Comparison of Eurocode 8 and Turkish Earthquake Code 2007 for Residential RC Buildings in Cyprus

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SUMMARY
The Cyprus Island is located at seismic zone and many destructive earthquakes have hit the island through its history. Currently, the majority of the buildings are low-mid rise concrete framed with non load bearing brick infill walls. Due to political issues two different seismic design codes are currently in use. These are Eurocode 8 and Turkish Earthquake Code 2007. Both codes use different seismic zoning maps with different PGA values. Due to huge difference in given ground shaking values, this research carried out to find out actual loading difference acting to structures. Two case studies carried out for two different cities. The slight difference gained for design base shear values for calculated residential building which is located at the capital city Nicosia even the seismic zoning maps have the PGA value difference of 0.1g. This research shows the fact that, use of Turkish Earthquake Code with current seismic zoning map results dangerous level underestimation of seismic loads in Famagusta region. The complete localised seismic loading comparison is presented.

Keywords: Cyprus, Eurocode 8, TEC 2007

1. INTRODUCTION

Cyprus has had many destructive earthquakes during its history. The latest destructive earthquake hit the island in 1953 (Mw=6.1) and caused 40 fatalities (Civil Defence Organisation, 2010). As seismic design knowledge increases, many different seismic zone maps and design codes have been used in Cyprus. Currently, two different design codes are used in Cyprus due to political issues. These are Eurocode 8 (EC8) and Turkish Earthquake Code 2007 (TEC 2007). Each design code use different seismic zoning maps with different Peak Ground Acceleration values.

Table 1.1 Name of the Design Codes Currently Used in Cyprus

	Turkish Standards (north part of the island)	*Eurocodes (south part of the island)*
Concrete Design Code	TS-500	EC-2
Seismic Design Code	TEC 2007	EC-8

The majority of buildings in Cyprus are low-mid rise residential RC buildings. This study provides a detailed comparison of design codes on residential buildings which are concrete framed with non load bearing brick infill. As the majority of buildings are not taller than 40 metres, the most used method for seismic design is the Equivalent Lateral Force Method. Both EC8 and TEC 2007 define similar simplified method.

Two codes provide their own seismic zoning map with same intensity parameter: PGA. However the intensity values differ between codes and this raises question about design code performance comparison.

2. SEISMIC DESIGN CODES AND CYPRUS

The figure below is the Eurocode 8 Cyprus National Annex provided seismic zoning map of Cyprus. The map and Eurocode 8 is being used since 2007 in the southern part of the island. However it is also possible to use Eurocodes in the northern part of the island but it is not compulsory.

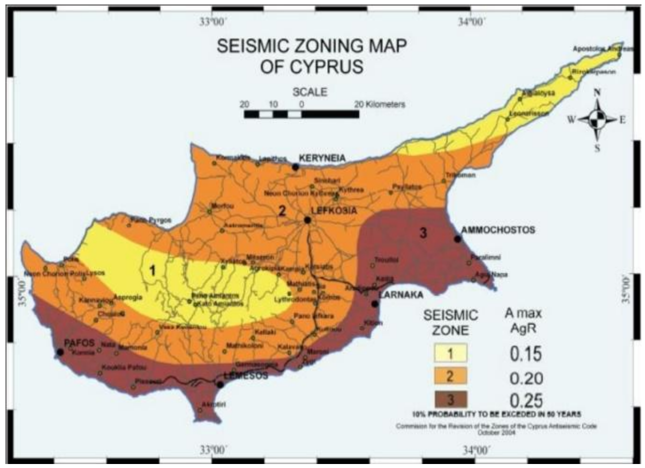

Figure 2.1 Seismic Zoning Map of Cyprus (from Eurocode 8 National Annex CYS EN 1998-1:2004) (Currently used in the southern part of the island)

The Turkish Earthquake Code 2007 is being used in the northern part of the island and the following map (figure 2.1) has been adapted to the code. However the TEC 2007 seismic zoning map is not as up-to-date as the Eurocode 8 map. Also according to the TEC 2007 map, higher ground shaking values can be seen compare to the EC8 map.

