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GENERAL PRESENTATION OF EUROCODE 8 – “DESIGN OF STRUCTURES FOR EARTHQUAKE RESISTANCE”

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2. INTRODUCTION

The Eurocode 8 (EC8) “Design of Structures for Earthquake Resistant” deals with the design and construction of buildings and civil engineering works in seismic regions is divided in six Parts.

The Part 1 is divided in 10 sections:

Section 1 – contains general information;

Section 2 – contains the basis requirements and compliance criteria applicable to buildings and civil engineering works in seismic regions;

Section 3 – gives the rules for the representation of seismic actions and their combination with other actions;

Section 4 – contains general design rules relevant specifically to buildings;

Section 5 – presents specific rules for concrete buildings;

Section 6 – gives specific rules for steel buildings;

Section 7 – contains specific rules for steel-concrete composite buildings;

Section 8 – presents specific rules for timber buildings;

Section 9 – gives specific rules for masonry buildings;

Section 10 – contains fundamental requirements and other relevant aspects for the design and safety related to base isolation.

Further Parts include the following:

Part 2 contains relevant provisions to bridges.

Part 3 presents provisions for the seismic strengthening and repair of existing buildings.

Part 4 gives specific provisions relevant to tanks, silos and pipelines.

Part 5 contains specific provisions relevant to foundations, retaining structures and geotechnical aspects.

Part 6 presents specific provisions relevant to towers, masts and chimneys.

In particular the Part 5 of EC8 establishes the requirements, criteria, and rules for siting and foundation soil and complements the rules of Eurocode 7, which do not cover the special requirements of seismic design.

The topics covered by Part 1- Section 1 namely: seismic action, ground conditions and soil investigations, importance categories, importance factors and geotechnical categories are discussed.

The definition of seismic action by Eurocode 8-Part 1 based in elastic response spectrum, ground acceleration time-histories and related quantities (velocity and displacement), and artificial accelerograms is addressed.

The characterization of dynamic properties by laboratory and field tests and classification of deposits is presented.

The site effects, the neotectonic conditions, the directivity effects, the frequency and pulses effects, the attenuation laws, the shape of valley, the topographic effects and importance categories are referred.

Also a comparison is done between Eurocode 8 and the geotechnical seismic codes adopted in different regions, in order to highlight the similitude and differences.

The education on earthquake geotechnical engineering, the role of Seismic Research Centres are discussed.

2. SEISMIC ACTION

The definition of the actions (with the exception of seismic actions) and their combinations is treated in Eurocode 1 “Action on Structures”.

In general the national territories are divided by the National Authorities into seismic zones, depending on the local hazard.

In EC 8, in general, the hazard is described in terms of a single parameter, i.e. the value a_g of the effective peak ground acceleration in rock or firm soil called “design ground acceleration”(Figure 1) expressed in terms of: a) the reference seismic action associated with a probability of exceeding (P_{NCR}) of 10 % in 50 years; or b) a reference return period (T_{NCR})= 475.

These recommended values may be changed by the National Annex of each country (e.g. in UBC (1997) the annual probability of exceedance is 2% in 50 years, or an annual probability of 1/2475).

where:

Se (T) elastic response spectrum,

T vibration period of a linear single-degree-of-freedom system,

α_g design ground acceleration,

T_B, T_C limits of the constant spectral acceleration branch,

$T_D$value defining the beginning of the constant displacement response range of the spectrum,

S soil parameter with reference value 1.0 for subsoil class A,

η damping correction factor with reference value 1.0 for 5 % viscous damping.

The earthquake motion EC 8 is represented by the elastic response spectrum defined by 3 components.

It is recommended the use of two types of spectra: type 1 if the earthquake has a surface wave magnitude Ms greater than 5.5 and type 2 in other cases.

The seismic motion may also be represented by ground acceleration time-histories and related quantities (velocity and displacement). Artificial accelerograms shall match the elastic response spectrum. The number of the accelerograms to be used shall give a stable statistical measure (mean and variance) and a minimum of 3 accelerograms should be used and also some others requirements should be satisfied.

For the computation of permanent ground deformations the use of accelerograms recorded on soil sites in real earthquakes or simulated accelerograms is allowed provided that the samples used are adequately qualified with regard to the seismogenic features of the sources.

For structures with special characteristics spatial models of the seismic action shall be used based on the principles of the elastic response spectra.

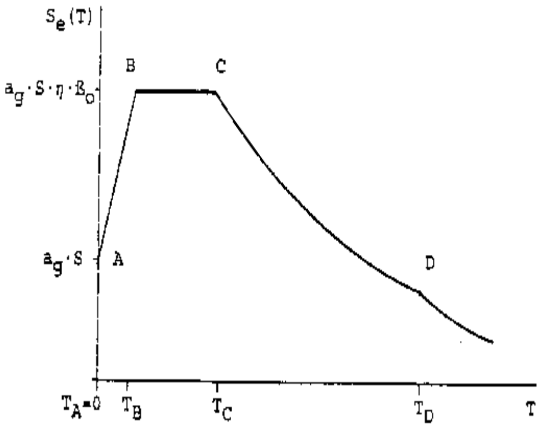

Figure 1 – Response spectra

3. GEOTECHNICAL CHARACTERIZATION

The geotechnical parameters obtained from laboratory and field tests for design purposes are summarized in Tables 1 and 2 (Sêco e Pinto, 1997). The symbols have the following meaning:

V_s = transverse wave velocity
V_p = longitudinal wave velocity
G_{max} = maximum shear modulus
E = elasticity modulus
S_u= undrained strength
ß = damping ratio

Table 1 – Field tests

Tests	Parameters		
	V_p	V_s	G_{max}
Refraction	x	x	x
Uphole	x	x	x
Downhole	x	x	x
Crosshole	x	x	x
Seismic cone	x	x	x

Table 2 – Laboratory tests

Tests	Parameters			
	G	E	ß	G_{max}
Resonant Column	x	x	x	x
Cyclic Triaxial	x	x	x	
Cyclic simple shear	x	x	x	
Cyclic torsional shear	x	x	x	

The variation of shear modulus and damping ratio with shear strain related gravel materials (GW), sandy soils (SW), clay soils of low plasticity (CL) and high plasticity (CH) are presented in Fig. 2 (Stokoe et al. 2004).

4. GROUND CONDITIONS

For the ground conditions five subsoil classes A, B, C, D and E are considered:

Subsoil class A – rock or other geological formation, including at most 5 m of weaker material at the surface characterised by a shear wave velocity V_s of at least 800 m/s;

Subsoil class B – deposits of very dense sand, gravel or very stiff clay, at least several tens of m in thickness, characterised by a gradual increase of mechanics properties with depth shear wave velocity between 360-800 m/s, N_{SPT}>50 blows and c_u>250 kPa.

Subsoil class C – deep deposits of dense or medium dense sand, gravel or stiff clays with thickness from several tens to many hundreds of meters characterised by a shear wave velocity from 160 m/s to 360 m/s, N_{SPT} from 15-50 blows and c_u from 70 to 250 kPa.

