EVALUATING FOUNDATION DESIGN CONCEPTS OF EUROCODE 7 & 8

J WANG
Trinity College, University of Cambridge, Trinity Street, Cambridge, CB2 1TQ, UK
jw455@cam.ac.uk

N I THUSYANTHAN
Schofield Centre, Engineering Department, University of Cambridge, Trumpington Street, Cambridge,
CB2 1PZ, UK.
it206@cam.ac.uk

SUMMARY: This paper presents design concepts of Eurocode 7 and 8 with regard to simple foundation design. Design methodology of Eurocode 7 is compared with that of BS 8004:1986. A simple design example of a pad foundation is used to compare Eurocode 7 and BS design methods. Seismic performance of the pad foundation of different dimensions is then analysed using PLAXIS dynamic code. The results of the dynamic analyses show that the seismic design of simple foundation needs to be performance-based.
Keywords: British Standards, comparison, design concept, Eurocode 7, Eurocode 8, improvement, SLS, spread foundation, ULS, worked example.

INTRODUCTION

From 2010, a complete suite of Eurocodes will replace national standards to become the common code of practice throughout Europe. This change means that all geotechnical engineers in the UK will be required by law to design their structures according to Eurocode 7 (EC7, normal operation design) and 8 (EC8, earthquake resistance design). The philosophical difference between Eurocodes and BS presents great challenge as well as some confusion in this transition era.

Even if the switch in mindset could be smooth, the inherent incompatibilities between EC7 and EC8 would still remain a puzzle. While EC7 neatly addresses Ultimate Limit State (ULS) designs through its three Design Approaches (DAs), one would struggle to find the corresponding methodology in EC8 Part 5 (EC8-5) which is supposed to be subsidiary to EC7. Furthermore, although serviceability is addressed in EC8 through its Damage Limitation State (DLS) concept, its embodiment remains implicit, with the informative section on seismic foundation designs (Section 5 and Annex F of EN 1998-5:2004) saying little more than ULS requirements.

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The purpose of this paper is to discuss the issues above in greater detail, and to call for further improvements that may be possible in EC7 and EC8-5.

EUROCODE 7 VERSUS BRITISH STANDARDS

EC 7 Part 1 (EC7-1): An Overview on Foundation Design

The recent version of EC7 was published in 2004, and was granted the status of a British Standard. Its Part 1, EN 1997-1:2004, outlines the requirements on various geotechnical designs under normal operations. Foundation design sections (spread and pile foundation, *section 5* & *6*) of EC7-1 offer the greatest detail.

EC7-1's philosophy on foundation design is widely welcomed, in that it makes a clear distinction between ULS and Serviceability Limit State (SLS) design. Taking spread foundation as an example, the following ULS requirements are identified by EC7-1[1]:

- *Overall Stability*
- *Adequate Bearing Resistance*
- *Adequate Sliding Resistance*
- *Adequate Structural Capacity*
- *No Combined Failure of Ground and Structure*

While the list on SLS requirements include:

- *No Excessive Settlement, both immediate and delayed*
- *Design against Heave, both immediate and delayed*
- *Design for Vibrating Loads*

Taking ULS shallow foundation design for example, the three design methods (*Analytical*, *Semi-empirical* and *Prescriptive Method*) suggested by EC7-1 places a lean towards the use of equations and partial factors. More specifically, the main code states that the designer should use "*commonly recognised methods*", but makes no reference to essential publications other than the highly abbreviated "*informative*" annexes of its own, where a detailed solution is given for the *Analytical Method*.

EC7-1: Relationship with BS 8004:1986

By rule of the European Committee for Standardisation (CEN), any conflicting national standards will have to be withdrawn after a short "coexistence" period with EC7-1. In the realm of foundation design, BS 8004:1986 will have to make way. However, due to their fundamental difference in philosophy, it is very difficult to determine which sections of BS 8004 are in "conflict" with EC7-1.

BS 8004 exemplifies the spirit behind the UK system of British Standards, which is to provide comprehensive guidance on design for experienced professionals. Unlike EC7-1, it provides much advisory information, i.e. not obligatory, and often refers readers to datasheets and other publications. Because of this nature of its design philosophy, BS 8004 does not distinguish ULS from SLS explicitly, but goes through a whole list of design considerations[2] one by one, which often overlaps with items in EC7-1 and beyond as illustrated over the page.