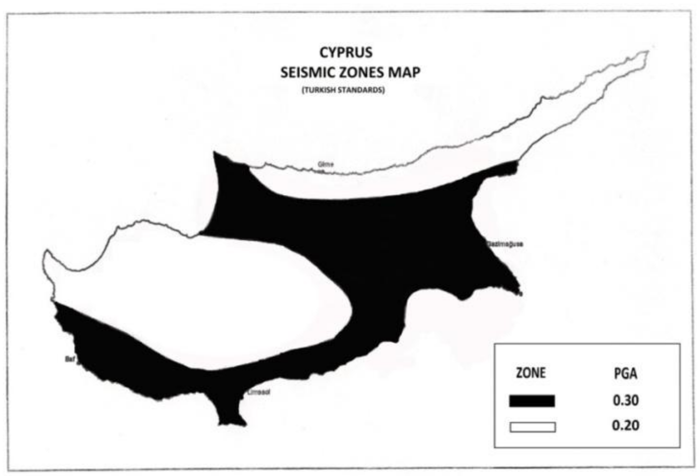

Figure 2.2 Seismic Zoning Map of Cyprus (from Turkish Standards) (Currently used in the northern part of the island)

Ground conditions have a huge effect on behaviour of the structure under lateral loads. Due to that reason several spectrum types provided by design codes for each soil type. Both codes consider the shear wave velocity to determine soil type. But, the Turkish Earthquake Code requires more specific definition of soil profile such as depth. For simplicity, generalised shear wave velocity values have been shown in table 2. Site period differences are covered by both codes but only Eurocode 8 provides soil amplification factors (S) which increases the spectral acceleration during all period range.

According to a recent United Nations` seismic hazard research in Nicosia region (Rogers and Algermissen, 2004), the estimated peak ground acceleration is 0.32g with 10% probability of exceedance in 50 years. This research also considers the contribution of site effects. The found lowest shear wave velocity for Nicosia is 209m/s (Rogers and Algermissen, 2004). However, there is no such up-to-date research on site effects for Famagusta region. The map below (USGS 2012), gives an idea about the general view of shear wave velocity profile for the Cyprus Island.

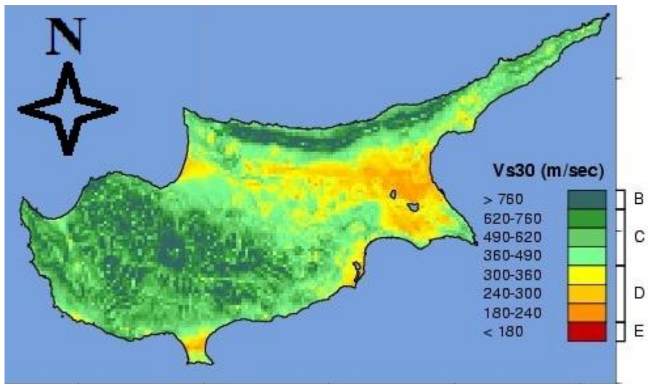

Figure 2.3 Shear Wave Velocity Map of Cyprus (USGS 2012)

As can be seen from the map, the Famagusta region (eastern part of the island), has average soil class D. This reflects to a high amplification of peak ground acceleration. With class D soil type, CYS EC8 suggests 0.34g and TEC 2007 map shows 0.3g for Famagusta city.

