Fundamental Period versus Seismic Damage for Reinforced Concrete Buildings

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SUMMARY:
The reliable evaluation of the fundamental period constitutes an essential step in estimation of seismic response both in seismic design and assessment according to the primary structural dynamic principles. Many empirical formulas attempt to estimate (especially for the design) this important property for the building's seismic behavior as a function of height given the structural typology. In the current research the fundamental period is estimated for typical building types representative of the materials, seismic codes and construction techniques of Southern Europe. They also represent groups of 180945 existing damaged buildings of an observational database created after the Parnitha's - Greece (7-9-1999) near field seismic event. The estimated fundamental periods for RC buildings of different heights and structural types are correlated to several degrees of the recorded damage. The influence of specific parameters on the seismic response and the development of damage are investigated and important conclusions are extracted from the wide database.

Keywords: seismic damage, vibration period, fundamental period, existing buildings, observational database

1. INTRODUCTION

The reliable and sufficient estimation of the natural period of vibration could play an essential role in the understanding of the global demands on the structure under an earthquake. Its evaluation is an essential step in estimating the seismic response both in seismic design and assessment. This important property for the building's seismic behavior is mainly dependent on mass, stiffness and strength and consequently on all the factors which affect them (dimensions in height and plan, morphology, irregularities, section properties, stiffness, cracking, etc.). Many empirical formulas attempt to estimate the fundamental period and they have been included in seismic codes. These formulas have been usually derived from empirical data through regression analysis of the measured fundamental period of existing buildings subjected to seismic actions. Despite the fact that several parameters affect the period of vibration (soil conditions, seismicity, construction practices) the empirical formulas are given as a function of height given the structural typology as its role is considered the most important (Goel & Chopra 1997, 1998, Crowley 2003, Crowley & Pinho 2004).

In the current research the fundamental period of vibration is estimated for several reinforced concrete building classes according to existing empirical formulas. The typical building types are representative of the materials, the seismic codes and the construction techniques of Southern Europe. The level of seismic design and detailing for RC buildings in Greece, could generally be discriminated in four subclasses (without, low, moderate and high seismic code). They also represent groups of 180945 existing damaged buildings in several degree, type and extent of an observational database. The damage database addresses to 24% of the total local number of buildings and it has been created after the elaboration of the results from post - earthquake surveys carried out after the occurrence of the Parnitha's - Greece (7-9-1999) near field seismic event in an extended urban region of Attica (Eleftheriadou 2009, Eleftheriadou & Karabinis 2011, 2012a, 2012b). The referred earthquake is considered the worst natural disaster reported in the modern history of Greece regarding the economic loss. The estimated fundamental periods for existing reinforced concrete buildings of several heights (considered as "low"-"middle"-"high" regarding height in Greece and generally in South Europe) and structural types (moment resisting frames - MRF, dual system of shear-wall- SW, with regular infills or without infill panels on the ground floor - *pilotis*) are correlated to the different degrees of the recorded damage. The role of several parameters influence on the seismic response and the development of damage are investigated and important conclusions are extracted from the wide database. The seismic behavior of the structures during an earthquake represents an experiment in a physical scale (1:1) and constitutes the most objective examination of the sufficiency of seismic codes and construction techniques.

2. FUNDAMENTAL PERIOD FOR REINFORCED CONCRETE BUILDINGS

2.1. Moment Resisting Frames (MRF)

The period - height expression for moment resisting frames in the Eurocode 8, design for earthquake resistance (CEN 2004), has the form of Eq. (2.1). The last has theoretically derived from the Rayleigh's method by assuming that the equivalent static lateral forces are linearly distributed over the height of the building and the base shear force is assumed to be proportional to $1/T^{2/3}$. The height is expressed in metres.

$$T = 0.075H^{0.75} \text{ (H in metres)} \tag{2.1}$$

It is important to clarify that the structural types of RC buildings in Southern Europe differ from those in USA due to the fact that the first usually have stiff infill panels (brick masonry) with an influence in building's total stiffness and hence to its natural period of vibration.