Subsoil class D – deposits to loose to medium cohesionless soil (with or without some soft cohesive layers), or of predominantly soft to firm cohesive soil characterised by a shear wave velocity less than 180 m/s, N_{SPT} less than 15 and c_u less than 70 kPa.

Subsoil class E – a soil profile consisting of a surface alluvium layer with Vs, 30 values of type C or D and thickness varying between about 5m and 20m, underlain by stiffer material with Vs,30>800m/s.

Subsoil S_1 – deposits consisting - or containing a layer at least 10 m thick - of soft clays/silts with high plasticity index (PI>40) and high water content characterised by a shear wave velocity less than 100 m/s and c_u between 10-20 kPa.

Subsoil S_2 – deposits of liquefiable soils, of sensitive clays, or any other soil profile not included in types A-E or S_1.

For the five ground types the recommended values for the parameters S, T_B, T_C, T_D, for Type 1 and Type 2 are given in Tables 1 and 2.

The recommended Type 1 and Type 2 elastic response spectra for ground types A to E are shown in Figures 3 and 4.

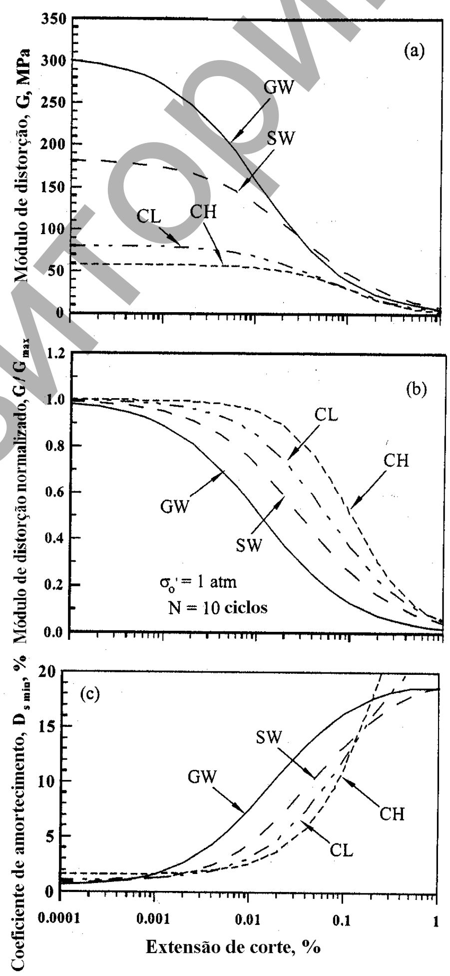

Figure 2 – Variation of shear modulus and damping ration with shear strain for (GW), ((SW) (CL) and (CH) materials (after Stokoe et al. 2004)

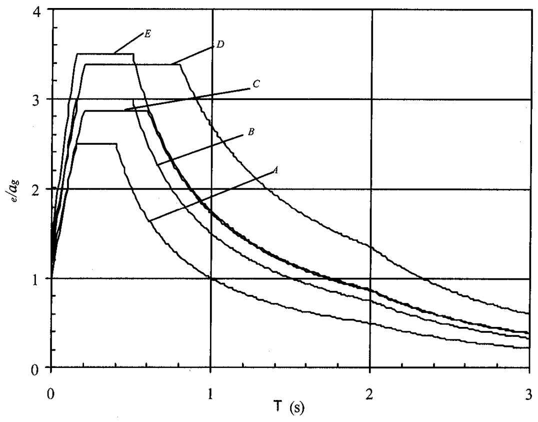

Figure 3 – Type 1 elastic response spectrum (after EC8)

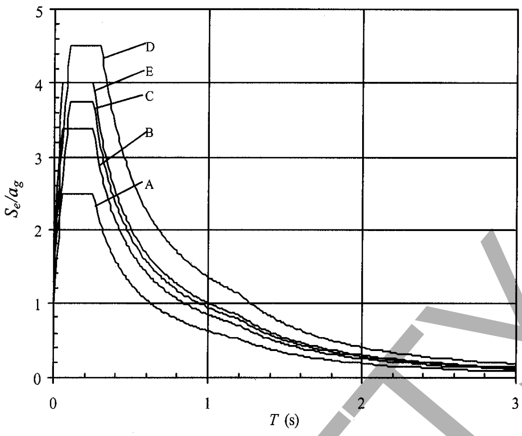

Figure 4 – Type 2 elastic response spectrum (after EC8)

Table 3 – Values of the parameters describing the Type 1 elastic response spectrum

Ground Type	S	T_B(s)	T_C(s)	T_D(s)
A	1.0	0.15	0.4	2.0
B	1.2	0.15	0.5	2.0
C	1.15	0.20	0.6	2.0
D	1.35	0.20	0.8	2.0
E	1.4	0.15	0.5	2.0

Table 4: Values of the parameters describing the Type 2 elastic response spectrum

Ground Type	S	T_B(s)	T_C(s)	T_D(s)
A	1.0	0.05	0.25	1.2
B	1.35	0.05	0.25	1.2
C	1.5	0.10	0.25	1.2
D	1.8	0.10	0.30	1.2
E	1.6	0.05	0.25	1.2

The recommended values of the parameters for the five ground types A, B, C, D and E for the vertical spectra are shown in Table 5. These values are not applied for ground types S1 and S2.

Table 5 – Recommended values of the parameters for the five ground types A, B, C, D and E

Spectrum	α_{vg}/α_g	T_B(s)	T_C(s)	T_D(s)
Type 1	0.9	0.05	0.15	1.0
Type 2	0.45	0.05	0.15	1.0

The actual ground classification of EC8 follows a classification based on shear wave velocity, on SPT values and on undrained shear strength, similar to UBC (1997) that is shown in Table 6.

Based on the available strong-motion database on equivalent linear and fully non-linear analyses of response to varying levels and characteristics of excitation Seed et al. (1997) have proposed for site depending seismic response the Figure 5 where A_0, A and AB are hard to soft rocks, B are deep or medium depth cohesionless or cohesive soils, C, D soft soils and E soft soils, high plasticity soils.