BS 8004:1986 ***EC7-1***

Ground Movement	←→	*Overall Stability, Settlement*
Ground Water, Flooding	←→	*Heave, Uplift*
Structural Considerations	←→	*Structural Capacity*
Allowable Bearing Pressure	←→	*Bearing Capacity*
Ground/Structure Interdependence	←→	*Soil/Structure Interaction*
Chemical Attack	←→	*c.f. Frost Damage, etc*
Exclusion of Moisture		
Strength of Partially Completed Structures		
Tolerances		
Ground Considerations		
Etc…		

However, EC7-1 takes one step further than BS 8004, in that it subdivides ULS requirements into 5 broad categories[1, 3]. Each category has a particular set of partial factor values associated, which should be applied in corresponding design calculations:

- **EQU**: *"loss of equilibrium of the structure or the ground, considered as a rigid body, in which the strengths of structural materials and the ground are insignificant in providing resistance"*
- **STR**: *"internal failure or excessive deformation of the structure or structural elements, including footings, piles, basement walls, etc, in which the structural material is significant in providing resistance"*
- **GEO**: *"failure or excessive deformation of the ground, in which the strength of soil or rock is significant in providing resistance"*
- **UPL**: *"loss of equilibrium of the structure or the ground due to uplift by water pressure (buoyancy) or other vertical actions"*
- **HYD**: *"hydraulic heave, internal erosion and piping in the ground caused by hydraulic gradients"*

Regarding ULS foundation design in particular, the main focal points are GEO and STR limit states. UPL and HYD cases should only be checked if buoyancy and hydraulic gradients are of concern, while EQU is mainly relevant to structural design, and is limited to rare cases such as rigid foundation bearing on rock[1].

On the other hand, specific equations or safety factors are seldom mentioned in BS 8004. Thus it would be difficult to persuade UK foundation engineers to give up their traditional freedom under the informative BS 8004, and to bury themselves into the rigidity of EC7-1. A possible way ahead may lie in the UK National Application Document (NAD) due to be published in March 2008. As an overriding document to the general EC7-1, its 1995 version provides cross-reference to the relevant BS codes, and states that British Standards are to be used whenever EC7-1 puts forward "*commonly recognised procedures*" and etc. It remains disappointing in a way, in that none of the "boxed values" given in EC7-1 are changed, and it still adheres to EC7-1's more analytical approach to foundation design[4]. The hope is that its 2008 version can use BS, or even ISO codes, as supplement advice to designers when using EC7-1. An expansion on sections such as the "*Semi-empirical Method*" and "*Prescriptive Method*" will also be welcomed, where local knowledge and experience can fit right in.

EC7-1 versus BS 8004: A Worked Example

Despite their fundamental difference in philosophy, EC7-1 and BS 8004 can still be compared directly in the realm of analytical designs. In this regard, EC7-1 adopts a concept of "*partial factors of safety*" that is very different from the traditional "*safety factor*" approach of BS. It also introduces three distinctive Design Approaches (DAs), all of which are applicable to foundation designs[1, 3]:

- **DA-1 Combination 1**:
  A1 '+' M1 '+' R1, essentially a STR Limit State approach
- **DA-1 Combination 2**:
  A2 '+' M2 '+' R1, essentially a GEO Limit State approach
- **DA-2**:
  A1 '+' M1 '+' R2, an Action & Resistance Factor approach
- **DA-3**:
  (A1* or A2†) '+' M2 '+' R3, an Action & Material Factor approach

Note 1. A1, M1, R1, etc refer to the "boxed values" of partial factor sets in Annex A of EC7-1
Note 2. *: on structural actions; †: on geotechnical actions

The simple example below illustrates the analytical design procedures for spread foundations based on *Section 6* and *Annex D* of EC7-1, as well as the BS 8004 approach.