2.2. Shear Walls (SW)

The fundamental period of shear wall buildings is usually evaluated with good approximation as the period of an equivalent cantilever. In reinforced concrete shear walls buildings both the lateral load resistance and the lateral stiffness is mainly provided by shear walls. Taking into consideration that many European reinforced concrete buildings are constructed with stiff masonry infill panels which are often not isolated from the RC frame, the period of vibration has probably been overestimated by the designers and hence the forces have subsequently been underestimated. The period – height formula of Eurocode 8 (CEN 2004) for structures with concrete or masonry shear walls, measuring height H from base in metres, is presented in Eq. (2.2):

$$T = 0.05H^{0.75} \text{ (H in metres)} \tag{2.2}$$

There are many experimental and semi - experimental formulas for estimating the fundamental period T_1 derived especially from ambient vibration measurements of non damaged buildings. In the current research simplified experimental expressions (Karabinis 1986) are used for the evaluation of the fundamental period of typical Greek RC buildings with several heights. The evaluated period of vibrations are afterwards correlated with the spectral accelerations of the 7th of September 1999 Parnitha's earthquake. For this purpose, both the mean period of T_m (50% reliability) and the characteristic period T_R (95% reliability) value of the fundamental period have been estimated regarding RC buildings with regular infills (uniform stiffness / n – normal) and with ground level without infill panels (p – *pilotis*). The following experimental formulas refer to typical buildings in Southern Europe and they are used in the estimation of the above mentioned fundamental periods:

$$T_{m,n} = 0.006H + 0.164 \text{ (sec), } [6 \leq H \leq 21\text{m}] \tag{2.3}$$

$$T_{R,n} = 0.006H + 0.073 \text{ (sec), } [6 \leq H \leq 21\text{m}] \tag{2.4}$$

$$T_{m,p} = 0.011H + 0.107 \text{ (sec)}, \quad [9 \le H \le 21\text{m}] \tag{2.5}$$

$$T_{R,p} = 0.011H + 0.048 \text{ (sec)}, \quad [9 \le H \le 21\text{m}] \tag{2.6}$$

Assuming that a two - storey building is considered of type «a» (“low” height), a four - storey of type «b» (“middle” height in Greece) and a seven - storey of type «c» (“high” height in Greece) the fundamental period T_1 has been estimated based on the upper expressions (Table 2.1). Furthermore, the value of the natural period has also been estimated according to the EC8 provisions which reflect the design and construction practices of the European building stock. For this purpose, the following typical building types have been used: a) Reinforced concrete Moment Resisting Frames and Shear Walls buildings with “low” height (type «a»); b) Reinforced concrete Moment Resisting Frames and Shear Walls buildings with “middle” height (type «b»); c) Reinforced concrete Moment Resisting Frames and Shear Walls buildings with “high” height (type «c»). The estimated values are demonstrated in Table 2.1 along with the previously mentioned values for each building type and floor level.

The stations with the recorded accelerograms in several regions of Attica and the epicentre of the 7^{th}-9-1999 earthquake are presented in Fig. 2.1 (ITSAK-AUTH, 2004). The elastic response acceleration spectra of seismic ground motions are presented in Fig. 2.2. In the same figure are also presented the previously evaluated fundamental periods for “low”, “medium” and “high” height buildings along with the elastic design earthquake spectrum of the first (1959) and the contemporary (2003) Greek Seismic Code. The percentage of damaged buildings in each height level represents the 29.78% (type «a»), 8.58% (type «b») and 1.65% (type «c») of the total number of buildings (164135) in the studied area, as it has resulted from the damage data analysis (Table 4.1).

3. DAMAGE DATA DERIVED FROM PARNITHA’S EARTHQUAKE (7-9-1999)

The vulnerability assessment of the current paper is based on the created damage database derived from post - earthquake surveys carried out after the September 7, 1999 Athens earthquake [*M*w= 5.9],

Table 2.1. Estimated fundamental periods

Number of floors	$T_{1,n}$ (sec) (Karabinis 1986)	$T_{1,p}$ (sec) (Karabinis 1986)	$T_{1,MRF}$ (sec) (EC8)	$T_{1,SW}$ (sec) (EC8)
2	0.11 ÷ 0.20	-	0.29	0.19
4	0.15 ÷ 0.24	0.18 ÷ 0.24	0.48	0.32
7	0.20 ÷ 0.29	0.28 ÷ 0.34	0.74	0.49