Table 6 – Ground profile types (after UBC, 1997)

Ground profile type	Ground description	Shear wave velocity Vs(m/s)	SPT test	Undrained shear strength (kPa)
S_A	Hard rock	1500	----	--------
S_B	Rock	760-1500	----	------
S_C	Very dense soil and soft rock	360-760	>50	>100
S_D	Stiff soil	180-360	15-50	50-100
S_E	Soft soil	<180	<15	<50
S_F	Special soils			

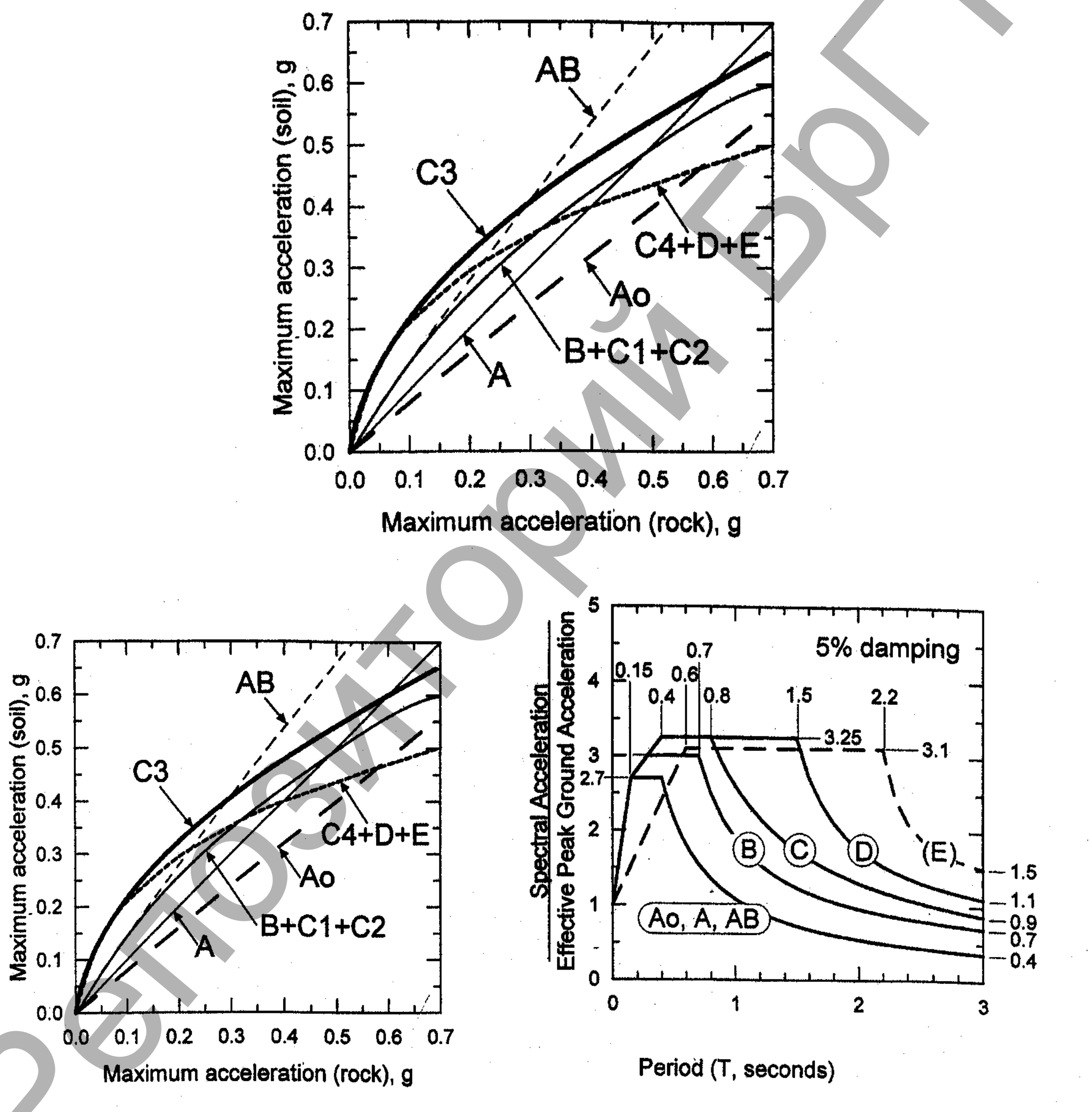

Figure 5 – Response spectra (after Seed et al., 1997)

5. IMPORTANCE CATEGORIES, IMPORTANCE FACTORS AND GEOTECHNICAL CATEGORIES

The structures following EC 8 (Part 1.2) are classified in 4 importance categories related with its size, value and importance for the public safety and on the possibility of human losses in case of a collapse.

To each importance category an important factor γ_I is assigned. The important factor γ_I = 1,0 is associated with a design seismic event having a reference return period of [475] years. The importance categories varying I to IV (with the decreasing of the importance and complexity of the structures) are related with the importance factor γ_I assuming the values [1,4], [1,2], [1,0] and [0,8], respectively.

To establish geotechnical design requirements three Geotechnical Categories 1, 2 and 3 were introduced in EC 7 with the highest category related with unusual structures involving abnormal risks, or unusual or exceptionally difficult ground or loading conditions and structures in highly seismic areas.

Also it is important to refer that buildings of importance categories [I, II, III] shall generally not be erected in the immediate vicinity of tectonic faults recognised as seismically active in official documents issued by competent national authorities.

Absence of movement in late Quaternary should be used to identify non active faults for most structures.

It seems that this restriction is not only very difficult to follow for structures such as bridges, tunnels and embankments but conservative due the difficult to identify with reability the surface outbreak of a fault.

Anastapoulos and Gazetas (2006) have proposed a methodology to design structures against major fault ruptures validated through successful Class A predictions of centrifuge model tests and have recommended some changes to EC8 - Part 5.

Comments: The following comments are presented: (i) no reference is made for the influence of strong motion data with the near fault factor (confined to distances of less than 10 km from the fault rupture surface) with the increases of the seismic design requirements to be included in building codes; (ii) also no reference is established between the ground motion and the type of the fault such as reverse faulting, strike slip faulting and normal faulting; (iii)

EC8 refers to the spatial variation of ground motion but does not present any guidance; (iv) basin edge and other 2D and 3D effects were not incorporated in EC8. The importance of shapes of the boundaries of sedimentary valleys as well as of deeper geologic structures in determining site response was shown from the analysis of records in Northridge and Kobe earthquakes.

6. LOCAL EFFECTS

6.1. Amplification

The influence of local soils conditions on site response following Seed and Idriss (1982) proposal is presented in Figure 6.

Based on records of earthquakes Idriss (1990) has shown that peak accelerations on soft soils have been observed to be larger than on rock sites (Figure 7). The high quality records from very recent earthquakes Northridge (1994), Hyogo-ken-Nambu (1995), Kocaeli (1999), Chi-Chi (1999) and Tottoriken (2000) have confirmed the Idriss (1990) proposal

