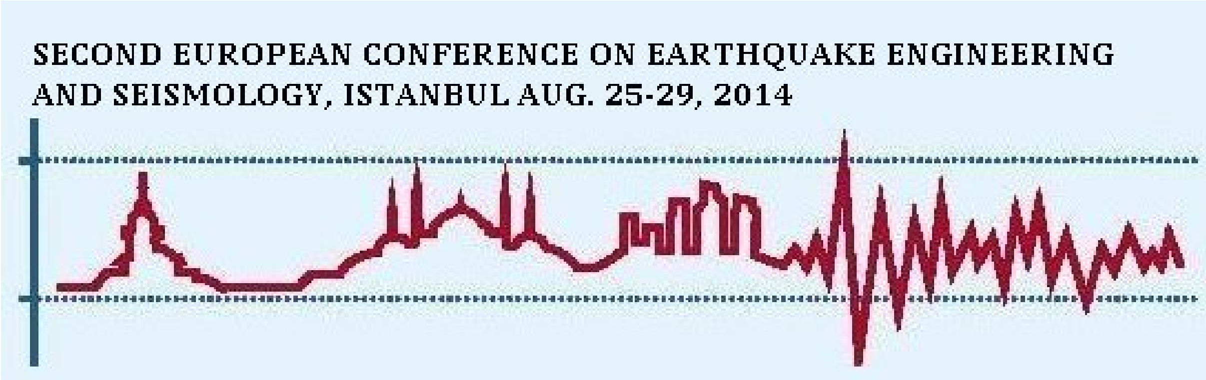

EARTHQUAKE DESIGN OF BUILDINGS WITH LARGE LIGHTLY REINFORCED CONCRETE WALLS

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ABSTRACT

Eurocode 8 part1 (CEN, 2004) includes some specific design provisions for buildings with large lightly reinforced concrete walls, which is an alternative way of design compared to the traditional design method with shear walls detailed to dissipate energy through hysteresis in plastic hinges at their base. This work attempts to quantify the effect of rocking of the foundations in reducing the forces acting on the vertical bearing elements in case of buildings that comply to the criteria of Eurocode 8 so that they may be designed as structures with large lightly reinforced concrete walls. A typical rectangular layout was analysed with 3, 4 and 5 storeys and for three different ground types, B, C and D. Isolated foundations were chosen for all vertical elements, so as to enable rocking of the walls. The results are discussed.

INTRODUCTION

Reinforced concrete buildings with large structural walls have proved to behave well in seismic events, even if the walls were designed only for gravity and not for lateral loads, with low reinforcement ratios and inadequate detailing according to modern design concepts. Typical examples of earthquakes in which similar buildings behaved well are the earthquakes of Chile in 1960 and 1985, Skopje in 1963, Caracas in 1967 and San Fernando in 1971 (Greifenhagen, 2006 and Fintel, 1995). The presence of large shear walls has guaranteed to numerous similar buildings good seismic performance and minor damages. Compared to frame-type structures, buildings with shear walls lead to less interstory drifts and distortions, and therefore less damage of both non-structural and structural elements (e.g. frame joints). Large shear walls also prevent undesirable seismic behaviour as the occurrence of soft story mechanism. Systems including large lightly reinforced concrete walls are designed to sustain seismic demand not by dissipating seismic energy through hysteresis in plastic hinges but by converting part of it into potential energy due to upward displacement of masses and by returning another part to the ground by radiation from their foundation (Fardis, 2009).

Eurocode 8 part1 (CEN, 2004) includes some specific design provisions for buildings with large lightly reinforced concrete walls based on the experience of past earthquakes, on laboratory tests (Bisch and Coin, 1998a, 1998b), as well as through the application of similar provisions in the seismic zone of southern France.

This work attempts to quantify the effect of rocking of the foundations in reducing the forces acting on the vertical bearing elements, namely the shear walls, due to soil-upper structure interaction in case of a building that may be designed as a structure with large lightly reinforced concrete walls according to the provisions of Eurocode 8.