Figure 2.1. Attica stations with the recorded accelerograms and the epicentre of Parnitha’s earthquake.

which is the first near field moderate - to - strong earthquake in the historical centre. It is the worst natural disaster reported in the modern history of Greece regarding the economic loss. Despite the fact that damage displayed significant differentiation from place to place, the most serious damages were observed at the northern suburbs which are closer to the epicentral area. The created damage database consists of 180945 existing damaged buildings in several degree, type and extent referring to the extended urban region of Attica. Comparing the total number of damaged buildings (180945) to the total number of buildings (753078) in the affected area (information selected from the National Statistics Agency of Greece according to the year 2000-1 statistical census) it is concluded that the dataset addresses to 24% of the total number of buildings in the wide region of Attica. The observational dataset has been developed after the first and/or the second round of inspections, which had been conducted in several regions of Athens, based on instructions provided by the Earthquake Planning and Protection Organization (EPPO) of Greece. However, the information referred only to qualitative characterizations of damage level by the inspection crews, as follows: a) *Green*: building with no or light damage, or building whose earthquake resistance has not been reduced, b) *Yellow*: building with moderate damage and reduced earthquake resistance, c) *Red*: building with very heavy damage or partial collapse, and d) *Collapse*: building that has collapsed (Fig.3.1) or is under demolition (Eleftheriadou 2009, Eleftheriadou & Karabinis 2011). A damage scale for the measurable recording, beyond the pre - mentioned qualitative characterization of seismic damage in Greek post - earthquake surveys, was presented in a previous research (Eleftheriadou & Karabinis 2010) wherein the performance levels are defined according to the physical description of the seismic damage and, as well, in terms of structural and economic damage index.

It is known that the vulnerability assessment requires a classification system to characterize the earthquake - exposed building stock and correlate it with the developed damage. In the current research, apart from the characteristics that affect the seismic response of a structure, the classification system is also dependent on the information collected from the post earthquake surveys. In the statistical database, the structural systems are divided into four groups: **1)** Reinforced concrete buildings (RC) with moment resisting frames or dual system (frame + shear walls); **2)** Mixed buildings (MIX) with vertical bearing structure constituted by elements of both masonry and reinforced

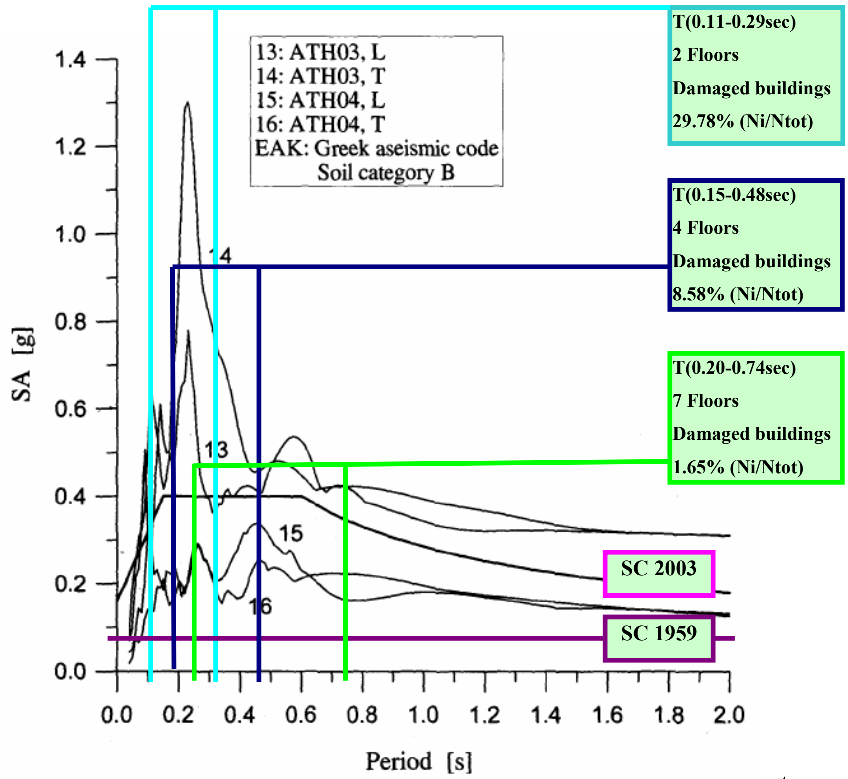

Figure 2.2. Elastic response spectra of the accelerograms ATHS03 & ATH04 and the 1st (Greek Seismic Code of 1959) along with the recent design seismic spectrum (Greek Seismic Code 2003).

