural and uncontrollable phenomena which occur since ancient times. This is due to the fact that the planet is a living being and it behaves as such, continuously changing its shape and structure. Since ancient times, before the inventing of measuring and investigation instruments, humans have tried to understand this phenomenon. Once the technology developed, earthquakes came out from the unknown and therefore some steps have been made to prevent the terrible seismic effects. One of the most obvious solutions to prevent situations like collapsing of the buildings and human lives losses is to perform a correct seismic design of structures. For this purpose at the same time with the development of investigating methods also new provisions for the existing design codes are appearing. It is noticed the tendency to combine various areas of expertise in order for a better consideration of all the factors that influence the highly efficient seismic design process.

All the design codes agree that the seismic effects and the effects of other loads included in the seismic design process are determined based on the linear–elastic behavior of the structure. The seismic structural analysis can be performed using computational methods for design such structures, namely the equivalent lateral force procedure and the response spectrum procedure. Both methods are based on the approximation of the yielding effects that can be taken into account through linear analysis of the structural system for the design spectrum. The effects of the horizontal component of the ground motion, the vertical component of the ground motion and the torsional motions of the structure are all considered in simplified approaches of the two procedures. The main difference between the two procedures lies in the distribution of the seismic lateral forces over the height of the building. In the equivalent lateral force procedure, the distribution is based on simplified formulas that are appropriate for regular structures as in the modal analysis. The distribution is based on properties of the natural vibration modes, which are determined from the mass and stiffness distribution.

Most of the international seismic design codes describe in detail the equivalent lateral force procedure and all of them provide the necessary computational relations. In this paper, several seismic design codes from various countries with high seismicity, located on different continents, are chosen as to achieve an overview. In order to determine the seismic force, F_b, the following general relation is usually used, having some variations from a design code to another:

$$F_b = CW\,, \tag{1}$$

where: W is the total weight of the structure and C – the seismic response coefficient, computed differently according to the design code prescriptions.

Due to the fact that in the relations provided by the Romanian standard P100/1-2006 and SR EN 1998-1-2004 (in accordance with the Eurocode), the mass of the structure is used instead its weight, the following relation is introduced:

$$W = gm\,, \tag{2}$$

where: g is the gravity acceleration, [m/s^2] and m – the total mass of the structure.

Table 1 comprises some relations used for computing the seismic force and the seismic response coefficients which are provided in different seismic design codes.

Table 1

Relations for Computing the Seismic Shear Base in Different Design Codes

(Cod de proiectare…, 2006; Eurocod8. Proiectarea structurilor…, 2004; Internat. Building Code, 2009; Building Standard Law, 2004; Earthquake Resistant Design…, 1996)

Design code	Shear base	Seismic response coefficient, *C* (dimensionless)
P100/1-2006	$F_b = \gamma_I S_d\left(T_1\right)\lambda mg$	$C = \gamma_I S_d\left(T_1\right)\lambda/g$
SR EN 1998-1-2004	$F_b = S_d\left(T_1\right)\lambda mg$	$C = S_d\left(T_1\right)\lambda/g$
IBC 2009, USA	$V = C_s W$	$C_S = \dfrac{S_{DS}}{R/I}$
Building Standard Law of Japan	$Q_i = C_i W_i$	$C_i = Z R_t A_i C_0$
Earthquake Resistant Design of Buildings, Chile	$Q_0 = CIP$	$C = \dfrac{2.75A_0}{gR}\left(\dfrac{T'}{T^0}\right)^n$

From Table 1 it can be noticed that the general shape of the seismic shear-base relation provided by eq. (1) is kept in all codes. The main difference is observed in the parameters that define the seismic response coefficient, *C*, and their variation limits In the next section the specific meanings and the ranges of the including parameters will be discussed.

The field of interest of this study is restricted to the influence of the specific site periods and the manner in which the soils are classified based on their geotechnical and geological characteristics and the velocity of shear waves.