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CHARACTERISTICS OF THE MODELLED BUILDINGS

Buildings with a typical rectangular layout and large lightly reinforced concrete walls were analysed (Figure 1, Kementzetzidis, 2014). Similar structural elements had all the same cross section dimensions, defined by the most unfavourably stressed element, i.e. columns 30/30 (corner) and 55/55 (middle), shear walls 30/500 and beams30/55, all dimensions in cm. Different number of stories, 3 to 5 and three different ground categories, B, C and D with characteristic values suggested by Eurocode 8 part1 (CEN, 2004) were examined. According to Eurocode 8 the different ground types are classified in relation to the value of the average shear wave propagation velocity $v_{s,30}$ or the value of the blowcount N_{SPT} (Standard Penetration Test). The respective values assumed in this work are shown in Table 1. The angle of shearing resistance for the different types of soil considered were determined in relation to the value N_{SPT} as well as the vertical effective stress (it was assumed σ_v’ = 250 kPa at a depth of 15 m) . Poisson’s ratio of the foundation medium, ν, was assumed 0.30 in all cases. Mass density of foundation medium, ρ, was assumed equal to 1.3 t/m^3. The average shear modulus of the foundation medium at small strain, G_{max}, was calculated as $G = \rho\ v_s^2$ (EN 1998-5, 2004) and its values are shown in Table 1. The reduced shear modulus $G_{red.,}$ owing to the strain levels induced by the design earthquake was calculated according to the respective average reduction factors provided by Eurocode 1998-5:2004 (Table 1). It is noted that the reduction in damping was not considered since its influence is not explicitly taken into account in the formulas included in ASCE (1999, 2006) which were used to calculate the spring characteristics. Non-cohesive soil was assumed.

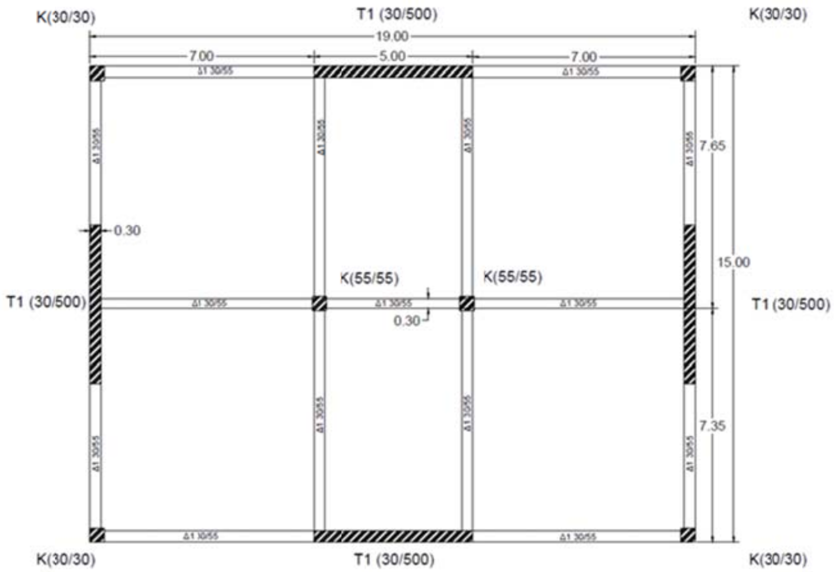

Figure 1. Typical layout of the models analysed

For each case study (number of stories and soil category) two models were examined: one with fixed vertical elements at their base, and one with springs at their base in all the degrees of freedom, so as to simulate translation, rocking and torsion effects. The characteristics of the springs were calculated according to ASCE (1999, 2006) in relation to the dimensions of the foundations, the embedment effect, and the soil characteristics in order to depict the soil-superstructure interaction and its effect in the seismic behaviour of the buildings. Isolated foundations were chosen for all vertical elements (with assumed height of effective embedment 1 m.) so that the effect of rocking of the walls is of significance (Antonaki 2012). In the cases considered, the structural elements had all the same cross section dimensions, defined by the most unfavourably stressed element. The dimensions of the footings were determined as the minimum required for all load combinations, according to the prescriptive method (Eurocode 7 part1, 2004c), assuming a value of uniaxial compressive strength (Figure 2). A common aspect ratio (length/width=12) was assumed in order to enable comparison of results. The bearing resistance for the foundations was calculated according to Vesic (1975).