Figure 3.1. Damage index: "Collapse" of a building after the 7-9-1999 Parnitha's earthquake (Karabinis, 1999).

concrete; **3)** Masonry buildings (MAS) with vertical elements of masonry and horizontal elements of reinforced concrete, metal or wood and **4)** Other buildings (OTH), which typically include any buildings not belonging to the previous groups. The reinforced concrete structures are further classified based on the different seismic code periods at the time of their design: RC1: without a seismic code or during the period 1959-1985 (pure level of seismic resistance); RC2: during the period 1985-1995 (medium level of seismic resistance); and RC3 after 1995 (high level of seismic resistance). The mixed structures are further classified into MIX1, MIX2, and MIX3 using identical criteria. The threshold of each period is identified with a change in Greek Seismic Codes. The level of seismic design and detailing for RC buildings in Greece, could generally be discriminated in four subclasses, as follows: 1) *No Seismic Code (before 1959):* with very low level or no seismic design and poor quality of detailing; 2) *Low Seismic Code (1959-1985: the 1st Greek Seismic Code of 1959* corresponding approximately to pre - 1980s codes in Southern Europe*)* with low level of seismic design; 3) *Moderate Seismic Code (1985-1995: the 1st Greek Seismic Code of 1959 with the 1985 Supplement Clauses* corresponding approximately to post - 1980s codes in Southern Europe*)*: with medium level of seismic design and reasonable seismic detailing; 4) *High Seismic Code (after 1995: NGSC2003,* similar to Eurocode 8*)*: with adequate level of seismic design according to the new generation of seismic codes and ductile seismic detailing of R/C members.

4. CORRELATION OF FUNDAMENTAL PERIOD WITH THE RECORDED DAMAGE – CONCLUSIONS

Despite the fact that many buildings have been disregarded from the database due to the lack of information, such as the structural type or the date of construction, the presented here building stock still remains a wide statistical database. After conducting statistical elaboration and analysis of the database, the correlation of damage level with the number of floors is attainable for 164135 buildings, as it is presented in Table 4.1. Moreover, the estimated fundamental periods for existing reinforced concrete buildings of several heights and structural types are correlated to the different degrees of the damage. For 30149 buildings regarding RC1 structural type, the correlation between the evaluated fundamental periods and the degree of damage along with the number of floors is presented in Table 4.2. In addition, the correlation between the above estimated period of vibration with the damage level and the number of floors is presented in Table 4.3 regarding 4501 buildings of RC2 structural type. Similarly, the correlation between the fundamental periods with the damage level and the number of floors is presented in Table 4.4 for 1591 buildings regarding RC3 structural type. The estimated fundamental periods refer to several heights ("low"–"middle"–"high") of existing reinforced concrete buildings based on the aforementioned equations.

The damage level of typical reinforced concrete (RC) structures with seismic damages is correlated with the estimated fundamental period T_1 after Parnitha's earthquake (7-9-1999). The advantage of the research is that the empirical vulnerability assessment has been extracted from a wide database which represents a real experiment in a physical scale 1:1. From the notice of the estimated fundamental periods according to the presented formulas for reinforced concrete buildings it comes up that the period T_m (50% reliability) value ($T_{1,m} = 0.20$) of "low" height RC buildings with regular infills (n – normal) (Karabinis 1986) is similar to the one (0.19) evaluated for seismic design according to EC8 regarding the "low" height RC shear wall buildings T. The respective value ($T_{1,R} = 0.11$) of the period T_R (95% reliability) is lower, whereas for "low" rise RC frame buildings of EC8 design provisions the period is greater (0.29). In addition, both the characteristic ($T_{1,R} = 0.15$ & $T_{1,R} = 0.18$) and mean period ($T_{1,m} = 0.24$) values (Karabinis 1986) are almost the same for "middle" height RC buildings with masonry infills in ground (n – normal) and without infill panels (p – *pilotis*). Regarding the EC8 "middle" height RC buildings the value (0.32) is close for shear wall buildings and it presents a disparity for moment resisting frames. The occasion is also the same regarding the "high" rise RC buildings: similar characteristic ($T_{1,R} = 0.20$ & $T_{1,R} = 0.28$) and mean period ($T_{1,m} = 0.29$ & $T_{1,m} = 0.34$) values for RC buildings with regular infills (n – normal) and without infill panels (p – *pilotis*) (Karabinis 1986), a relatively close period value (0.49) regarding the corresponding EC8 shear wall buildings and a great difference (0.74) regarding the building type of RC moment resisting frames.