2. Importance of Vibration Period

After several disastrous earthquakes which took place in the last century and due to the continuous work of researchers, it can be stated that the state of knowledge has reached a level which can provide an efficient seismic design. Nevertheless, each year efforts are made to optimize and complete the seismic design codes, based on the gained experience.

The response of a structure during an earthquake depends on the characteristics of ground motion, the foundation soil and the type of the structure. For structures founded on rock or very stiff soils, the foundation motion is essentially, the same with the one experienced in the soil when the foundation or excavation is absent. This motion is the free field ground motion. In the case of soft soils, the foundation motion differs from that in the free field due to the coupling of the soil and structure during an earthquake (Jonson, 2003).

Most of the design codes consider the assumption that the motion experienced by the base of a structure during an earthquake is actually the same as the free-field ground motion. Taking this fact into account it is noticed that the nature of the foundation soil exerts an influence not only on the design requirements but also on the seismic response in that site.

The ground motion in a site depends on the dynamic characteristics of the foundation soils and the seismic stiffness. This effect is reflected through the site coefficients, S, which are included in the Romanian SR EN 1998-1-2004 norm and its National Annex SR EN 1998-1/NA. These site coefficients depend on the properties and geology of the soils and rocks.

The norm P100/1-2006 as well as SR EN 1998-1-2004 include in the seismic force relation the β coefficient which is introduced by $S_d(T)$ factor from the seismic response coefficient. The β coefficient depends on the stiffness of the soil and on the acceleration amplification from bedrock to the surface of the soil. This coefficient depends on the period of the structure and the period of the soil.

Although the seismic resonance is a controversial subject, to know the natural vibration of the structure and of the foundation soil is necessary in order to avoid the possible resonance ranges.

The seismic design code provides a uniform margin against collapse at the design ground motion. In view to accomplish this desideratum the ground motion hazards are defined in terms of maximum considered earthquake ground motions. The seismic hazard is based on a lower estimate of the margin against collapse inherent in structures (NEHRP Recommended Provisions…, 2003).

SR EN 1998-1-2004 provides several values for the site coefficient as well as for T_B, T_C and T_D depending on the site classes (A, B, C, D, E). However, the National Annex of the same design code mentions that in Romania the site classes are divided into three categories characterized by corner periods. This zonation is performed based on the recorded earthquakes from 1977, 1986 and 1990 (Building Standard Law, 2004). Table 2 presents the site coefficients prescribed by SR EN 1998-1-2004 and the National Annex.

It can be noticed that in the seismic zonation of Romania the values of the site coefficients and of the site periods provided by SR EN 1998-1/NA are unchanged from the ones in P100/1-2006 norm. This fact is due to the small number of seismic records of the earthquakes in our country which prevents from having more detailed information.

Table 2

Site Coeffiecinets (Eurocod8. Proiectarea structurilor…, 2004; Eurocod8. Proiectarea structurilor…, 2008)

	SR EN 1998-1-2004					SR EN 1998-1/NA		
Site class	*A*	*B*	*C*	*D*	*E*	Z_1	Z_2	Z_3
S	1.0	1.2	1.15	1.35	1.4	1	1	1
T_B	0.15	0.15	0.20	0.20	0.15	0.07	0.10	0.16
T_C	0.4	0.5	0.6	0.8	0.5	0.7	1.0	1.6
T_D	2.0	2.0	2.0	2.0	2.0	3.0	3.0	2.0

In addition to the relation of the seismic response coefficient provided by the American design code IBC 2009 (Table 1) there are other relations for the coefficient applied depending on the type of structures, as such (Internat. Building Code…, 2009):

$$C_S \le \frac{S_{D1}}{T\left(R/I\right)} \quad (3), \qquad C_S \ge 0.044 S_{DS} I \quad (4), \qquad C_S \ge \frac{0.5 S_1}{R/I} \quad (5).$$

Therefore, the seismic response coefficient, C_S, depends on the parameters used for defining the design spectral response acceleration in the short period range, S_{DS}, and the design spectral response acceleration at a period of 1 s, S_{D1}. At the same time these values depend on two site coefficients, F_a and F_v, which are defined using the mapped maximum considered earthquake spectral response acceleration at short periods (S_s) and the mapped maximum considered earthquake spectral response acceleration at period of 1 s (S_1). In Table 3 are presented the values of the site coefficients depending on the design spectrum parameters.