Table 2.1 Ground Types Description (EC8 and TEC 2007)

SOIL TYPE		DEFINITION	
EC8	TEC 2007	EC8	TEC 2007
A	Z1	Rock or other rock-like geological formation Vs>800m/s	Very dense sediment, gravel and solid clay Vs<700m/s
B	Z2	Deposits of very dense sand, gravel, or very stiff clay 360m/s < Vs < 800m/s	Dense sediment gravel, very stiff clay 300m/s <Vs< 700m/s
C	Z3	Deep deposits of dense or medium dense sand, gravel or stiff clay 180m/s < Vs < 360m/s	Medium dense sediment and gravel, stiff clay 200m/s <Vs< 300m/s
D	Z4	Deposits of loose-to-medium cohesionless soil Vs < 180m/s	Weak sediment, soft clay with alluvium layer High water table Vs<200m/s
E		A surface of alluvium layer with water table a layer of Type C or D on Rock	
S1	-	A layer of at least 10 m thick soft clays/silts	-
S2	-	Sensitive clays, or any other soil profile not included in types A – E or *S*1	-

Also TEC 2007 requires higher ductility characteristics compare to Eurocode 8. The used material also affects the ductility behavior of the structure and TEC 2007 puts a limit to upper yield strength of the reinforcement steel. It is known that, as the yield strength of steel increases, the ductility characteristics reduces and steel becomes more brittle (Dogangun, 2009). TEC 2007 aims to use ductile material and keep the reduction factor high.

Table 2.2 Used Material Comparison (TEC 2007, EC8, EC2, CYS EC2 NA)

	TURKISH EARTHQUAKE CODE 2007	EUROCODE 8	
DUCTILITY	MEDIUM AND HIGH	MEDIUM	HIGH
Characteristic strength of reinforcement	Fyk ≤ 420MPa	Fyk ≤ 600 (CYS EC2 NA)	Fyk ≤ 600 (CYS EC2 NA)
Characteristic strength of Concrete	Fck ≥ C20/25	Fck ≥ C16/20	Fck ≥ C20/25
Type of the reinforcement	BÇI (220) BÇIIIa (420)	B or C type reinforcement	C type reinforcement
Minimum strain of reinforcement at maximum stress	10%	5% (EC2)	7.5% (EC2)

Table 2.3 Spectrum Parameters (EC8 and TEC 2007)

	Soil Factor		**Beginning of Peak range (seconds)**		**End of Peak range (seconds)**		**Spectral Acceleration Coefficient**	
Ground Type	EC8 (S)	TEC 2007	EC8 (T_B)	TEC 2007 (T_A)	EC8 (T_C)	TEC 2007 (T_B)	EC8	TEC2007
Type A or Z1	1	1	0.15	0.10	0.40	0.30	2.5	2.5
Type B or Z2	1.2	1	0.15	0.15	0.50	0.40	2.5	2.5
Type C or Z3	1.15	1	0.20	0.15	0.60	0.60	2.5	2.5
Type D or Z4	1.35	1	0.20	0.20	0.80	0.90	2.5	2.5
Type E or Z4	1.4		0.15		0.50			
S1 and S2	EC8 requires special studies to provide the corresponding values of *T*B, *T*C and *T*D.							

As can be seen from table 4, soil classification is well distributed in Eurocode 8. But in Turkish Earthquake Code 2007 has limited options in terms of soil type selection. Also Eurocode 8 allows special ground type (S1 and S2) use by deriving site specific period values.

Furthermore, both codes provide different response spectrums with period differences. Also Eurocode 8 defines the soil amplification factors at response spectrum stage. The EC8 supplied seismic zoning map is for rock conditions and soil factors (S) balance the total spectral acceleration. However there is no such soil amplification factor in TEC2007. The TEC 2007 spectrums only vary by the change of soil period.

