IMPLEMENTATION OF EUROCODE 8 IN CROATIA

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ABSTRACT:

For many years Eurocodes are applied for structural design in Croatia. During these years many questions have been opened and verifications have been made to define National Application Documents in the application of ENV Eurocode series. Now analysis are performed to enable the acceptance of final EN Eurocode standards. Most uncertainties and questions were connected with Eurocode 8 which is of specific importance for Croatia since 92 percent of state teritory is earthquake prone (MSK intensities 7° and above). This paper considers specially earthquake design response spectra, design ductilities (DCL, DCM and DCH) and material selection. Experiences gained will serve when decision will be made about National Determined Parameters. Solutions are directed to find acceptable reliability and safety for earthquake resistant structures with reasonable cost increase.

KEYWORDS: Eurocode 8, ENV 1998, EN 1998, design response spectra, design ductility, construction materials

1 INTRODUCTION

Application of Eurocodes - standards for structural design in Croatia follow principles of Construction Product Directive (89/106/EEC) with a final goal to accept new European and World knowledge in the construction field. Recent application requires numerous additional activities which are in course or will be perfomed in near future.

2 WHAT WAS DONE AND WHAT IS UNDER PREPARATION

2.1 First step of Eurocodes application - ENV version

Application of Eurocodes started in Croatia about ten years ago (ENV version). Eurocodes were introduced in teaching programmes of structural engineering of Croatian universities. Translation of English-written standards to Croatian language as well as education of professionals started. Through new Technical regulations Eurocodes for design of concrete and masonry structures (ENV 1992 and ENV 1996) were introduced in the state legislative system. In parallel Eurocodes ENV 1991, ENV 1997 and ENV 1998 were accepted to have compatible system defining actions, foundations, design and detailing.

Each part of standard has its relevant National Application Document (NAD) which defines necessary national specific values (in seismic map), boxed values and national standards in the areas where European standards were not available. Most boxed values were accepted as recommended in ENV 1998 series of standards.

2.1.1 Seismological map and response spectra

Available and accepted seismological map does not represent design value of ground acceleration but intensity map (MSK-64). Conversion from intensities to acceleration was done applying some (older) empirical formulae, applying engineering knowledge and expertise from past earthquakes, analysing recent strong motion records and recent construction practice and level. Following correlations between maximum ground acceleration a_g and intensities were used:

$$\log a_g = 0{,}25\, I + 0{,}25 \quad \text{(Murphy, 1977)} \tag{1}$$

or indirect correlation of magnitude, intensity and acceleration

$$I = 1{,}56\, M - 1{,}78 \text{ (Tezcan, 1978)} \tag{2}$$
$$I = 1{,}52\, M - 0{,}15 \text{ (Ribarič, 1982)} \tag{3}$$
$$I = 1{,}50\, M - 0{,}5 \text{ (Sikošek, 1986)} \tag{4}$$

and further by attenuation functions as for example

$$a = 5600 e^{0,8M} / (R + 40)^2 \text{ (Esteva, 1973)} \tag{5}$$

Values calculated by the above formulae connected to intensities values and values defined in NAD are given in table 1.

Table 1 - Average values of maximum ground acceleration, a_g (in percent of g) as function of earthquake intensities accepted in NAD

Intensity level - degrees	**VI**	**VII**	**VIII**	**IX**
	Maximum ground acceleration in percent of *g*			
Murphy (1977)		10	18	32
Esteva (1973)		11	19	32
MSK-64		5-10	10-20	20-40
MSC-76		10	20	40
NAD, HRN ENV 1998-1-1	5	10	20	30

Earthquake return period is defined for 500 years what is compatible with return period of the recently used seismological map and similar to Eurocode 8 requirement (475 years). Accepted design life of structure is in the moment 100 years. This gives some increase in the reliability in comparison with structures designed for 50 years design life.