Table 3.

Site Coefficients F_a and F_v (Building Standard Law…, 2004)

Site class	Values of F_a					Values of F_v				
	$S_S \le 0.25$	$S_S=0.5$	$S_S=0,75$	$S_S=1.0$	$S_S \ge 1.25$	$S_1 \le 0.1$	$S_1=0.2$	$S_1=0.3$	$S_S=0.4$	$S_S \ge 0.5$
A	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
B	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
C	1.2	1.12	1.1	1.0	1.0	1.7	1.6	1.5	1.4	1.3
D	1.6	1.4	1.2	1.1	1.0	2.4	2.0	1.8	1.6	1.5
E	2.5	1.7	1.2	0.9	0.9	3.5	3.2	2.8	2.4	2.4

The Japanese design code, Building Standard Law of Japan (BSL), has been revised in 2000 with the purpose to create a proper basis for a performance based design . On the other hand, the Japanese design code from 1924 was the first in the world which required structural calculation in considering seismic force (Tomohiro, 2010).

The seismic response coefficient from BSL is computed using the relation from Table 1, where: Z is the seismic zone factor; R_t is the design spectral coefficient depending on the cornerperiod, T_C , and on the fundamental natural period of the structure, T; A_i is the lateral shear distribution factor of i-th story and C_0 is standard shear coefficient (Building Standard Law…, 2004).

The BSL provides values for the seismic coefficient in accordance with a map which divides Japan in three main regions: *A*, *B* and *C*, characterized by the values of the seismic hazard zone coefficient. Thus, for region *A* the coefficient Z equals 1.0; for the *B* region the value of Z is 0.9 and for region *C* the value of Z is 0.8. A resemblance is noticed between the approaches of country zonation adopted by the Japanese design code and by Romanian the SR EN 1998-1/NA .

The Earthquake Resistant Design of Buildings (ERDB) in Chile was revised in 2000. The seismic response coefficient used for computing the seismic force is given in Table 1, where: n, T' are parameters relative to the foundation soil type, A_0 – the maximum effective acceleration, R – the reduction factor, T^0 – the period of mode with the highest translational equivalent mass in the direction of analysis (Earthquake Resistant Design…, 1996).

Table 4 presents the values of these coefficients provided by the Chilean design code.

Table 4
Parameter Values Related to Soil Types
(Earthquake Resistant Design…, 1996)

Soil type	$T^0(s)$	$T'(s)$	n
I	0.15	0.20	1.00
II	0.30	0.35	1.35
III	0.75	0.85	1.80
IV	1.20	1.35	1.80

3. The Influence of the Local Soil Conditions

One of the most important but less controlable aspects is to know the real state of the local soil conditions. Depending on the stiffness characteristics and on the seismic wave velocities, the foundation soils are ones of the main elements in performing a correct seismic design. There are numerous examples in the human history when due to the local soil conditions a lot of damage took place during an earthquake, *e.g*. Niigata earthquake or Alaska earthquake, both from 1964.

Due to this reason all seismic design codes are taking into account the importance of the soil conditions through site coefficients. The site classes are more of less detailed from a country to another based on the local classification criteria.

The SR EN 1998-1-2004 and IBC 2009 design codes are using the same parameter in classifying soils, namely the shear waves propagation velocities, $v_{s,30}$. Table 5 presents a comparison between the classifications provided by these codes.