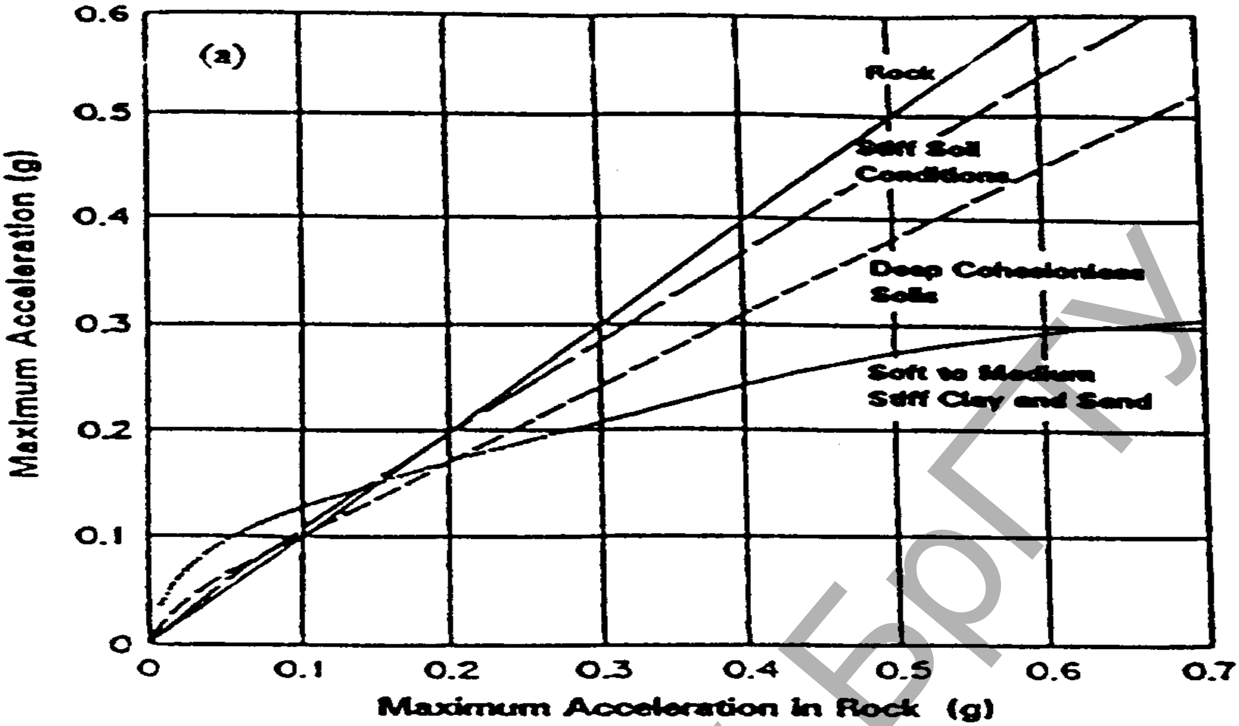

Figure 6 – Influence of local soil conditions on site response (after Seed and Idriss, 1982)

Based in strong motions records obtained during Hyogoken-Nanbu earthquake in four vertical arrays sites and using and inverse analysis Kokusho and Matsumuto (1997) have plotted in Figure 8 the maximum horizontal acceleration ratio against maximum base acceleration and proposed the regression equation:

Accsurface/Accbase=2.0 exp(-1.7 Acc/980) (1)

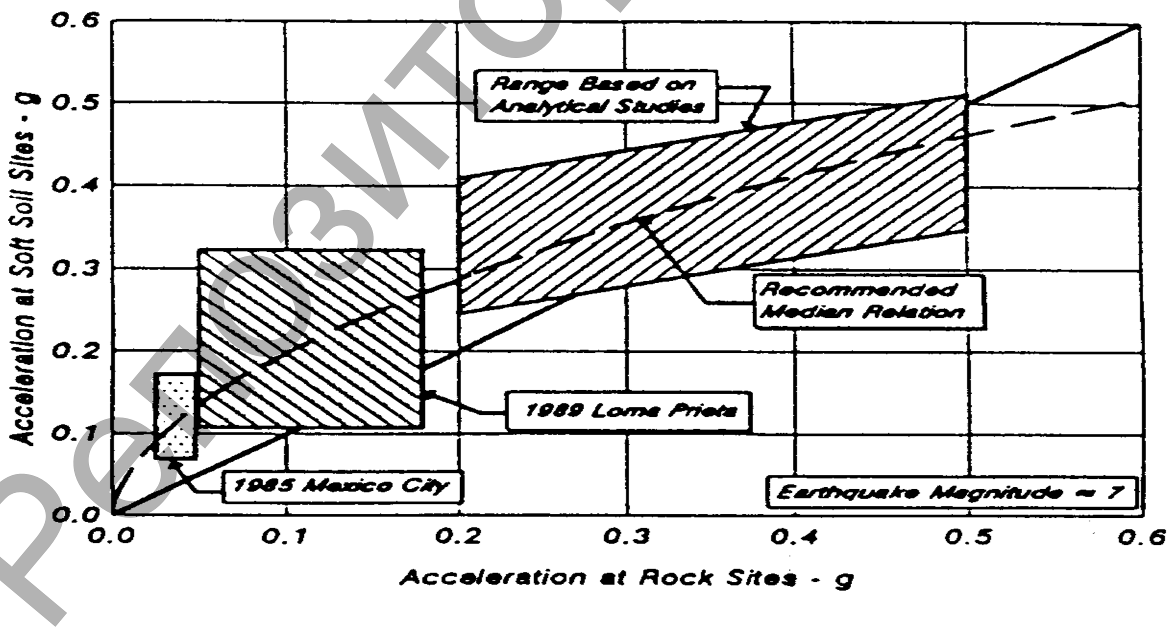

Figure 7 – Influence of local soil conditions on site response (after Idriss, 1990)

Surface acceleration / Base acceleration = 2.0 exp (-1.7 Acc/980) (1)

It is important to stress that the following factors play an important role on site effects: (i) earthquake frequency; (ii) duration of earthquakes; (iii) ressonance effects; (iv) basin effects; (v) directivity effects ; e (vi) non linear behaviour.

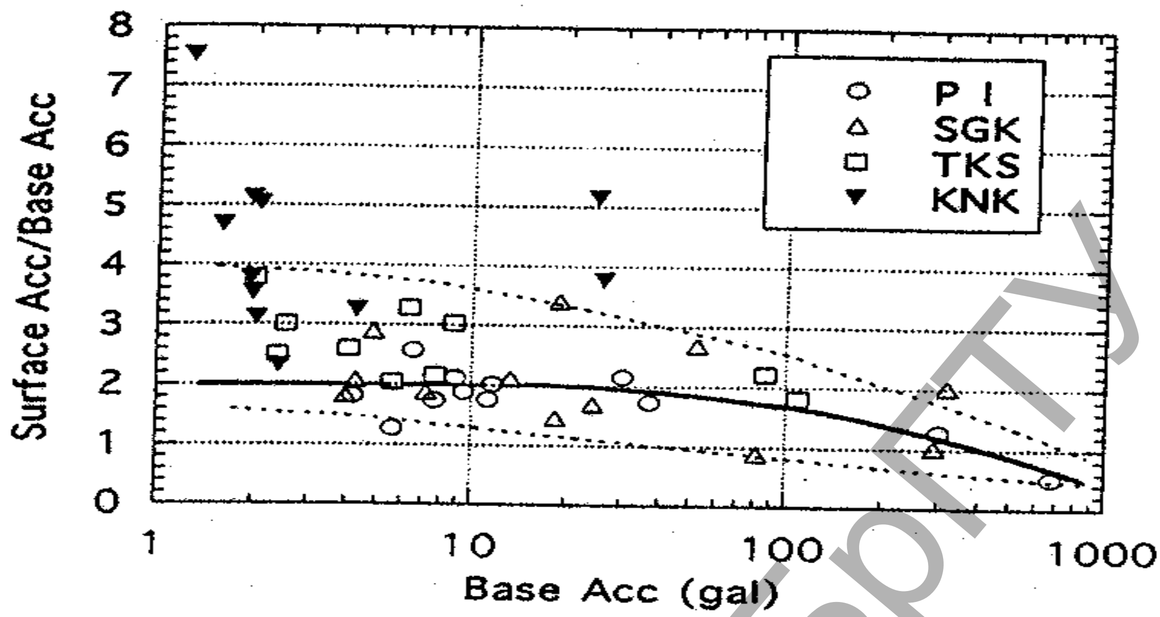

Figure 8 – Maximum horizontal acceleration ratio plotted against maximum base acceleration (after Kokusho and Matsumoto, 1997)

6.2. NEOTECTONICS

The tectonic conditions should include tectonic mechanisms, location and description of faults (normal, stryke and reverse) and estimation of fault activity (average slip rate, slip per event, time interval between large earthquake, length, directivity effects, etc), these factors are important to assess the involved risk.