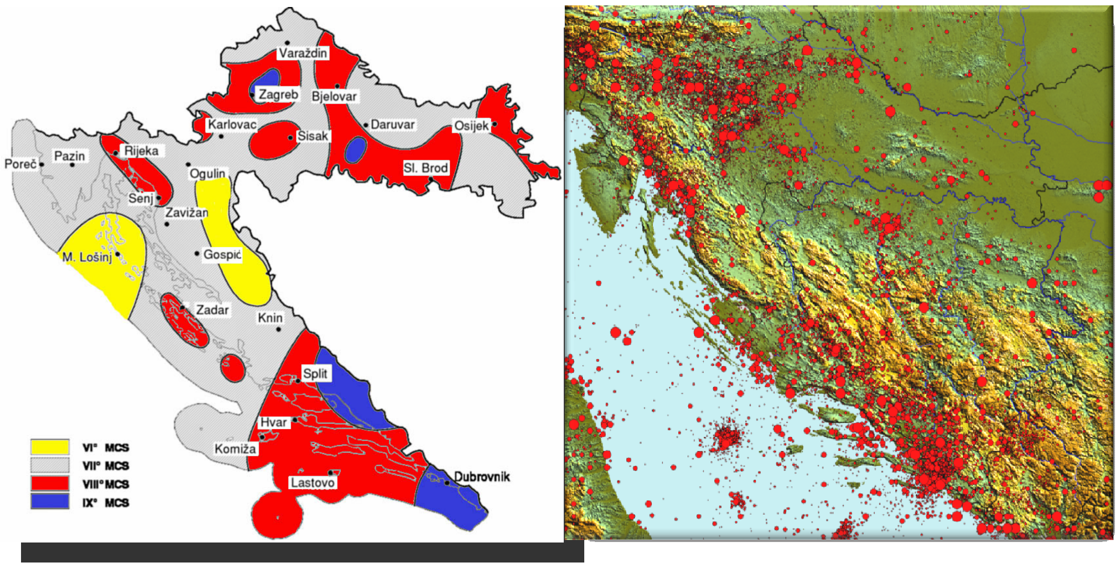

Figure 1 - Seismological map of Croatia (intensities) and earthquakes recorded last 2373 years (magnitudes)[5]

Some other European countries applied the same approach of semi-empirical correlation between intensities and acceleration. Selected response spectra are identical as proposed in the standard.

2.1.2 Story drift

Some changes were introduced in the NAD in comparison to the recommended value in standard. Changes were introduced to allow for the 95 years of return period for serviceability limit state.

2.1.3 Importance factors and behaviour factors for buildings

Selected factors correspond to the proposed values in the standard. Such decision introduced some incompatibility between the importance factor γ_I defined for the 50 years design life and seismological map using 100 years design life.

2.2 Second step of Eurocodes application - EN version

The official application of Eurocodes - EN version did not start yet, it is expected to start in 2010. However, preparation works started in 2006 by nomination of Technical Committee (TC) and ten Subcommittees under the umbrella of Croatian Standards Institute. Several steps in parallel are in course. List of terms and definitions was prepared to unify translation procedure. Translation of about 4900 pages of Eurocodes is in work. National Determined Parameters and National Annexes are under preparation. As a first step Eurocodes will be accepted in English version up to the end of 2008 to enable to start learning and training of the engineering community and not only of TC members. New seismological map including ground accelerations is under development. Comparative examples of computation of structures are under work to show what will be the final effect of new codes.

As Eurocode 8 prescribes shape of response spectra, defines ground categories and relevant amplifications but not an absolute numerical values of quantities defining earthquake hazard, new seismological map as a part of the National Annex shall include this hazard at the level of base rock. New seismological map will follow completely Eurocode requirements: 475 years of return period, 10 percent of probability, 50 years of design life of structure. It may be expected that according to the recent development in seismology and increased number of strong motion records some changes in earthquake zoning will occur, since recently valid map of intensity based earthquake zones is about 20 years old.

2.2 Training as imperative

Training for new standards started in the early stage of transfer to Eurocodes. Key persons at the national level were trained at several location in EU bodies and in education centres (e.g. Imperial College). Then this knowledge was transferred at the national level through engineering faculties, Civil Engineering Institute and Engineering Chamber. Eurocodes users were trained during almost three years in the frame of "Days of licensed civil/structural engineers". More than thousand of them are participating to regular training seminars devoted to different aspects of new codes.

3 WHY ENV SERIES AS A FIRST STEP?

There are three essential reasons why Croatia in by-law-regulated area started with Eurocodes - ENV series, including Eurocode 8, application. First, about 92 percent of Croatian state territory is earthquake prone (intensities 7 and above) where design of earthquake resistant structure is compulsory. Second, technical regulations dated from 80-ies were old fashioned, not including new development during almost 30 years. Eurocodes offered good way to introduce new knowledge with incorporation of national needs. Third, the fact of increased activities in the construction sector (post-war development in residential housing, erection of large office building and intensive construction of highways with many large bridges and state as investor) gave rise to the need to revise actual situation as fast as possible.