Table 5
Soil Classification in SR EN 1998-1-2004 and IBC 2009

SR EN 1998-1-2004			IBC 2009		
Site class	Description of the stratigraphic profile	$v_{s,30}$ m/s	Site class	Desciption of the stratigraphic profile	$v_{s,30}$ m/s
A	Rock or other rock like geological formation	>800	*A*	Hard rock	>1,500
B	Deposits of very dense sand, gravel or very stiff clay	360…800	*B*	Rock	760…1,500
C	Deep deposits of dense or medium dense sand, gravel or stiff clay	180…360	*C*	Very dense soil and soft rock	370…760
D	Deposit of loose-to-medium cohesionless soil	<180	*D*	Stiff soil	180…370
E	Soil profile consisting of a surface alluvium layer with v_s values of type *C* or *D*		*E*	Soil	<180
S_1, S_2	Soft clays/silts with a high plasticiy index : liquefiable soils	<100	*F*	Soils requiring site specific evaluation	

Although the site classes are named in the same manner (*e.g. A*, *B*, *C*,…) in both codes, the description of the soils are not the same.

The American design code includes a soil type, named *hard rock*, which is defined by a very high shear wave velocity. Also, in terms of rock class, the American code offers a smaller value of the shear wave velocity than the one in SR EN 1998-1-2004. For the rest of the site classes there can be noticed some similarities between the description of the soil stratigraphy and the values of the shear wave velocities.

The Japanese design code has a simplified method for classifying soils, namely

a) type I (hard soil) ;
b) type II (medium soil);
c) type III (soft soil).

The parameter used for soil classification in BSL is the fundamental period of vibration of the soils, T_g .The following relation is used (Marino *et al.*, 2005)

$$T_g = \sqrt{32 \sum_{i=1}^{L} \frac{h_i \left(H_{i-1} + H_i/2\right)}{V_i^2}} . \tag{6}$$

where: L represents the number of soil layers existing between the base of the foundation and the rock soil; h_i, H_i and V_i represent, respectively, the thickness, depth and shear wave propagation velocity of the i-th soil layer.

Based on the fundamental period of foundation soil, T_g, the site classes have the following approximated limits (Marino *et al.*, 2005):

a) the soil type I, T_g = 0…0.2 s;
b) the soil type II, T_g = 0.2…0.7 s;
c) the soil type III, T_g = 0.7…0.9 s.

In the same manner as the SR EN 1998-1-2004 design code, the Japanese code supplies the values of the corner periods. These corner periods are used in BSL to determine the design spectral coefficient, R_t, depending on the soil type. The following values are provided (Building Standard Law…, 2004):

1° hard soil, T_C = 0.4;
2° medium soil, T_C = 0.6;
3° soft soil, T_C = 0.8.

The Chilean design code classifies the soil types into four main classes (Earthquake Resistant Design…, 1996):

a) soil type I: rock - natural material with *in situ* shear wave propagation velocity, $v_s \geq 900$;
b) soil type II: soils with $v_s \geq 400$ in the upper 10 m;
c) soil type III: permanently unsaturated sand, unsaturated gravel or sand, cohesive soils, saturated sand;
d) soil type IV: saturated cohesive soil.

From all the above mentioned it is noticed that the studied design codes classifies soils in various ways. This happens because each country has its own national classification criteria and also it has different numbers of national seismic records and large scale experiments data. Apart from this, the shear wave propagation velocities play a very important role in sites classification. This remark is realistic because the design codes are applied in countries from different continents which have different geology and seismic activity.

4. Conclusions

The knowledge of the seismic force in the design process is an essential step. All the studied design codes provide computational relations for the shear base force and for the used coefficients, presented under various names and notations. Essentially, these coefficients have approximately the same meanings, the only difference being their values. Also, another key element in determining the correct seismic shear base is knowing the fundamental periods of vibration for the foundation soils.

Every design code has a soil classification based on national criteria and on parameters used for defining the soil classes. There are some resemblances between the classifications provided by SR EN 1998-1-2004 and IBC 2009 design codes defining the soil classes based on the values of the shear wave velocities.