Determination of neotectonic activity implies first the qualitative geomorphologic analysis of air photos and topographic maps. The GPS system is another powerful means of monitoring the crustal mobility.

The following classification for slip rates: extremely low to low for 0.001 mm/year to 0.01 mm/year, medium to high 0.1 mm/year to 1 mm/year and very high to extremely high 10 mm/year to 100 mm/year.

The most dangerous manifestation concerning the landfill stability and integrity is the surface fault breaking, intersecting the landfill site.

The current practice is the deterministic approach in which the seismic evaluation parameters were ascertained by identifying the critical active faults which show evidence of movements in Quaternary time.

Following (ICOLD, 1989) an active fault is a fault, reasonably identified and located, known to have produced historical fault movements or showing geologic evidence of Holocene (11 000years) displacements and which, because of its present tectonic sitting, can undergo movements during the anticipated life of man-made structures.

To assess if there is the potential for a significant amount of surface displacement beneath the dam several backhoe trenches are excavated with 3 to 4 meters deep and 30 to 50 meters long and should be inspected and log the exposures geologic features.

Recently a fault investigation method other than trenching has been developed, called the long Geo-slicer method in which long iron sheet piles with a flat U-shaped cross section are driven into an unconsolidated bed, iron plate shutters are inserted to face these iron sheet piles and the piles and shutters are pulled out to take undisturbed samples of strata of a certain width. This method is advantageous in regard to the ease of securing land for conducting investigations compared with trenching and the ease of bringing the strata samples back to the laboratory for detailed observations (Tamura et.al, 2000).

When active faults are covered with alluvium geophysical explorations such as seismic reflection method, sonic prospecting, electric prospecting, electromagnetic prospecting, gravity prospecting and radioactive prospecting can be used (Takahashi et al., 1997). Of these the seismic reflection method can locate faults if geological conditions are favourable, and confirm the accumulation of fault displacements based on the amount of displacements in strata that increases with strata age.

The tectonic conditions should include tectonic mechanisms, location and description of faults (normal, stryke and reverse) and estimation of fault activity (average slip rate, slip per event, time interval between large earthquake, length, directivity effects, etc), these factors are important to assess the involved risk.

Determination of neotectonic activity implies first the qualitative geomorphologic analysis of air photos and topographic maps. The GPS system is another powerful means of monitoring the crustal mobility.

Cluff et al.(1982) have proposed the following classification for slip rates: extremely low to low for 0.001 mm/year to 0.01 mm/year, medium to high 0.1 mm/year to 1 mm/year and very high to extremely high 10 mm/year to 100 mm/year.

6.3. Attenuation Relations

Attenuation relations can be divided into 3 main tectonics classification shallow crustal earthquakes in active tectonics regions, regions subduction earthquakes and shallow crustal earthquakes in stable continental regions.

The following attenuation relations were proposed: Idriss model (1995) and Sadigh et al. model (1997) have only horizontal component and Abrahamson and Silva (1977) relation have been used for vertical component.

Sommerville et al. (1977) have shown that directivity has a significant effect on long-period ground motions for sites in the near-fault region

The attenuation relationships for estimating earthquake ground motions rely on recorded data and should incorporate ground motion parameters. The values of mean peak acceleration were presented by Trifunac and Brady and compared with recorded data in Figure 9, has shown that the range of the recorded data is about a factor of 4 and the range of calculated mean values is closer to a factor of 10.

6.4. Topographic Amplification Factors

For the stability verification of ground slopes EC8 recommends simplified amplification factors for the seismic action to incorporate the topographic effects. Such factors should be applied for slopes with height greater than 30 m.