During the early nineties only ENV series of Eurocodes were available. It was found that differences between existing approaches and Eurocode - ENV approach were so extensive that lot of time, learning and experience in application will be needed to transfer from the old to the new approach. Differences between ENV series of standards and later issued EN series is substantially smaller. Therefore Croatia first started with ENV series of Eurocodes.

At the first stage only concrete and masonry structures were included. Main reason was the fact that these types of structures cover about 80 percent of all construction works in Croatia. Therefore majority of professionals were interested for Eurocodes for these types of structures. Other types of structures (steel, composite, timber and aluminium) were covered at the university level and in the minor part elsewere.

4 HOW APPLICATION OF EUROCODES IS PERFORMED AND ACOMPANYING PROBLEMS

Technical regulation for concrete structures allowed during two years parallel application of existing (old) regulations and Eurocodes. Most structures were designed in this period using both systems to have the possibility to compare final results and to understand differences. The other reason was "verification" of Eurocodes on existing structures, either only in the design stage, or even with structure completed. Then, comparison of simple design schemes and their result analysis using "old" and "new" schemes enabled good insight to the new design system.

In this period a lot of questions arise in the engineering community, specially among designers. As in the period which preceded the introduction of Eurocodes, main principles remained same: to design earthquake resistant structure initial structural concept shall be sane, simple and clean. Assumptions made in the design shall be reflected in structural behaviour using proper structural detailing, construction with adequate material qualities followed by construction of required quality. In the design process most uncertainties arised when selecting design ductility class, selecting proper design software and the availability of selected materials (e.g steel).

4.1 Earthquake action

More parameters have influence to the correct assessment od earthquake action. Starting position is design ground acceleration, a_g, and the choice of suitable design response spectrum. As the spectrum is dependent of the soil class, the result depends of the correct choice of the soil conditions. This is not an easy task in the initial stage of design development when soil conditions can be only estimated. Calculated periods may differ substantially from the actual periods of the building completed and any structural changes in the stage after building completion are almost impossible. The shape of design response spectrum has decisive role to the magnitude of earthquake forces and its shape is based on relatively large scatter of data. All this facts influenced the change from design response spectrum of ENV - EC version to the final EN - EC version. Offering two sets of design response spectra in EN - EC version gave the designer possibility to adopt solution suitable to the local seismic situation, depending of the earthquake magnitude. First set iz for $M > 5,5$ (type 1) and second for $M \leq 5,5$ (type 2). The last one is extremely unsuitable for stiff masonry structures.

Design response spectrum depends on the soil type (A, B, C in EC - ENV version). Such classification has been found unsuitable to the actual soil conditions and decision making in such circumstances was difficult. Non-existence of the soil maps directed designers to decide on the basis of reports of soil investigations which didn't gave answers connected to earthquake requirements. In the recent EC - EN version more soil types were introduced (A, B, C, D, E, S1, S2) but classification remained still in hands of geotechnical and not structural engineers. Table 2 shows comparison of soil types between EC - ENV and EC - EN versions on the basis of shear wave velocities, v_s.

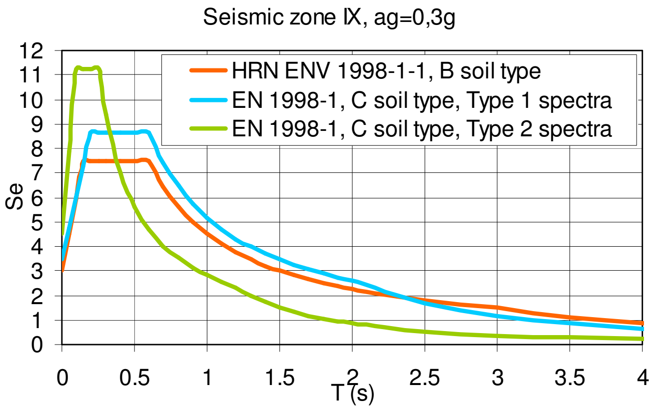

Figure 2 - Some elastic response spectra according to Eurocode ENV and EN version [15]

Table 2 - Comparison between EC - ENV and EC - EN version for soil types based on shear wave velocities [15]