Also, there are some similarities between the Japanese design code BSL and SR EN 1998-1-2004/NA:2008, based on providing the corner period values depending on the nature of the foundation soil. The main difference between these codes lies in the used parameters for site classification, namely T_g and v_s. Actually, the natural period of vibration of the foundation soil in BSL is computed using the value of the shear wave velocity in that layer. Therefore, this highlights the importance of knowing these values for the sites.

Even though the classifications are more or less detailed the remarkable thing is the importance granted to them in order to have a performant seismic design.

To sum up, there are different ways to take into account the influence of the foundation soils in computing the seismic shear base forces. The presence of various coefficients depending on the foundation soil highlights the growing interest of the researchers and of the government officials to provide precise information for seismic design as to prevent the terrible effects that may occur.

REFERENCES

* * * *Cod de proiectare seismică.* Partea I. P100/1-2006, Bucureşti, 2006.

* * * *Eurocod 8: Proiectarea structurilor pentru rezistența la cutremur.* Partea 1. SR EN 1998-1-2004, 15 decembrie 2004.

* * * *International Building Code*. International Code Council, Inc., 2009.

* * * *Building Standard Law* (BSL). Ministry of Constructuction, Building Center of Japan, Tokyo, Japan, 2004.

* * * *Earthquake Resistant Design of Buildings* (*Diseno sismico de edificios*), NCh433. of 96, Chile, 1996

* * * *NEHRP Recommended Provisions for Seismic Regulations for New Buildings and other Structures*. Part 1-15, Fema 450, Washington, D.C., 2003.

* * * *Eurocod 8: Proiectarea structurilor pentru rezistența la cutremur,* Partea 1: *Reguli generale, acțiuni seismice şi reguli pentru clădiri.* Anexa Națională SR EN 1998-1:2004/NA:2008, 28 noiembrie 2008.

Johnson J.J., *Soil Structure Interaction: Statement of the Problem*. In *Earthquake Engineering Handbook*. CRC Press, 2003, Ch. **10**, 10-1/10-29.

Marino E.M., Nakashima M., Mosalam K.M., *Comparison of European and Japanese Design of Steel Building Structures*. Engng. Struct., **27**, 827-840, 2005.
Tomohiro H. *Introduction to the Building Standard Law*. Japanese Building Codes and Building Control System, Building Center of Japan, April 2010.

MODALITĂȚI DE LUARE ÎN CONSIDERARE ÎN UNELE CODURI A INFLUENȚEI CONDIȚIILOR DE TEREN ÎN CALCULAREA FORȚEI SEISMICE TĂIETOARE LA BAZĂ

(Rezumat)

Pentru ingineria civilă cunoaşterea şi controlarea acțiunii seismice este esențială pentru a se putea preveni efectele ce pot să se producă în timpul unui cutremur. Efectele acțiunilor seismice se pot determina pe baza comportării liniar-elastice a structurii. Una dintre metodele de calcul structural la acțiunea seismică, cel mai des utilizate dar şi prezente în diferite coduri de proiectare, este metoda forțelor laterale asociate modului de vibrație fundamental. Esențial pentru această metodă este determinarea corectă a forței tăietoare de bază. În cadrul formulării acesteia se ia în considerare influența condițiilor de teren prin diferiți coeficienți care sunt în funcție de zonarea seismică, categoria de pământ şi perioada fundamentală de vibrație.

În lucrare se urmăreşte evidențierea modului în care anumite coduri naționale şi internaționale iau în considerare influențele condițiilor de teren în calculul seismic al structurilor. Astfel, sunt prezentate diferite tipuri de clasificări ale amplasamentelor în funcție de zonarea seismică şi a perioadelor de colț sau al factorului de teren. Se mai prezintă de asemenea diferite modalități de calcul pentru forța seismică tăietore de bază. Prevederi ale următoarelor norme internaționale şi naționale au fost luate în considerare pentru a se putea realiza aceste comparații şi evidențieri: codurile de proiectare ale Statelor Unite ale Americii, cele din Chile, Japonia şi România precum şi Eurocod.