Table 1. Soil characteristics assumed

Ground type	N_{SPT} (blows/30cm)	φ (angle of shearing resistance in deg)	$v_{s,30}$ (m/s)	G_{max} (average shear modulus in kPa)	G_{red} (reduced due to cyclic shear strain in kPa
Soil B	51	55	360	220320	121176
Soil C	33	36	270	123930	55769
Soil D	9	10	100	17000	6800

According to Eurocode 8 a building may be designed as a system of large lightly reinforced walls if a number of parameters are met, e.g. the fundamental period in each horizontal direction is less than 0.5 s for fixed conditions at the base of the building, and the large shear walls resist at least 65% of the seismic base shear and support at least 20% of the total gravity loads in each direction. For the chosen layout, buildings with more than 5 stories possess fundamental period exceeding 0.5 s and therefore are not allowed to be designed as structures with large lightly reinforced walls according to Eurocode 8. The fundamental periods T_1 of the buildings analysed are shown in Tables 2 and 3 for both cases: vertical elements assumed as fixed at their base and for springs under the footings (Kementzetzidis, 2014).

Table 2. Fundamental periods T_1 (sec) along x- direction (i.e. longer side of the layout) for two different types of foundation considered (fixed or with springs)

Soil category	5-story		4-story		3-story	
	Fixed	Springs	Fixed	Springs	Fixed	Springs
	T_1	T_1	T_1	T_1	T_1	T_1
B	0.413	0.519	0.291	0.409	0.188	0.305
C		0.590		0.466		0.361
D		0.736		0.6041		0.457

Table 3. Fundamental periods T_1 (sec) along y- direction (i.e. shorter side of the layout) for two different types of foundation considered (fixed or with springs)

Soil category	5-story		4-story		3-story	
	Fixed	Springs	Fixed	Springs	Fixed	Springs
	T_1	T_1	T_1	T_1	T_1	T_1
B	0.413	0.419	0.291	0.379	0.188	0.276
C		0.549		0.426		0.324
D		0.689		0.558		0.417

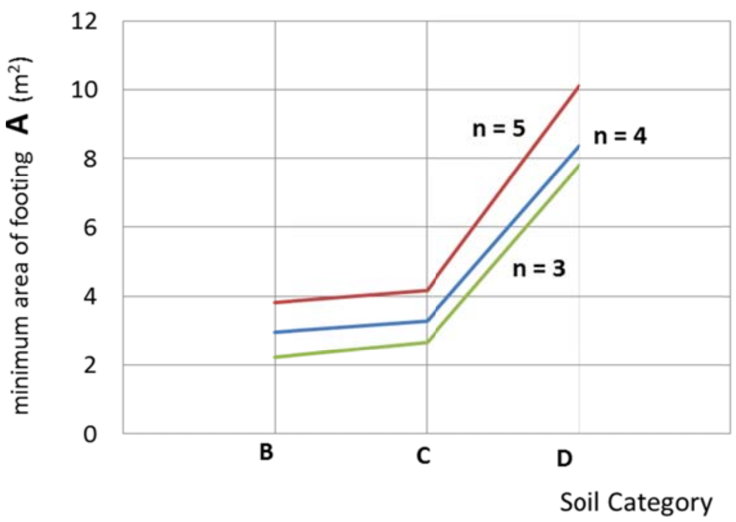

Figure 2. Minimum area required for shear wall footings vs. number of storeys and soil type