Table 2.4 Spectrum Ordinates (EC8, TEC2007)

	$T \leq T_B$	$T_B \leq T \leq T_C$	$T \geq T_C$
TEC	$S_e = a_{gR}[1 + 1.5\frac{T}{T_B}]$ $S_d = \frac{a_g}{R_a}[1 + 1.5\frac{T}{T_B}]$	$S_e = 2.5 \cdot a_{gR}$ $S_d = \frac{2.5 \cdot a_g}{R_a}$	$S_e = 2.5 \cdot a_{gR}[\frac{T_C}{T}]^{0.8}$ $S_d = \frac{2.5 a_g}{R_a}[\frac{T_C}{T}]^{0.8}$
EC8	$S_e = a_g \cdot S[1 + \frac{T}{T_B}(\eta 2.5 - 1)]$ $S_d = a_g S[\frac{2}{3} + \frac{T}{T_B}(\frac{2.5}{q} - \frac{2}{3})]$	$S_e = 2.5 \cdot a_g \cdot S \cdot \eta$ $S_d = \frac{2.5}{q} \cdot a_g \cdot S$	$T_C \leq T \leq T_D \rightarrow S_e = 2.5 a_g \cdot S \cdot \eta \cdot [\frac{T_C}{T}]$ $T_C \leq T \leq T_D \rightarrow S_d \begin{cases} = \frac{2.5}{q} a_g \cdot S \cdot [\frac{T_C}{T}] \\ \geq \beta \cdot a_g \end{cases}$ $T_D \leq T \leq 4s \rightarrow S_e = 2.5 a_g \cdot S \cdot \eta \cdot [\frac{T_C T_D}{T^2}]$ $T \geq T_D \rightarrow S_d = \frac{2.5}{q} a_g \cdot S \cdot [\frac{T_C T_D}{T^2}] \geq \beta \cdot a_g$

The fundamental period of the structure can be found by either using dynamic analysis or either using code provided empirical formulas. However with the latest revision of Turkish Earthquake Code, the use of empirical formulas is prohibited and only dynamic analysis is available to find fundamental period of the structure.

Table 2.5 Base Shear Formulas for Design Codes (EC8, TEC2007)

	TEC 2007	EC 8
Base Shear Formula	$V_t = S_d . W/g$	$F_b = S_d . \lambda . W/g$ $\lambda = 0.85$ for Tc<2s

3. CASE STUDY

Two site locations have been chosen for case study (Figure 3) and the same building has been used for the analysis for both locations. Case study 1 building is located in Capital city Nicosia and case study 2 building is located at another big city, Famagusta. These two cities are located at highly seismic regions and seismic maps provide different ground shaking values. TEC 2007 map gives 0.3g for both Nicosia and Famagusta and on the other hand CYS EC8 provided seismic zoning map gives 0.2g for Nicosia and 0.25g for Famagusta (Northern). Both seismic maps have 10% exceedance probability in 50 years.

An ordinary 5 storey apartment building has been chosen for the case study (Figure 4). It is known that the majority of buildings are low to mid rise reinforced concrete moment resisting frame, in both chosen cities. The case study includes the comparison of the inelastic response spectrums, base shear and bending moment values acting to the building by using both seismic design codes.

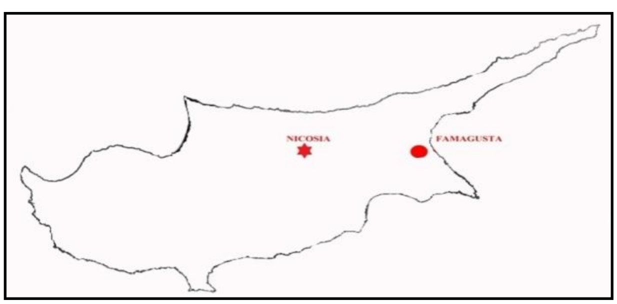

Figure 3.1 Two Different Sites Chosen for Case Study

The figure 3.1 shows the chosen locations for case study. Case study 1 is chosen in Nicosia and case study 2 is chosen in Famagusta. Furthermore the figures below gives the details of chosen case study building in 3 dimensional model (Fig.3.2) and plan (Fig 3.3)