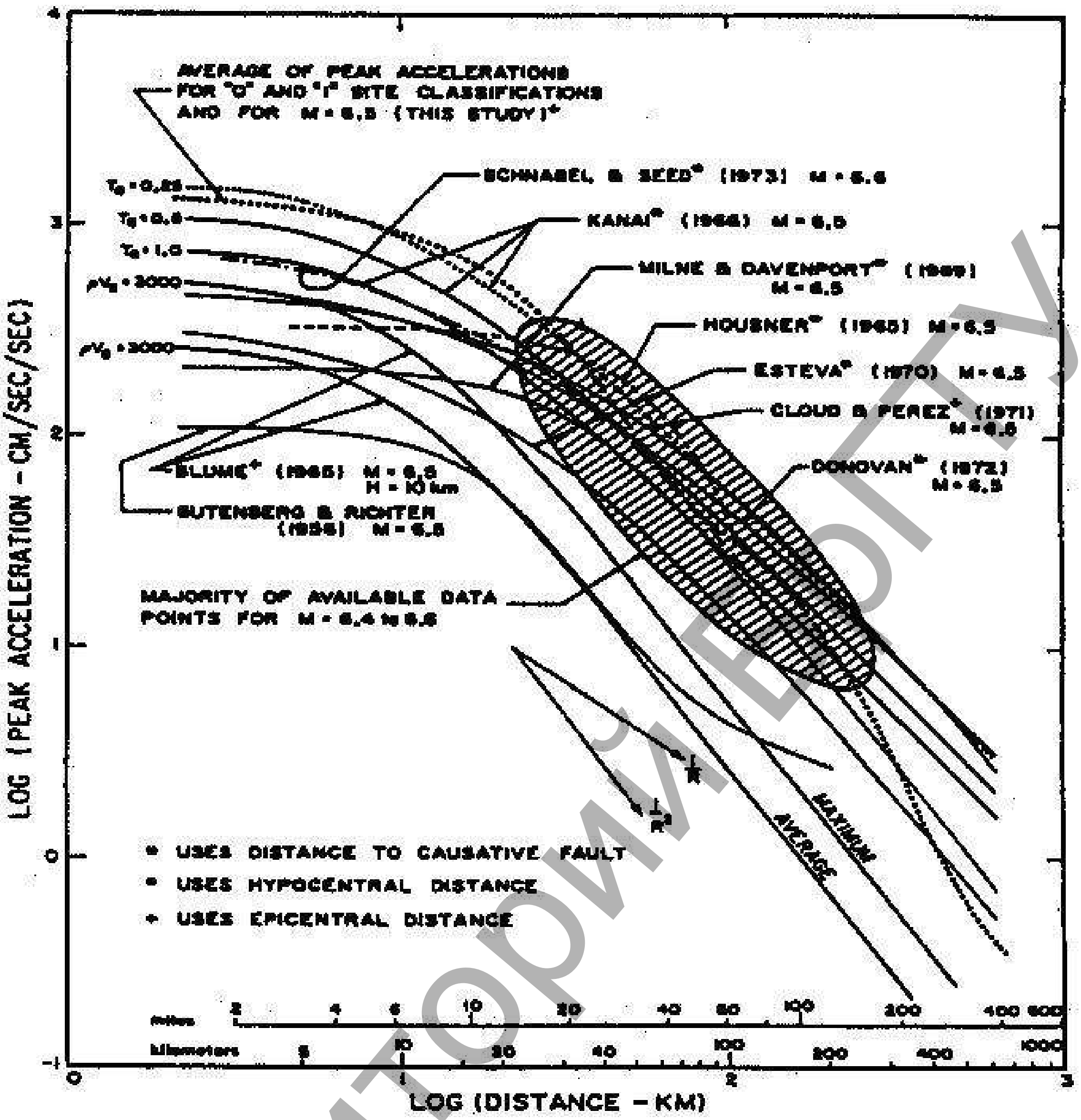

Figure 9 – Attenuation relationships (after Trifunac and Brady)

The following recommendations are given:

(i) for slopes angles less than 15° the topography effects can be neglected;

(ii) for isolated cliffs and slopes a value of S ≥ [1,2] should be used;

(iii) for slopes angles > 30° a value of S ≥ [1,4] should be used and S ≥ 1,2 for smaller slope angles;

(iv) in the presence of a looser surface layer more than [5] m thick, the smallest value given in (ii) and (iii) shall be used increased by at least [20%].

No reference is made for 2 D models or 3 D models and for the frequency range amplifications observed in 2 D and 3 D models.

However Paolucci (2005) have pointed that amplification factors for 2D analyses are of the same range of EC8, but for 3D analyses the values are 25% higher.

To assess the topographic amplification is important to separate from the site amplification. Also topographic amplification varies with the frequency content of the earthquake (Pitilakis et al., 2001).

One recent example is related with the topographic amplification occurred in the coastal bluffs of the Pacific Palisades during the January 17, 1994 Northridge earthquake. The slopes with 40 to 60 m height and steep between 45 to 60 degrees failure.

Parametric studies conducted by Idriss (1968) on 27 and 45 degrees clay slopes using finite element method have shown that the magnitude of peak surface acceleration was greater at the crest surface of the slope than at points lower on the slope, but comparing the peak ground acceleration at the crest to that at some distance behind the crest in some cases the acceleration at the crest was much greater, in other case cases there was little difference. The natural period of the soil column behind the crest of a slope was responsible for much more amplification of the input motion than the slope geometry.

Ashford et al (1997) concluded that topographic effects can be normalized as a function of the ratio of the slope height and wave length of the motion and the trend is shown in Figure 10.

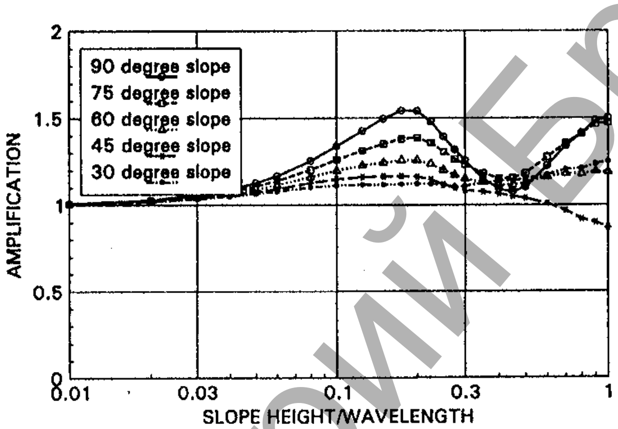

Figure 10 – Amplification effects of steep slopes (after Ashford et al, 1997)

7. CODES and STANDARDS

The International Association for Earthquake Engineering (1992) compiled in the last version of Earthquake Resistant Regulations – "A World List" seismic codes of 37 countries.

The actual tendency is to prepare unified codes for different regions but keeping the freedom for each country to choose the safety level defined in each National Document of Application. The global safety of factor was substituted by the partial safety factors applied to actions and to the strength of materials.

For the occasion of the Second International Conference on Earthquake Geotechnical Engineering, held in Lisbon, 21-25 June, 1999, a Session on Codes Standards and Safety evaluation took place with the purpose to review and to highlight the similitude and differences of the geotechnical seismic codes adopted in different regions.

The different adopted codes are summarized in Table 7.

Life safety was the motivating factor in the development of standards controlling the design of structures (Finn, 1999).

The codes are important but that they need to be used with caution. Pecker (1999) said "Although the safety of a construction does not rely only upon codes and standards which are used for its design and construction, those documents help significantly to minimize the most commonly encountered causes of deficiencies and fallacies in seismic areas".

Also the lessons learned from the seismic behavior of geotechnical structures are important for the revision of existing design codes.

Table 7 – Codes

Codes	Covered Topics	References
Eurocode nº8	Ground motions, liquefaction, slope stability, retaining structures, soil-structure interaction	Pecker (1999) Cuellar (1999) Sêco e Pinto (1999b)
North America Codes	Ground motions, liquefaction, soil-structure interaction, foundations, embankment dams, waste landfills	Finn (1999) Seed and Moss (1999)
Asian Countries Codes	Ground motions, liquefaction, tanks, foundations, lifelines, tailing dams, harbors	Yasuda (1999)
New Zealand Codes	Ground motions, liquefaction, foundations, retaining structures	Pender (1999)

8. EducaTION IN EARTHQUAKE ENGINEERING

T. K. Mimoto, e T. Hayakawa. Present state of applications of geophysical methods to characterization of active faults. Journal of Japan Society of Engineering Geology, 38, pp.118-129, 1997.

Tamura, C., S. Kanyo, T. Uesaka, I. Nagayama e Y. Wakizaka. Survey and evaluation of active faults on dam construction in Japan. Paper nº 2493. 12th WCEE, Auckland, New Zealand, 2000.

TC4 (ISSMGE) (1993). Manual for Zonation on Seismic Geotechnical Hazards, published by the Japanese Society of Soil Mechanics and Foundation Engineering, Tokyo.

UBC (Uniform Building Code) International Conference of Building Officials", Whittier, California, Vol. II, 1997.

Yasuda, S. Seismic design codes for liquefaction in Asia. Proc. of the Second International Conference on Earthquake Geotechnical Engineering, Lisbon, Vol. 3, pp.1117 - 1121. Edited by Pedro Sêco e Pinto. Published by A.Balkema, 1999.

Earthquakes are very complex and dangerous natural phenomena, which occur primarily in known seismic zones, although severe earthquakes have also occurred outside these zones in areas considered be geologically stable. As a result, regulatory agencies became more stringent in their requirements for demonstration of adequate seismic stability and design engineers responded by developing new and more convincing design approaches than had previously been used. Thus the past years have seen a major change in interest and attitude towards this aspect of design.