Table 1: *Partial Factor Sets for ULS* shallow foundation design based on EC7-1*

(1) Partial Factors on Actions (γ_F) or the Effects of Actions (γ_E), based on Table A-3 of EC7-1 Annex A					
Action		Symbol	Set		
Duration	Condition		*A1*	*A2*	
Permanent	Unfavourable	γ_G	1,35	1,0	
	Favourable		1,0	1,0	
Variable	Unfavourable	γ_Q	1,5	1,3	
	Favourable		0	0	
(2) Partial Factors for Soil Parameters (γ_M), based on Table A-4 of EC7-1 Annex A					
Material Property		Symbol	Set		
			M1	*M2*	
Angle of shearing resistance (tanφ')		γ_φ'	1,0	1,25	
Effective cohesion		γ_c'	1,0	1,25	
Undrained shear strength		γ_{cu}	1,0	1,4	
Unconfined compressive strength		γ_{qu}	1,0	1,4	
Weight density (γ)		γ_γ	1,0	1,0	
(3) Partial ResistanceFactors (γ_R) for Shallow Foundations, based on Table A-5 of EC7-1 Annex A					
Resistance		Symbol	Set		
			R1	*R2*	*R3*
Bearing capacity		$\gamma_{R;v}$	1,0	1,4	1,0
Sliding resistance		$\gamma_{R;h}$	1,0	1,1	1,0

*Note: Only the partial factor tables for STR and GEO limit states are incorporated, which are most relevant for ULS shallow foundation design. For EQU, UPL and HYD limit-state design, one must use the other partial factor tables specified in Annex A of EC7-1

<u>Description of Design Task:</u>

Determine the minimum width of a 0.5 m thick, square pad foundation to satisfy ULS requirements for a permanent vertical load of 800 kN and a variable vertical load of 180 kN. The bearing of the foundation is on soft clay 1 m below ground level. The detailed configuration and soil properties are shown in Figure 1. The column on the foundation is ignored for simplicity.

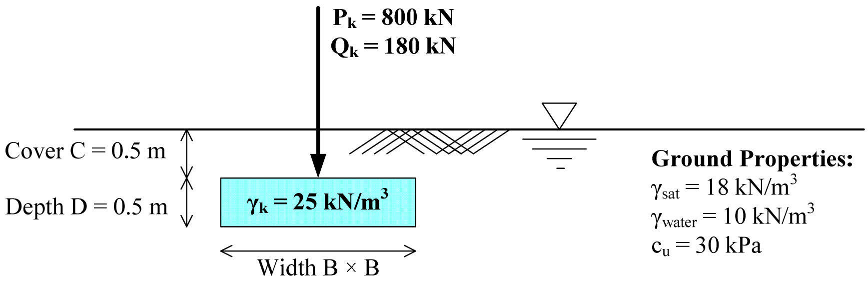

Figure 1: *Undrained Spread Foundation Design*

EC7-1: Design Approach 1 Combination 2

Combination 2 nearly always governs DA1 design as long as the loading is substantially vertical, thus should be calculated first. The weight of foundation and backfill is:

$$G_{pad,k} = B^2 \times (0.5 \times 18 + 0.5 \times 25) = 21.5 \times B^2 \text{ (kN)}.$$

The design value of vertical actions is given by:

$$V_d = \gamma_G(P_k + G_{pad,k}) + \gamma_Q Q_k \qquad (1)$$

The design value of R_d is given by *equation D.1* of *Annex D* of EC7-1:

$$R_d / A' = (\pi + 2)\, c_{u,d} b_c s_c i_c + q_d \qquad (2)$$

In this case,

$V_d = \boldsymbol{1.0} \times 800 + \boldsymbol{1.3} \times 180 + \boldsymbol{1.0} \times 21.5 \times B^2 = 1034 + 21.5 \times B^2$ (kN),

$c_{u,d} = c_{u,k} / \gamma_{cu} = 30 / \boldsymbol{1.4} = 21.4$ kPa,

$b_c = 1$(horizontal surface), $i_c = 1$ (loads purely vertical)

$s_c = 1 + 0.2B'/L' = 1 + 0.2 = 1.2$ (square pad)

$q_d = (18 / \boldsymbol{1.0}) \times (0.5 + 0.5) = 18$ kPa

$A' = A = B^2$ (m^2, no loading eccentricity, no bending moments)

$R_d = [(3.14 + 2) \times 21.4 \times 1 \times 1.2 \times 1 + 18] \times B^2 = 150 \times B^2$ (kN)

It is required that $V_d \leq R_d$, i.e. $1034 + 21.5 \times B^2 \leq 150 \times B^2$, and the minimum B would be **2.84** m for this approach.