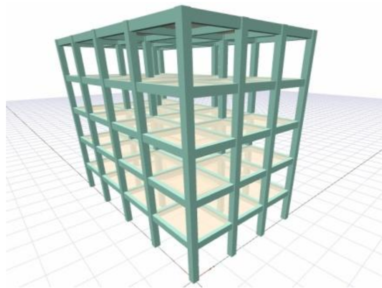

Figure 3.2 3D Model of Building Sample

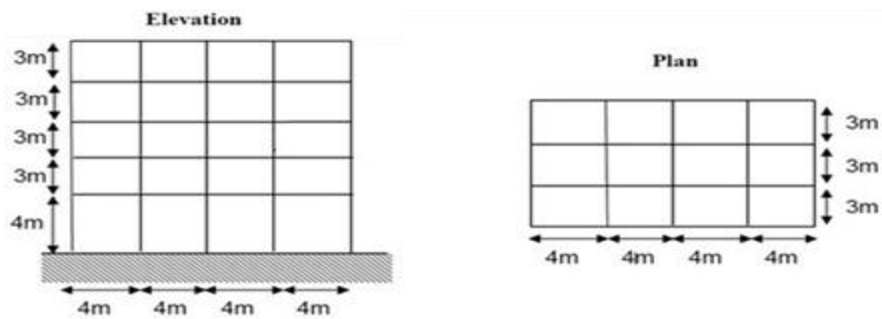

Figure 3.3 Elevation and Floor Plan for 5 Storey Building

Table 3.1 Dimensions of Structural Elements

	Storey: 1, 2, 3	***Storey: 4, 5***
Column	400mm x 400mm	350mm x 350mm
Beam	250mm x 500mm	
Slab Thickness	150mm	

As the imposed load participation factor (n) is same in both codes, the seismic mass is taken a single value for the case study. Traditional hallow bricks used in terms of non load bearing infill partitions.

To avoid any confusion the fundamental period of structure has been calculated by using Rayleigh Formula. SAP2000 software has been used to find displacements of each storey and then the fundamental period determined to be 0.49 seconds.

Base shear calculation is similar in each code. However ductility reduction factors, q (EC8) and R (TEC 2007) can vary and have an effect on the applied base shear. For the case study, high ductile design (DCH) has been chosen for both codes as the TEC 2007 requires DCH Design for Highly Seismic Regions. The ductility reduction factors are listed below;

Table 3.1 Code Provided Ductility Reduction Factors (EC8, TEC2007)

	Ductility Reduction Factor for Concrete DCH MRF
Eurocode 8	q= 5.85
Turkish Earthquake Code 2007	R= 8

4. RESULTS

The inelastic design spectrums generated to visualise the actual acceleration that is taken into account at design stage. It can be seen from the figure 4.1 that similar results are obtained for the Nicosia (Fig 4.1.a) case study even there is 0.1g difference between the maps. The lack of the soil amplification parameters and high ductility behaviour factor requirements of TEC 2007, the inelastic spectra is balanced with EC 8.