Text books that cover soil dynamics and earthquake engineering are useful instruments for the lecturers and students and the most popular are: Clough and Penzien (1975), Prakash (1981), Das (1983), Wolf (1985), Humar (1990), Lay and Wallace (1995), Kramer (1995), Ishihara (1996), and Bolt (1999).

Due to the lessons learned from recent earthquakes (Sêco e Pinto, 1996) much progress has been made in the past years in developing and improving understanding of the seismic behavior of geotechnical structures. Due to this circumstance the textbooks do not cover adequately the recent developments and need to be supplemented with class notes. This situation obliges to a continuous effort for the lecturers in order to be up-to-date with the last developments in earthquake engineering.

Also it is important to narrow the gap between the university education and the professional practice. As one lecturer can not be a specialist in all topics some lectures should be given by outstanding practice professionals.

It is also important to stress the activities of EERI (Earthquake Engineering Research Institute), founded in 1948 that include investigations of destructive earthquakes, technical workshops, and coordination of research problems in earthquake engineering. EERI produces a wide variety of publications including technical monographs, earthquake reports, conference proceedings, and seminar notes, as well as multimedia slide sets, videotapes and CD-ROMs. A monthly Newsletter and a quarterly journal are published for members. The EERI web site is a valuable resource.

Videotapes and slide sets from Kobe earthquake (1995), Northidge (1994), Loma Prieta (1989), Armenia (1988) earthquakes were prepared. Also there are available slide sets from Umbria-Marche (1997), Erzincan (1993), Costa Rica (1991), Philippines (1990), Iran (1990) and Mexico (1985) earthquakes.

A lecture series on soil and structure response to earthquakes delivered by some “gurus” of earthquake engineering are available in videotapes:

Lecture1: “Understanding and Predicting Soil Behavior” by Prof. H.Bolton Seed;

Lecture 2: “ Introduction to Structural Dynamics” by Prof. A. K. Chopra;

Lecture 3:“ Understanding and Predicting Structural Behavior” by Prof. P.C. Jennings;

Lecture 4:“ Soil-Structure Interaction“ by Prof. A.S. Veletsos.

Also other institutes such as National Center of Earthquake Engineering Research (NCEER) established in 1986, Federal Earthquake Management Agency (FEMA), United States Geological Services (USGS), National Geophysical Design Center(NGDC), Earthquake Engineering Research Center(EERC), the Disaster Research Center (DRC) have published several reports, journals and also organized data base of earthquakes and tsunamis, and social behaviours during accidents.

9. CONCLUSIONS

Earthquakes are very complex and dangerous natural phenomena, which occurs primary in known seismic zones, although severe earthquakes have also occurred outside these zones in areas considered being geologically stable. As a result, regulatory agencies became more stringent in their requirements for demonstration of adequate seismic stability and design engineers responded by developing new and more convincing design approaches than had previously used. Thus the past years have seen a major change in interest and attitude towards this aspect of design..

The lessons learned from recent earthquakes such as: Northridge (1994), Kobe (1995), Umbria-Marche (1997), Kocaeli (1999), Athens (1999), Chi-Chi (1999) and Bhuj (2001) have provided important observational data related with the seismic behavior of geotechnical structures.

The work performed by the Commission of the European Communities (CEC) in preparing the “Structural Eurocodes” in order to establish a set of harmonised technical rules is impressive. However we feel that some topics deserve more consideration.

The need of cost effective methods to upgrade buildings by developing new specific foundations techniques is a major problem. So the objective of reducing the earthquake motion transferred to the structure through the foundation by developing innovative constructive techniques for soil improvement and soil reinforcement is getting increase attention.

One very important question to be discussed is: (i) how detailed a seismic code must be; (ii) what is the time consuming to establish a set of harmonised technical rules for the design and construction works? (iii) How to improve the relations between the users: relevant authorities, clients and designers? and (iv) how to implement in practice that codes may not cover in detail every possible design situation and it may require specialised engineering judgement and experience? It is hoped that the contributions to be presented by CEN members, in the next years, will help to clarify several questions that still remain without answer.

From the analysis of past incidents and accidents occurred during the earthquakes it can be noticed that all the lessons have not deserved total consideration, in order to avoid repeating the same mistakes.

It is important to stress that a better understanding of geotechnical structures during the occurrence of earthquakes can only be achieved by a continuous and permanent effort.

In dealing with this subject we should always have in mind:

"There`s a fount about to stress
There`s a light about to beam,
There`s a flower about to blow,
There`s a warmth about to glow;
There`s a midnight darkness changing
Into grey,
Men of thought and men of action,
Clear the way"

REFERENCES

Abrahamson, N. A. and W. J. Silva. Empirical response spectral attenuation relations for shallow crustal earthquakes. Sei. Res. Lett. 68, nº 1, pp. 94-127, 1997.

Ambraseys, N. N. Engineering serismology. Earthquake Engineering and Structural Dynamics, Vol.

Ashord, S.A., Sitar, N., Lysmer, J., e Deng, N.. Topographic effects on the seismic response of steep slopes. Bulletin of the Seismological Society of America, 87(3), 1997.

Celebi, M. Unique ground motions recorded during the Northridge (California) earthquake and implications. Special Session on "Lessons learned from Northridge and Kobe earthquakes. Proc. 11 World Conference on Earthquake Engineering, Mexico, 1996.

Cetin, K.O e Seed, R.B. Nonlinear shear mass participation factor (r_d) for cyclic shear stress ratio evaluation, Research Report nº UCB/GT-2000/08, University of California, Berkeley, 2001.

Clough, R.W. e Penzien, J. Dynamic of Structures. McGraw- Hill, 1975.

Coty, P.A. e Tao, D. Provision of Earthquake Engineering Information in the US, 10 th World Conference, Earthquake Engineering, Madrid, 1992, pp 6105-6109, 1992.

Cuellar. V. Codes and standards for Europe. Proc. of the Second International Conference on Earthquake Geotechnical Engineering, Lisbon, Vol. 1, pp. 443 - 439. Edited by Pedro Sêco e Pinto. Published by A.Balkema, 1999.

Das, B.M. 1983. Fundamentals of Soil Dynamics. Elsevier.

EERI The Hyogo-Ken Nanbu Earthquake Great Hanshin Earthquake Disaster January 17, 1995.

.Eurocódigo 8. Design of structures for earthquake resistance". ENV, 1998.

Eurocódigo 8. Design provisions for earthquake resistance of structures - Part 5 Foundations, Retaining Structures and Getechnical Aspects, ENV1998.

Finn, W. D. L. Codes, standards and seismic safety evaluation of earth structures. Theme Lecture. Proc. of the Second International Conference on Earthquake Geotechnical Engineering, Lisbon, Vol.31, pp. 1091 – 1106. Edited by Pedro Sêco e Pinto. Published by A. Balkema, 1999.

IAEE (International Association of Earthquake Engineering) 1992. Earthquake Resistant Regulations. A World List –1992, 1996.