EC7-1: Design Approach 1 Combination 1

In shallow foundation design, Combination 1 usually serves as a check to Combination 2. Equations (1) and (2) still hold for this approach. The partial factor values for DA1 Combination 1 can be adjusted as follows:

$G_{pad,k} = 21.5 \times B^2$ (kN)

$V_d = \boldsymbol{1.35} \times 800 + \boldsymbol{1.5} \times 180 + \boldsymbol{1.35} \times 21.5 \times B^2 = 1350 + 29 \times B^2$ (kN)

$c_{u,d} = c_{u,k} / \gamma_{cu} = 30 / \boldsymbol{1.0} = 30$ kPa,

$b_c = 1$, $i_c = 1$, $s_c = 1.2$, $q_d = (18 / \boldsymbol{1.0}) \times (0.5 + 0.5) = 18$ kPa, $A' = A = B^2$ (m^2)

$R_d = [(3.14 + 2) \times 30 \times 1 \times 1.2 \times 1 + 18] \times B^2 = 203 \times B^2$ (kN)

It is required that $V_d \leq R_d$, i.e. $1350 + 29 \times B^2 \leq 203 \times B^2$, and the minimum B would be **2.79** m for this approach.

EC7-1: Design Approach 2

In this case, Equations (1) for V_d still holds, while R_d is obtained by applying the partial factor $\gamma_{R,V}$ of set R2 to the unfactored bearing resistance value, R_k, i.e.

$$R_d / A' = (R_k / A') / \gamma_{R,V} = [(\pi + 2)\, c_{u,k} b_c s_c i_c + q_k] / \gamma_{R,V} \quad (3)$$

Thus:

$G_{pad,k} = 21.5 \times B^2$ (kN)

$V_d = \boldsymbol{1.35} \times 800 + \boldsymbol{1.5} \times 180 + \boldsymbol{1.35} \times 21.5 \times B^2 = 1350 + 29 \times B^2$ (kN)

$c_{u,k} = 30$ kPa, $b_c = 1$, $i_c = 1$, $s_c = 1.2$, $q_k = 18 \times (0.5 + 0.5) = 18$ kPa, $A' = A = B^2$ (m^2)

$R_d = [(3.14 + 2) \times 30 \times 1 \times 1.2 \times 1 + 18] / \boldsymbol{1.4} \times B^2 = 145 \times B^2$ (kN)

It is required that $V_d \leq R_d$, i.e. $1350 + 29 \times B^2 \leq 145 \times B^2$, and the minimum B would be **3.41** m for this approach.

EC7-1: Design Approach 3

DA3 adopts a similar procedure to DA1, and Equations (1) and (2) are both applicable. The vertical forces and backfill weight are "structural actions", thus partial factor set A1 is used. Adjusting the partial factor values for DA3 gives:

$G_{pad,k} = 21.5 \times B^2$ (kN)

$V_d = \boldsymbol{1.35} \times 800 + \boldsymbol{1.5} \times 180 + \boldsymbol{1.35} \times 21.5 \times B^2 = 1350 + 29 \times B^2$ (kN)

$c_{u,d} = c_{u,k} / \gamma_{cu} = 30 / \boldsymbol{1.4} = 21.4$ kPa,

$b_c = 1$, $i_c = 1$, $s_c = 1.2$

$q_d = (18 / \boldsymbol{1.0}) \times (0.5 + 0.5) = 18$ kPa, $A' = A = B^2$ (m^2)

$R_d = [(3.14 + 2) \times 21.4 \times 1 \times 1.2 \times 1 + 18] \times B^2 = 150 \times B^2$ (kN)

It is required that $V_d \leq R_d$, i.e. $1350 + 29 \times B^2 \leq 150 \times B^2$, and the minimum B would be **3.34** m for this approach.