The structures were analysed using the SAP2000 software with response spectrum analysis. All design parameters were in accordance with Eurocode 8 (CEN, 2004). The analysis was performed without taking into account any influence of the infill walls (except for the increase in the total load). The design acceleration spectrum of Eurocode 8 part 1 was used, with A=0.24g (seismicity zone II) and behavior factor q=3.0. Accidental eccentricities $e_{ax} = 0.05\ L_{ay}$ and $e_{ay} = 0.05\ L_{ax}$, where L_{ay}, L_{ax} the average dimensions of the storey layout at directions *y* and *x*, respectively, were assumed to calculate torsional effects of eccentricities in order to account for uncertainties (in the location of masses and in the spatial variation of the seismic motion).

RESUTLS

The main results of the analysis are depicted in Figures 3 to 6. Rocking spring constant, K_θ, had the most significant contribution to the reduction of bending moments at the base of shear walls, $K_\theta= G_{red} /(1-v)\ \beta_\psi BL^2$, where G_{red}= reduced shear modulus, v= Poisson's ratio of the foundation medium, β_ψ=correction factor for embedment for translation along L, B=width of the basement perpendicular to the direction of horizontal excitation, and L=length of basement in the direction of horizontal excitation (ASCE (1999, 2006). As the soil deteriorates (from category B to D) the constant K_θ decreases considerably (Figure 3), despite the increase in the dimensions of the footings (Figure 2) owing to the significant reduction of the shear modulus G_{red}.

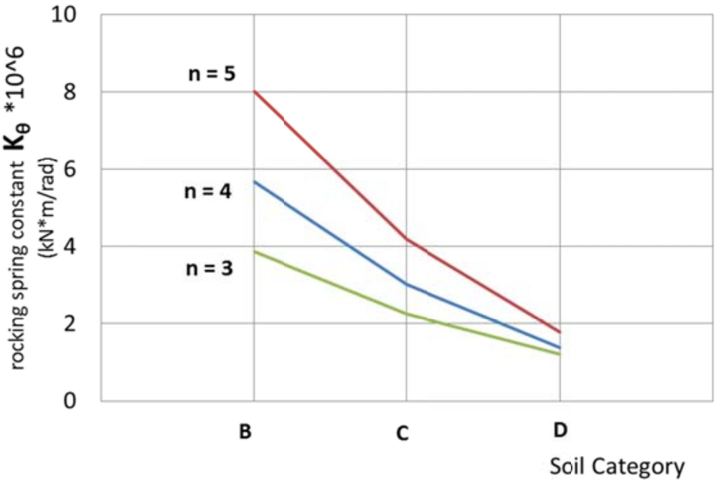

Figure 3. Rocking spring constant K_θ vs. number of storeys and soil type

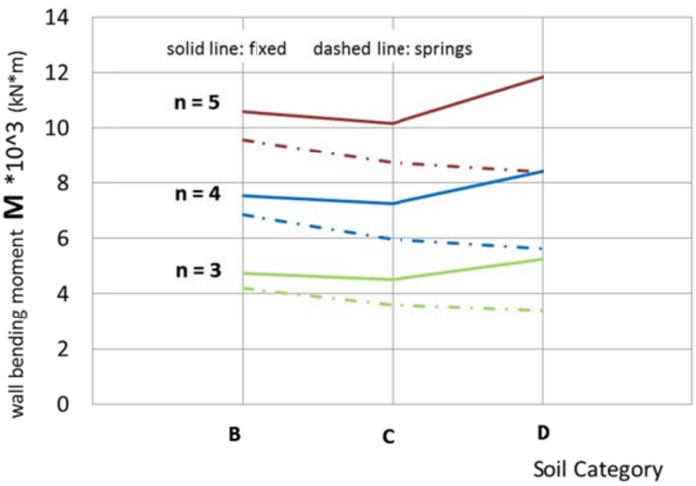

Figure 4. Maximum bending moment at the base of shear walls for springs and fixed conditions