Table 4.1. Correlation of the estimated fundamental periods with the level of the recorded damage after Parnitha's (7-9-1999) earthquake and the number of floors for 164135 buildings

Number of Floors	T_1 (sec) (Karabinis 1986)	T_1 (sec) (EC8)	Damage Level: Light (Green)	Damage Level: Moderate (Yellow)	Damage Level: Extensive (Red)	Damage Level: Collapse (Black)	Total number of buildings
1	$T_{1,R} = 0.11$ $T_{1,m} = 0.20$ (regular infills)	0.19(SW) 0.29(MRF)	(22 496)	(16 913)	(2 778)	(1 208)	(43 395)
			13.71%	10.30%	1.69%	0.74%	26.44% (N_i/N_{tot})
2			(28 952)	(17 723)	(1 567)	(644)	(48 886)
			17.64%	10.80%	0.95%	0.39%	29.78% (N_i/N_{tot})
3	$T_{1,R} = 0.15$ $T_{1,m} = 0.24$ (regular infills) $T_{1,R} = 0.18$ $T_{1,m} = 0.24$ ("*pilotis*")	0.32 (SW) 0.48(MRF)	(21 230)	(12 014)	(728)	(266)	(34 238)
			12.93%	7.32%	0.44%	0.16%	20.86% (N_i/N_{tot})
4			(10 084)	(3 795)	(158)	(48)	(14 085)
			6.14%	2.31%	0.10%	0.03%	8.58% (N_i/N_{tot})
5			(9 315)	(1 826)	(47)	(18)	(11 206)
			5.68%	1.11%	0.03%	0.01%	6.83% (N_i/N_{tot})
6			(7 120)	(1 015)	(20)	(2)	(8 157)
			4.34%	0.62%	0.01%	0.00%	4.97% (N_i/N_{tot})
7	$T_{1,R} = 0.20$ $T_{1,m} = 0.29$ (regular infills) $T_{1,R} = 0.28$ $T_{1,m} = 0.34$ ("*pilotis*")	0.49(SW) 0.74(MRF)	(2 270)	(427)	(9)	(0)	(2 706)
			1.38%	0.26%	0.01%	0.00%	1.65% (N_i/N_{tot})
≥8			(1 187)	(256)	(17)	(2)	(1 462)
			0.72%	0.16%	0.01%	0.00%	0.89% (N_i/N_{tot})
Total number of buildings			(102 694)	(53 969)	(5 324)	(2 188)	(164 135) (N_{tot})
			62.54%	32.88%	3.24%	1.33%	100.00%

Table 4.2. Correlation of the estimated fundamental period T_1 with the level of the recorded damage for 30149 buildings of RC1 structural type with low level of seismic design