HRN ENV 1998-1-1		EN 1998-1	
A	$v_s \geq$ 800 m/s $v_s \geq$ 400 m/s (at 10 m depth)	$v_s >$ 800 m/s	A
B	$v_s \geq$ 200 m/s (at 10 m depth) to $v_s \geq$ 350 m/s (at 50 m depth)	$v_s =$ 360 - 800 m/s	B
C	$v_s \leq$ 200 m/s	$v_s =$ 180 -360 m/s	C
		$v_s \leq$ 180 m/s	D
		v_s for type C and D, depth 5-20 m, base of stiffer material with $v_s >$ 800 m/s	E
		Additional	S1 S2

Design response spectra further depends of behaviour factors of structure, i.e. of the material and type of structure, and fulfilment of special conditions (plan and elevation symmetry) and selected ductility class.

Specially sensitive question is the choice of ductility in shear wall systems. Depending on energy dissipation capacity, ductility substantially differs. Squat walls are "punished" because of their low ductilities. Factor k_w taking into account influence of prevailing failure mode of bearing walls may deliver, under some circumstances, non-logical results as negative values what is physically impossible. Although there are some restriction in use of q-factors, the coverage of the problem seems to be not complete.

EC - EN version gives lower and higher limit for k_w value within limits $0{,}5 \leq k_w \leq 1{,}00$. Value 0,5 is predicted for squat and value 1,0 for high walls, respectively.

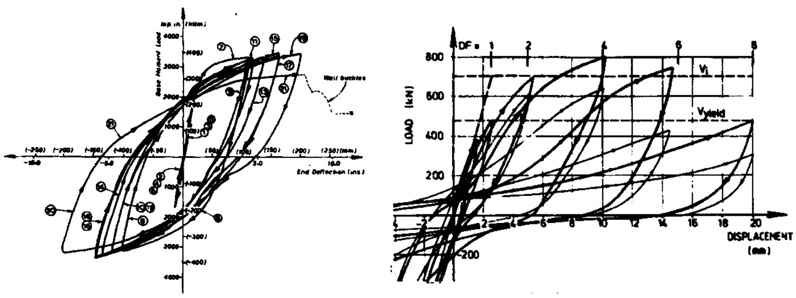

Figure 3 - Hysteretic behaviour of ductile (high) wall and squat (low) wall (after Paulay, 1980) [4]

4.2 Design ductility

The question is how to connect ductility class (DCL, DCM and DCH in EC - ENV version and DCM and DCH in EC- EN version) and the earthquake magnitude. EC 8 does not either prescribes nor suggest how to make this choice. Form the standpoint of structural behaviour it is essential to design and erect the structure which will have compliance of bearing capacity and ductility. The structure shall not be brittle (high bearing capacity - low ductility), but shall not be to flexible (low bearing capacity - high ductility) what leads to high damage of non-bearing elements and large repair costs.

How to transfer these requirements into a suitable design, i.e. how to select design ductility? The EC 8 - ENV version specifies that low ductility should be used only with fundamental parts of EC 2 (ENV 1992-1-1) and EC 6 (ENV 1996-1-1) and applying design rules and detailing given in EC 8 - ENV version without any additional calculation. Moderate (DCM) and high (DCH) ductilities require complete fulfilment od EC 8 - ENV version provisions. Important provisions are that under repeated loads in postelastic range no brittle failure shall occur (DCM) and that stable mechanisms with high dissipation of hysteretic energy under earthquake input shall occur (DCH). The consequence is that for a non-ductile structure (DCL) q=1,0 and for ductile q>1,0 (or ≥1,5 as prescribed by standard).

Acceptable design approach for structures classified in DCM ductility class is linear calculation using design spectrum as the elastic spectrum divided by behaviour factor q and modified by k_{d1} and k_{d2} exponents to allow for soil class (A, B, C); energy dissipation mechanisms is achieved by ductile behaviour of structural elements located in well studied positions. Computer programs are available for such calculations.

Concerning structures in DCH ductility class essential requirement is that critical zones shall have higher capacity then relevant action effect may cause. These critical zones as a potential plastic hinges shall have high capacity of plastic rotation. Brittle failure shall be prevented as well other inconvenient failure modes (at column - beam joints, at foundation level, at element which shall remain in elastic range). High level of redundancy will provide energy dissipation at more bearing elements without important failures. Usually neglected influence of non-bearing elements (e.g. infill walls) may have both positive and negative effect and shall be taken into account. Such analysis are not possible using software available on the market and for the time beeing EC - EN version gives a set of formulae to overstep present situation. For designers this situation is almost non-acceptable because it's time consuming and requires much more hand calculations.