Existing Approach by BS 8004:

The traditional BS approach is to apply an overall safety factor, γ, of ***3.0*** to the allowable bearing stress, while loads and overburden pressures will be used unfactored. The design equations are:

$$V_d = V_k = P_k + G_{pad,k} + Q_k \quad (4)$$

$$R_d / A' = (\pi + 2)\, c_{u,k} b_c s_c i_c / \gamma + q_k \quad (5)$$

And check for $V_d \leq R_d$

Based on this particular design situation:

$G_{pad,k} = 21.5 \times B^2$ (kN)

$V_d = 800 + 21.5 \times B^2 + 180 = 980 + 21.5 \times B^2$ (kN)
$c_{u,k} = 30$ kPa, $b_c = 1$, $i_c = 1$, $s_c = 1.2$, $\gamma = 3.0$
$q_k = 18$ kPa, $A' = A = B^2$ (m^2)
$R_d = [(3.14 + 2) \times 30 \times 1 \times 1.2 \times 1 / \boldsymbol{3.0} + 18] \times B^2 = 79.7 \times B^2$ (kN)

It is required that $V_d \leq R_d$, i.e. $980 + 21.5 \times B^2 \leq 79.7 \times B^2$, and the minimum B would be **4.11** m for this existing BS approach.

The ULS designs are summarised for the various approaches in the table 2 below.

Table 2: *Minimum foundation dimension required by each of the methods*

EUROCODE 7				BS 8004: 1986
DA1 Combination 2	**DA1** Combination 1	**DA2**	**DA3**	
2.84 m	2.79 m	3.42 m	3.34 m	4.11 m

EC7-1 states that unless all three DAs have been checked, the design would not be safe to its standards (although some NADs state that only one or two of the three DAs need checking). Thus, square pad of dimensions 3.42 m × 3.42 m would satisfy EC7-1's ULS requirements, and is governed by Design Approach 2. This seems significantly less conservative than the traditional BS approach, which yields a minimum dimension of 4.11 m × 4.11 m. However, it should be noted that for a complete analytical design, both ULS and SLS requirements need to be addressed. The existing BS approach uses overall safety factor to satisfy SLS, hence provides a ULS design which often satisfies SLS automatically. But for EC7-1, SLS needs to be checked separately, and often governs the end design. Therefore, it is rather difficult to compare the design of EC7-1 with that of BS directly.

EUROCODE 8

Eurocode 8: An Overview

Eurocode 8 (EC8) intends to cover the entire span of seismic design, and focuses predominantly on structural elements. Geotechnical aspects are addressed in Part 5 of EC8 (EC8-5). There is hope for improvement in EC8 in many areas.

First of all, EC8-5 only addresses ULS design effectively on Bearing and Sliding, and no further. The concept of Damage Limitation State[5] as in Part 1 of EC8 (EC8-1) is hardly mentioned, let alone considerations on permissible settlements or rotations. The code can thus be described as sufficiently detailed to be obligatory, but not informative enough to be advisory.

Secondly, although EC8-5 is largely a subsidiary to EC7, their design methodologies do not coincide. Throughout *Section 5* of EC8-5 on *Foundation Systems*[6], no specific design procedure is mentioned apart from the over-simplified analytical equations. However, even these equations raise confusions. EC8-5 clearly states that its provisions are "*in addition to…EC7-1*", but fails to employ the three analytical DAs of EC7-1 in any obvious manner. In fact, according to its *Annex F*, EC8-5 employs a partial factor approach that resembles DA3, and is the only approach that the designer should use. Another question is how its "design normal force" (N_{Ed}) or "design friction resistance" (F_{Rd}) differs from V_d and R_d in EC7-1, and what partial factors should be applied to them. Issues like these are making EC8-5 incompatible with EC7-1, which can cause confusion.

Thirdly, due to the structural bias of EC8 on the whole, its Part 5 fails to address the probabilistic nature of soil properties or failure. For example, the "normative" (i.e. obligatory) section of EC8-5 on liquefaction analysis, *Annex B*, employs a very simplified chart that relates Cone Penetration Test (CPT) results with stress ratios causing liquefaction. But liquefaction can only be interpreted as a possibility, and can never be guaranteed against even if soil data fall into the bottom-right "safe region" of the chart. Another over simplification is in *Table F.1* of *Annex F*, where soil is classified as being either "*purely cohesive*" or "*purely cohesionless*", which clearly doesn't help the designer much.

UK has a long history of very low seismic activity. Thus no corresponding BS codes are available as a counterpart to EC8.