Number of Floors	T_1 (sec) (Karabinis 1986)	T_1 (sec) (EC8)	Damage Level for RC1 Structural Type (moment resisting frames or frame-wall - earlier than 1985)				
			Light (Green)	Moderate (Yellow)	Extensive (Red)	Collapse (Black)	Total number of buildings
1	$T_{1,R} = 0.11$ $T_{1,m} = 0.20$ (regular infills)	0.19(SW) 0.29(MRF)	(1 017)	(1 948)	(110)	(52)	(3 127)
			3.37%	6.46%	0.36%	0.17%	10.37% (N_i/N_{tot})
2			(2 699)	(5 771)	(252)	(133)	(8 855)
			8.95%	19.14%	0.84%	0.44%	29.37% (N_i/N_{tot})
3	$T_{1,R} = 0.15$ $T_{1,m} = 0.24$ (regular infills)	0.32 (SW) 0.48(MRF)	(2 745)	(6 248)	(227)	(94)	(9 314)
			9.10%	20.73%	0.75%	0.31%	30.89% (N_i/N_{tot})
4			(1 450)	(2 380)	(59)	(15)	(3 904)
			4.81%	7.89%	0.20%	0.05%	12.95% (N_i/N_{tot})
5	$T_{1,R} = 0.18$ $T_{1,m} = 0.24$ ("*pilotis*")		(1 044)	(1 196)	(15)	(7)	(2 262)
			3.46%	3.97%	0.05%	0.02%	7.50% (N_i/N_{tot})
6			(910)	(718)	(10)	(1)	(1 639)
			3.02%	2.38%	0.03%	0.00%	5.44% (N_i/N_{tot})
7	$T_{1,R} = 0.20$ $T_{1,m} = 0.29$ (regular infills)	0.49(SW) 0.74(MRF)	(356)	(309)	(3)	(0)	(668)
			1.18%	1.02%	0.01%	0.00%	2.22% (N_i/N_{tot})
≥8	$T_{1,R} = 0.28$ $T_{1,m} = 0.34$ ("*pilotis*")		(186)	(190)	(3)	(1)	(380)
			0.62%	0.63%	0.01%	0.00%	1.26% (N_i/N_{tot})
Total number of buildings			(10 407)	(18 760)	(679)	(303)	(30 149) (N_{tot})
			34.52%	62.22%	2.25%	1.01%	100.00%

Table 4.3. Correlation of the estimated fundamental period T_1 with the level of the recorded damage for 4501 buildings of RC2 structural type with medium level of seismic design

Number of Floors	T_1 (sec) (Karabinis 1986)	T_1 (sec) (EC8)	Damage Level for RC2 Structural Type (moment resisting frames or frame-wall – between 1985-1995)				
			Light (Green)	Moderate (Yellow)	Extensive (Red)	Collapse (Black)	Total number of buildings
1	$T_{1,R} = 0.11$ $T_{1,m} = 0.20$ (regular infills)	0.19(SW) 0.29(MRF)	(146)	(256)	(5)	(6)	(413)
			3.24%	5.69%	0.11%	0.13%	9.18%(N_i/N_{tot})
2			(523)	(1 078)	(43)	(30)	(1 674)
			11.62%	23.95%	0.95%	0.67%	37.19%(N_i/N_{tot})
3	$T_{1,R} = 0.15$ $T_{1,m} = 0.24$ (regular infills)	0.32 (SW) 0.48(MRF)	(408)	(800)	(37)	(12)	(1 257)
			9.06%	17.77%	0.82%	0.27%	27.93%(N_i/N_{tot})
4			(203)	(305)	(6)	(1)	(515)
			4.51%	6.78%	0.13%	0.02%	11.44%(N_i/N_{tot})
5	$T_{1,R} = 0.18$ $T_{1,m} = 0.24$ ("*pilotis*")		(181)	(210)	(5)	(2)	(398)
			4.02%	4.67%	0.11%	0.04%	8.84%(N_i/N_{tot})
6			(88)	(67)	(2)	(0)	(157)
			1.96%	1.49%	0.04%	0.00%	3.49%(N_i/N_{tot})
7	$T_{1,R} = 0.20$ $T_{1,m} = 0.29$ (regular infills)	0.49(SW) 0.74(MRF)	(22)	(28)	(1)	(0)	(51)
			0.49%	0.62%	0.02%	0.00%	1.13%(N_i/N_{tot})
≥8	$T_{1,R} = 0.28$ $T_{1,m} = 0.34$ ("*pilotis*")		(26)	(9)	(1)	(0)	(36)
			0.58%	0.20%	0.02%	0.00%	0.80%(N_i/N_{tot})
Total number of buildings			(1 597)	(2 753)	(100)	(51)	4 501(N_{tot})
			35.24%	61.16%	2.22%	1.13%	100.00%