Result of present situation is that designers make their choice between DCL and DCM ductility classes independently of earthquake magnitude. It is hard to believe that this is a rational solution for areas of strong earthquakes. Earthquake force is substantially increasing for DCL ductility class, available ductility is low, and for unexpectable earthquake safety may be questionable. Capacity design is not yet established as every-day method in design process and remained only to be used in study-types of analyses.

EC - EN version reflects this problem in the same way, but gives the possibility of non-linear analysis using push-over method which is relatively simple and understandable for designers. Basics of this non-linear method are given in the Annex B of the EC - EN version and are founded on the works of Ljubljana, Slovenia school of earthquake engineering (Fajfar).

4.3 Material requirements

In concrete structures material requirements cover concrete quality (min C16/20 for DCL and min C20/25 for DCM and DCH) and fulfilment of other requirements given in EN 206-1 and steel quality (EN 10080 and EN 10138). In masonry structures compressive strength of masonry units and mortar and percent of voids reflects their ability for earthquake zones.

Special problem connected with DCH class of ductility is the requirement for steel quality. EC - ENV version requires for reinforcing steel to be a high ductile steel having yield strength of 500 or 450 MPa and tensile strength to yield strength ratio of $\geq$ 1,15 and $\leq$ 1,35 or $\geq$ 1,20 and $\leq$ 1,35 respectively, plus elongation at failure of $\geq$ 6 % (for DCM) or $\geq$ 9 % (for DCH). Steels with such properties are not available on the European market. Available qualities in the moment are only steels with 500 or 550 MPa yield strength and elongation at failure of $\leq$ 7 %. Relationship between requirements for earthquake situation in EC - EN standards and on the market available steel quality conforming to standard for reinforcing steel (EN 10080) is not well established. Some changes are necessary in this respect.

The above requirements for reinforcing steel relates to the reinforcement of critical zones to achieve suitable length of plastic joints and high local ductility i.e. high rotational capability. Additionally, higher values of $\varepsilon_{su,k}$ i f_t / f_y give well controlled and economical post elastic mechanisms. But it may not be expected that for zones outside of critical one some other steel quality would be used, what would be very complicated solution.

4.4 Other requirements

Criteria for *good structural choice* which contribute to the overall ductile behaviour and prevent brittle failures or early mechanisms formation include well selected distance between centre of masses and centre of stiffness and centre of bearing capacity, two-way bearing capacity and stiffness, horizontal diaphragm action at the story levels, adequate foundation and tensional stiffness - can be achieved through designer's high knowledge and understandings of earthquake phenomena.

The case is similar as with *good choice of calculation method* which includes structural model and calculation method. Structural model may be simple 2D or 3D models, and calculation method may be simple modal or multimodal analysis. Suggestion given in the standard concerning model choice and calculation choice is very useful and serve as guidance to designer to come to the right decision.

Requirements and rules for *good structural detailing* existed even it recent practice, but now, an important step in Eurocodes was done to improve such practice.

5 CONCLUSIONS

Considering all 'pro et contra' in the EC8 - ENV application one can conclude that such approach resulted with positive effects, although there are also some opinions that it was possible to wait for the EC8 - EN version.

Applying EC8 - ENV version has shown in the large range from design of real structures to the analyses and parametric studies of simple models what changes and problems are present and what should be done when defining National Determined Parameters in National Annexes. Based on present results the fact is that more reinforcing steel and more concrete would be needed what will slightly increase the cost of the structure in comparison to the present one. In the same time design according to EC8 - EN standard will result in more reliable and more safe structure having well balanced bearing capacity and ductility. Designer's time consumed and design cost will increase but in the total cost of the building this may be neglected.

Lot of learning is required to understand in detail all EC8 - EN requirements and application rules. Comparison with the previous provisions has almost no sense because two situations are so different that they are incomparable. Today and tomorrows structures are much more complex than previous, clients' requirements are growing and engineering profession should follow recent scientific development. Close co-operation between architects and structural engineers in the early stage of design may contribute to offer to the client reliable, safe and economic structure.

Set of Eurocodes - standards for structural design cover these needs.

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