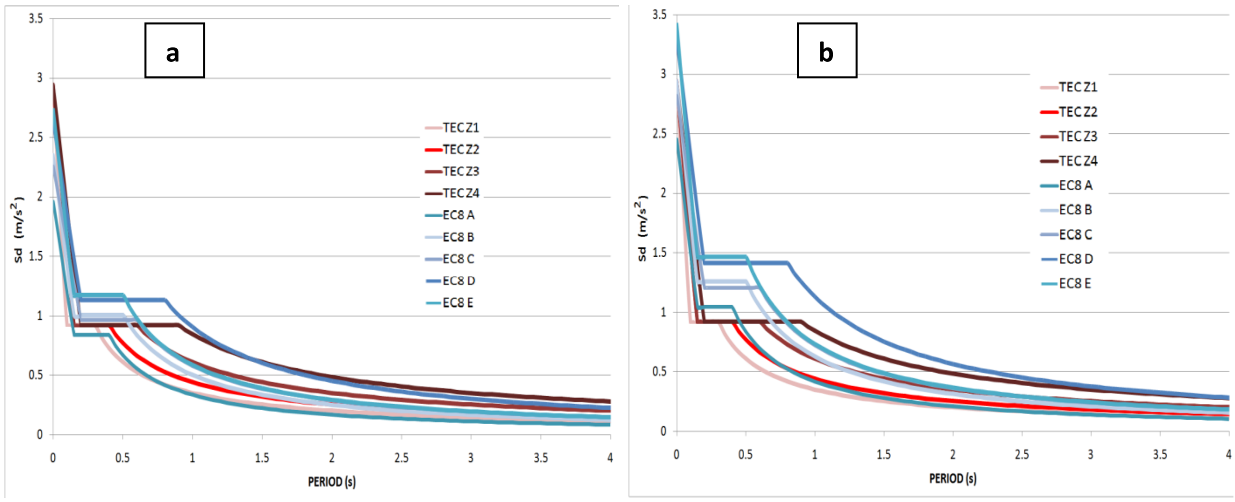

Figure 4.1 Inelastic Design Spectrums for **a**.Nicosia (Left) and **b**.Famagusta (Right) for EC8 and TEC 2007

However the inelastic spectrum for Famagusta, shows up to 60% higher values for EC8. This is due to the PGA difference of 0.05g.

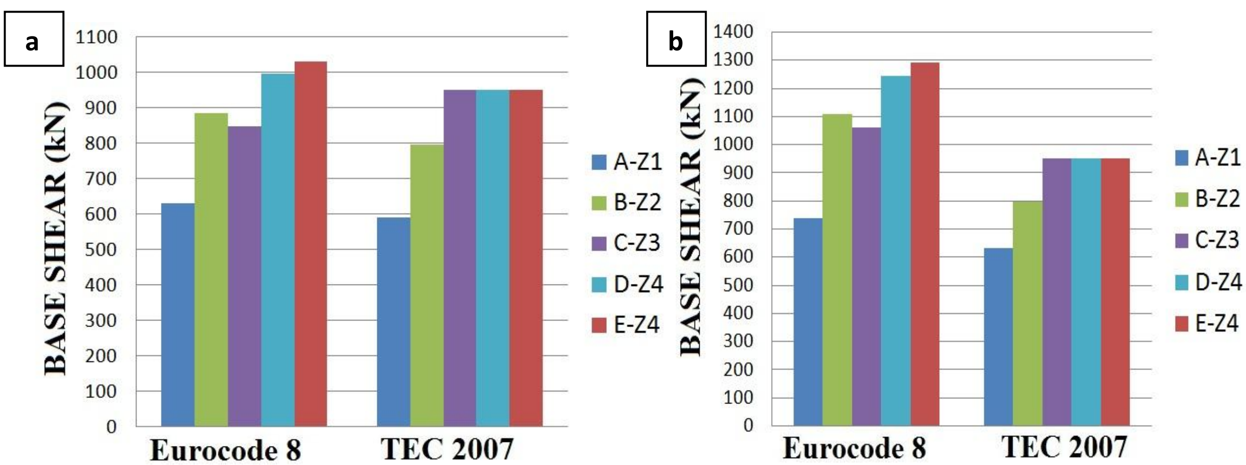

Figure 4.2 Base Shear Values for **a.** Case Study 1 Nicosia (Left) and for **b.** Case Study 2 Famagusta (Right)

The difference in base shear for Nicosia sample is not visible as the difference is not so high. The highest difference in base shear is likely to occur for soft soil conditions and less than 10% difference obtained for the Nicosia soft soil case study. However, more than 30% difference in base shear occurred in the Famagusta case study.