A correlation analysis is fulfilled between the elastic response acceleration spectra of ground motions after Parnitha's earthquake and the evaluated fundamental periods for "low", "medium" and "high" rise buildings along with the elastic design earthquake spectrum of the first (1959) and the contemporary (2003) Greek Seismic Code. It is concluded that peak ground accelerations of the 7th of September Parnitha's earthquake in most records were between the lower and the upper bound of the evaluated according to experimental values of fundamental period for similar buildings (Karabinis 1986) for all (considered as "low" – "middle" – "high") RC building types with regular infills (n – normal) and with ground level without infill panels (p – *pilotis*). A disparity is noticed for EC8

Table 4.4. Correlation of the estimated fundamental periods with the level of the recorded damage for 1591 buildings of RC3 structural type with high level of seismic design

Number of Floors	T_1 (sec) (Karabinis 1986)	T_1 (sec) (EC8)	Damage Level for RC3 Structural Type (moment resisting frames or frame-wall - after 1995)				
			Light (Green)	**Moderate (Yellow)**	**Extensive (Red)**	**Collapse (Black)**	**Total number of buildings**
1	$T_{1,R} = 0.11$ $T_{1,m} = 0.20$ (regular infills)	0.19(SW) 0.29(MRF)	(57)	(101)	(3)	(2)	(163)
			3.58%	6.35%	0.19%	0.13%	10.25%(N_i/N_{tot})
2			(194)	(364)	(10)	(9)	(577)
			12.19%	22.88%	0.63%	0.57%	36.27%(N_i/N_{tot})
3	$T_{1,R} = 0.15$ $T_{1,m} = 0.24$ (regular infills)	0.32 (SW) 0.48(MRF)	(127)	(206)	(15)	(3)	(351)
			7.98%	12.95%	0.94%	0.19%	22.06%(N_i/N_{tot})
4			(66)	(69)	(3)	(2)	(140)
			4.15%	4.34%	0.19%	0.13%	8.80%(N_i/N_{tot})
5	$T_{1,R} = 0.18$ $T_{1,m} = 0.24$ (“*pilotis*”)		(99)	(81)	(5)	(0)	(185)
			6.22%	5.09%	0.31%	0.00%	11.63%(N_i/N_{tot})
6			(57)	(47)	(0)	(0)	(104)
			3.58%	2.95%	0.00%	0.00%	6.54%(N_i/N_{tot})
7	$T_{1,R} = 0.20$ $T_{1,m} = 0.29$ (regular infills)	0.49(SW) 0.74(MRF)	(25)	(27)	(0)	(0)	(52)
			1.57%	1.70%	0.00%	0.00%	3.27%(N_i/N_{tot})
≥8	$T_{1,R} = 0.28$ $T_{1,m} = 0.34$ (“*pilotis*”)		(14)	(5)	(0)	(0)	(19)
			0.88%	0.31%	0.00%	0.00%	1.19%(N_i/N_{tot})
Total number of buildings			(639)	(900)	(36)	(16)	(1 591)
			40.16%	56.57%	2.26%	1.01%	100.00%

“high” height evaluated fundamental period regarding the referring earthquake. Noticeable is the difference between the seismic demand of the seismic elastic design spectrum of the first (1959), the contemporary (2003) Greek Seismic Code and the values of peak ground accelerations from Parnitha’s earthquake records.

From the analysis results it occurs that the majority of buildings that developed several degree, type and extent of damage belong to “low” height buildings with estimated period values close to the peak ground accelerations of the Athens earthquake ground motions. The last conclusion is connected to the fact that these buildings belong to the meizoseismal area of the northern suburbs close to the epicentral area (e.g. Ano Liosia, Aharnes, Fyli, Menidi, Ilion, Filadelpheia, Kamatero, Zefyri) where the most serious damages were observed. The aspect that the causes of the developed damages are owed to a single parameter is considered oversimplified. In general, damage displayed significant differentiation from place to place, as well as a peculiar geographic distribution. Generally, the unlike damage distribution of the 1999 Parnitha’s earthquake reflected the destructive combination of two factors: the source directivity and the site effect (Roumelioti *et al.* 2004). Based on geological, tectonic and morphological characteristics of the affected area and on the elaboration of damage recordings for intensity evaluation, it has been suggested that intensity distribution was the result of the combination of a number of parameters. Both topography and local soil conditions significantly affected the spatial variability of seismic motion.

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