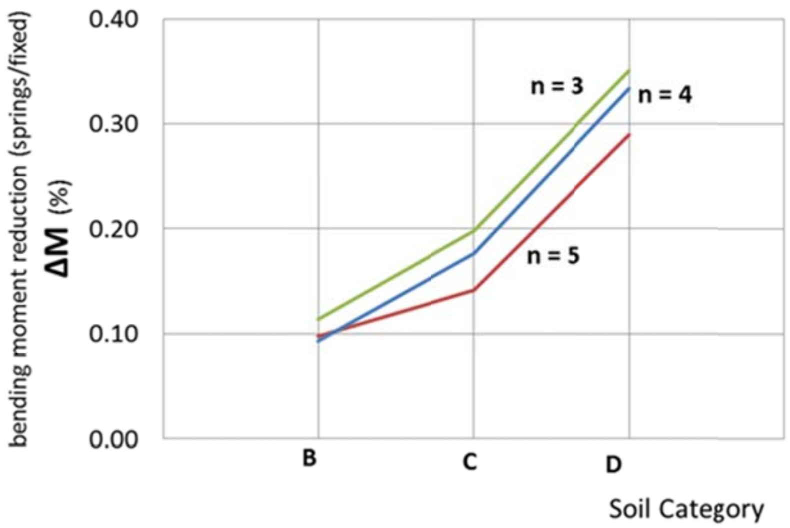

Figure 5. Bending moment reduction ΔM at the base of shear walls for the analysis with springs as compared to the analysis with elements fixed at their base

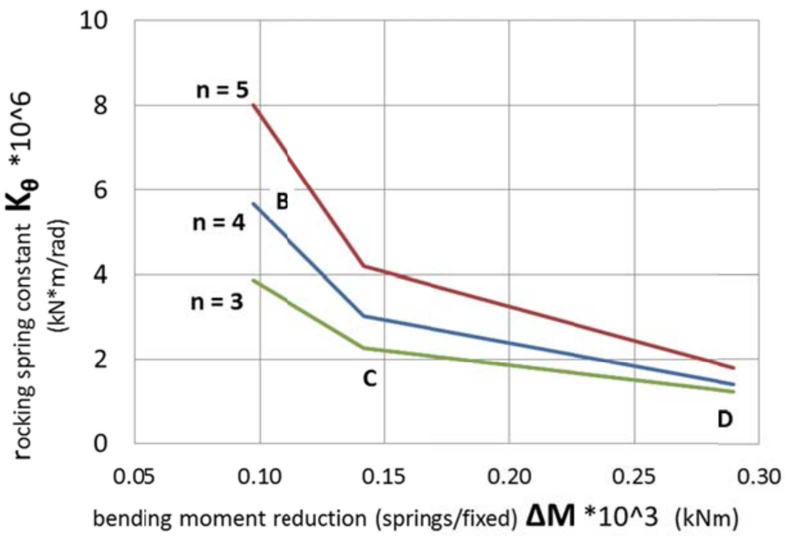

Figure 6. Rocking spring constant K_θ vs. bending moment reduction ΔM for the analysis with springs as compared to the analysis with elements fixed at their base

CONCLUSIONS

The introduction of springs at the base of footings results in reduction of the bending moments, ΔM, at the base of the vertical structural elements from 9% to 35% as compared to the respective bending moments in case the elements are assumed to be fixed at their base. The reduction in the bending moment increases as the soil category decreases, due to the significant reduction of the value of the shear modulus G. The highest difference ΔM was observed in case of soil type D (Figure 4), which is in accordance with previous experimental observations (Anastasopoulos et al, 2012).

In buildings with less number of storeys the reduction ΔM seems to increase, compared to similar buildings with more storeys. This trend seems to increase as the soil category decreases. On the contrary, the values of the rocking spring constant K_θ between buildings with different number of storeys differ more in soil B than in soil D (Figure 6).

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