Idriss, I. M. Response of soft soil during soil earthquakes". Proc. H. Bolton Seed Memorial Symposium, pp.273-290, 1990.

Idriss, I. M. An overview of earthquake ground motions pertinent to seismic zonation. Proc. 5 th Int. Conf. Seismic Zonation, Nice, pp. 2111-2126, 1995.

Idriss, I.M. e Sun, J.L. User's manual for SHAKE 91, Center for Geotechnical Modeling, University of California, Davis, CA, 1992.

Ishihara, K. Soil behaviour in earthquakes geotechnics. Clarendon Press. Oxford, 1996.

Kawasumi, H. General report on the Niigata Earthquake, Tokyo Electrical Engineering, Collegue Press, 1964.

Kokusho, T. e Matsumoto, M. Nonlinear site response during the Hyogoken-Nanbu earthquake recorded by vertical arrays in view of seismic zonation methodology. Proc of the Discussion Special Technical Session on Earthquake Geotechnical Engineering during 14th ICSMFE, Hamburg, Edited by Pedro S.Sêco e Pinto. Published by Balkema., pp. 61-69.Kramer S. L. 1995. Geotechnical Earthquake Engineering. Prentice Hall, 1997.

Kramer S. L. Geotechnical Earthquake Engineering. Prentice Hall, 1995.

Paolucci, R. e Rimoldi, A. Seismic amplification for 3D steep topographic irregularities. Paper 87, 12th European Conference on Earthquake Engineering, London, 2002.

Pecker, A. Session: Codes, standards and safety evaluation. General Report. Proc. of the Second International Conference on Earthquake Geotechnical Engineering, Lisbon, Vol. 3, pp.1107 - 1109. Edited by Pedro Sêco e Pinto. Published by A.Balkema, 1999.

Pitilakis, K.D., Makra, K.A. e Raptakis, D.G. "D vs 1D effects with potential applications to seismic norms: The cases of EUROSEISTEST and Thessaloniki. XV ICSMGE TC4 Satellite Conference on Lessons Learned from Recent Strong Earthquakes, pp 123- 133. Edited by Atilla Ansal, 2001.

Sêco e Pinto, P. S Considerations on the geotechnical behavior of structures during earthquakes. Key Note. Special Session on "Lessons learned from Northridge and Kobe earthquakes". Proc. 11 World Conference on Earthquake Engineering, Mexico, 1996.

Sêco e Pinto, P.S. The relation between Eurocode 8 and Eurocode 7. Proc. of the 12 th. European Conference on Soil Mechanics and Geotechnical Engineering. Amsterdam, Vol.3, pp.2223-2228. Edited by F.B.J. Barends, J. Lindenberg, H.J. Luger, L. de Quelerit and A. Verruit. Publisher A. A. Balkema, 1999b.

Sêco e Pinto, P. Eurocode 8 – Design provisions for geotechnical structures Special Lecture. 3rd Croatian Soil Mechanics and Geotechnical Engineering Conference, CD-ROM, Hvar, 2002.

Sêco e Pinto, P. Seismic behaviour of geotechnical structures. Inaugural lecture, Proc. 13 th Regional African Conference of Soil Mechanics and Geotechnical Engineering pp 3- 24., Marrakech, Edited by M.Sahli, L.Bahi & R.Khalid, 2003.

Sêco e Pinto, P. S. E Oliveira, R. A recent difficult foundation problrm. The case of the New Tagus bridge. Special Lecture. Proc. 4th International Conference on Cases Histories in Geotechnical Engineering, St. Louis, USA, 1998.

Seed, R.B e R.F.S., Moss Recent advance in US codes and policy with regard to seismic geotechnics. Proc. of the Second International Conference on Earthquake Geotechnical Engineering, Lisbon, Vol. 3, pp.1111 - 1116. Edited by Pedro Sêco e Pinto. Published by A.Balkema, 1999.

Seed, R.B., Chang, S. W., Dickenson, S.E. and Bray, J. B. Site dependent seismic response including recent strong motion data". Proc of the Discussion Special Technical Session on Earthquake Geotechnical Engineering during 14th ICSMFE, Hamburg, pp. 125-134. Edited by Pedro S.Sêco e Pinto. Published by Balkema, 1997.

Somerville. Engineering art: earthquake ground motion". Proc. Geotechnical Earthquake Engineering in Soil Dynamics III, Edited by P. Dakoulas, M. Yegian and R.D. Holtz, Geotechnical Special Publication. N° 75, ASCE, Vol.1, pp 1-38, 1998.

Stokoe, K.H. II, M. B. Darendeli, R.D., Andrus e L.T., Brown Dynamic soil properties: Laboratory, field and correlation studies. Theme Lecture. Proc. of 2nd International Conference on Earthquake Geotechnical Engineering, Lisboa. Edited by Pedro Sêco e Pinto. Published by A. Balkema, Vol.3, pp. 811-845, 1999.

Stokoe, K.H. II, Darendeli, M.B., Menk, F,Y e Choi, W.K., Comparison of the Linear and Nonlinear Dynamics properties of Gravels, sands and Clays. Proc. of 3rd International Conference on Earthquake Geotechnical Engineering, Berkeley , Editors D.Doolin, A. Kammerer, T. Nogami, R.B. Seed e I.Towhata, Vol. 1 pp.1-4, 2004.

Streeter, V.L., E.B. Wylie e F.E. Richart. Soil motion computation by characteristics method. ASCE National Structural Engineer Meeting, San, 1973

Takahashi,

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PECULIARITIES OF DESIGNING PILED-RAFT FOUNDATIONS FOR MULTI-STOREY AND HIGH-RISE BUILDINGS

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ABSTRACT: Currently in Multi-Storey and High-rise building to avoid intolerable relative settlement of separate constructions raft foundations are used. In connection with excessive loads base settlement often exceeds assumed value. In that case pile foundations are used. Often pile foundations are applied in comparative favorable ground conditions at the surface of the base. In such cases increase the bearing capacity of foundations and reduce construction cost are questions of first-rate importance for designers. One of the ways to increase the bearing capacity of a piled foundation is taking into account soil resistance in the base of the raft. Raft is similar to shallow foundation and can transfer significant part of the load into the base. It allows reducing number of pile in the foundation or shortening their length. As a result building terms and foundation costs reduce considerably. However, nowadays in Belarus there is no reliable and suitable in design practice methods of calculation of piled-raft foundations. In order to devise such methods we have analyzed the results of piled foundation tests fulfilled by various authors up to date and have carried out series of field and laboratory investigations in Minsk. The most important results of the investigations are provided in the article.

Introduction

Of late years pile foundations are used extensively in connection with increase number of storeys and load increment on the soil. Often pile foundations are applied in comparative favorable ground conditions at the surface of the base. In such cases increase the bearing capacity of foundations and reduce construction cost are questions of first-rate importance for designers. One of the ways to increase the bearing capacity of a piled foundation is taking into account soil resistance in the base of the raft. Piled raft is similar to shallow foundation and can transfer significant part of the load into the base. It allows reducing number of pile in the foundation or shortening