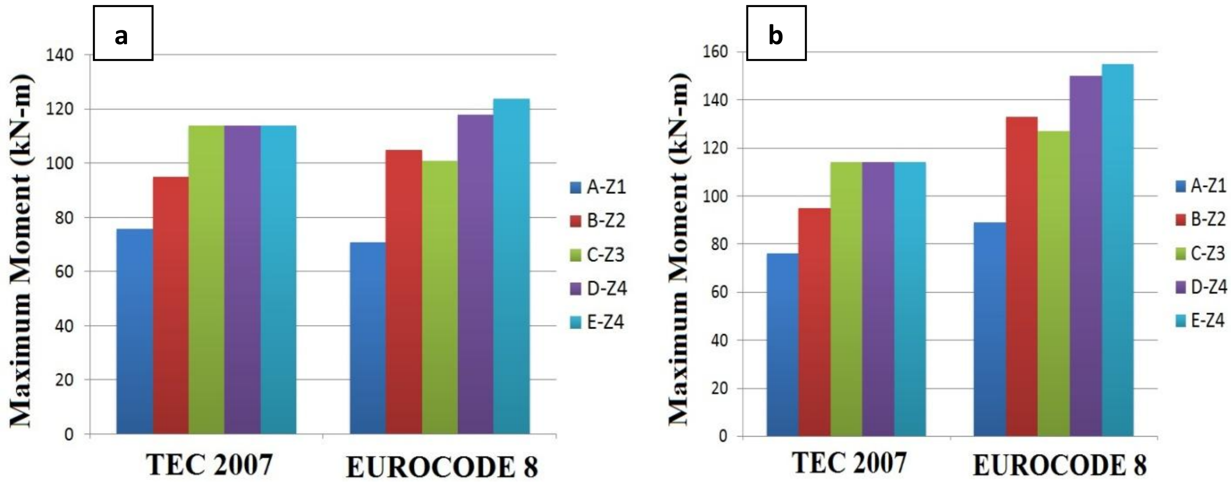

Figure 4.3 Column Moments at Base for **a.** Case Study 1 Nicosia (Left) and for **b.** Case Study 2 Famagusta (Right)

As can be seen from the figure above, the maximum bending moment values act on the ground floor columns. For the Famagusta study the maximum acting moment difference is 41kN which is relatively high value. It should be noted that, for the soft soil conditions in Famagusta, Eurocode 8 results much higher forces compare to the TEC 2007.

5. CONCLUSION

Eurocode is an up-to-date standard and provides seismic zoning map for Rock conditions. The supplied soil factors (S) and different spectrum types can be used to determine the site specific spectrum. This has been enabled by provided soil period and amplification factors. However TEC 2007 provided Seismic Zoning Map specifies the soil amplification within the given ground shaking value and the code only allows the site period change by different spectrum types. For the very soft soil types, EC8 gives much greater base shear values compare to TEC 2007 and this suggests that early judgment of design codes in Cyprus by the provided seismic zoning map is not appropriate.

Five-storey moment resisting RC residential building is used at two different site conditions for the case study and similar results obtained for Nicosia City. However the case study for Famagusta City shows the fact that, using Eurocode 8 results more than 30% base shear difference and reminds the issue of “under designing” the buildings in Famagusta city and generally in the northern part of Cyprus.

Also both codes are widely known as different. For example, TEC2007 provided DCH design requires higher ductility reduction factors, as there is a higher limit to strain capacity of reinforcing steel. High reduction factor of TEC2007 also results the low base shear values.

Finally, the results indicate a significant difference in seismic loading for an ordinary apartment building in Famagusta region. This reminds the fact that, EC 8 provided soil amplification factors resulted in much higher values, even map provided PGA value is small compare to TEC 2007 map. This shows the fact that, soil amplification plays huge fact on the spectral acceleration and TEC 2007 provided Seismic Zoning map for Cyprus should be urgently revised by increasing the map ground shaking values relatively to the site conditions. Alternatively, switching to Eurocodes in the northern part of the island also can be a solution to this issue as the country specific data (National Annexes) already exists for Cyprus.

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