EC8-5 Foundation Design: A Closer Look

EC8-5 has a specific section on foundation systems, which tries to address seismic design requirements for foundations in general. However, as with the entire EC8, it still disappointingly exhibits a strong structural bias, and is reluctant to provide much information or guidance on serviceability. For example, in the shallow foundation section, EC8-5 only states that the design should be "safe" against seismic bearing and sliding failures, but makes too simple an effort in defining the word "safe" itself. According to *Section 5* and *Annex F*, the design only needs to satisfy the following equation so as to be deemed "safe" by EC8-5[6, 7]:

$$\frac{(1-e\overline{F})^{c_T}(\beta\overline{V})^{c_T}}{\overline{N}^a\left[\left(1-m\overline{F}^k\right)^{k'}-\overline{N}\right]^b}+\frac{(1-f\overline{F})^{c'_M}(\gamma\overline{M})^{c_M}}{\overline{N}^c\left[\left(1-m\overline{F}^k\right)^{k'}-\overline{N}\right]^d}-1\le 0, \qquad (6)$$

where $\overline{N}=\dfrac{\gamma_{Rd}N_{Ed}}{N_{max}}$, $\overline{V}=\dfrac{\gamma_{Rd}V_{Ed}}{N_{max}}$, and $\overline{M}=\dfrac{\gamma_{Rd}M_{Ed}}{BN_{max}}$

In this equation, $\overline{N}$, $\overline{V}$ and $\overline{M}$ are the non-dimensional loading parameters for vertical loading, horizontal loading and bending moment transfer during the seismic action respectively. N_{max} is the ultimate bearing capacity of the foundation under a vertical centred load; B is the foundation width; $\overline{F}$ is the dimensionless soil inertia force; and γ_{Rd} is the soil model partial factor as defined in EC8-1.

EC8-5 does not make an explicit statement on how the seismic design action force, N_{ed}, should be related to the static loading forces, P_k and Q_k, as it depends strongly on the response of superstructures to this particular earthquake. Normally N_{ed} should be determined from a separate seismic structural loading analysis. Here it is taken as the sum of P_k and Q_k, both unfactored, to avoid complication of matters, i.e. N_{ed} = 800 + 180 = 980 kN.

For the same design example as before, it can be verified that a 4.08 m × 4.08 m square pad just satisfies such requirement with the additional EC8 parameters listed below and in Table 3.

Table 3. *Seismic parameters based on EC8-1 and EC8-5*
Soil Type: Purely Cohesive Soil, Model Partial Factor: γ_{Rd} = 1.00 for non-sensitive clays

EC8-1 Parameters	Partial Factors (As Recommended by EC8-5)	EC8-5 Parameters
$a_{gR} = 0.5$ g $\gamma_I = 1.1$ $M_s = 6.0$ Type B Ground $\gamma_I = 1.1$ $S = 1.4$ $T_B = 0.15$ $T_C = 0.5$ $T_D = 2.0$	$\gamma_M = \gamma_{cu} = 1.4$	a = 0.7 b = 1.29 c = 2.14 d = 1.81 e = 0.21 f = 0.44 m = 0.21 k = 1.22 k' = 1.0 $c_T = 2.0$ $c_M = 2.0$ $c'_M = 1.0$ β = 2.57 γ = 1.85

The ultimate bearing capacity, N_{max}, per unit length of a strip foundation can be calculated by equation (7) below, according to *Annex F* of *EC8-5*:

$$N_{max} = (\pi + 2)\frac{c_u}{\gamma_M}B = (3.14 + 2)\times\frac{30}{1.4}\times 4.08 = 449.5\ kNm^{-1} \qquad (7)$$

The total bearing capacity, $N_{max,tot}$, is then: $N_{max,tot} = 449.5 \times 4.08 = 1834$ kN

If $\overline{N}$ is the only active loading parameter (i.e. $\overline{V}$ and $\overline{M}$ are both zero), the left-hand-side (LHS) of Equation (6) will equal -1 (i.e. "safe") irrespective of the width of the foundation. To avoid this ridiculous situation, V_{Ed} is chosen as 50 kN while M_{Ed} is still kept at zero. Thus, according to *Annex F*, $\overline{N}$ and $\overline{V}$ can be determined by Equations (8) and (9) below:

$$\overline{N} = \frac{\gamma_{Rd} N_{Ed}}{N_{max,tot}} = \frac{1.00\times 980}{1834} = 0.534, \quad (0 < \overline{N} < 1, \text{ thus OK!}) \qquad (8)$$

$$\overline{V} = \frac{\gamma_{Rd} V_{Ed}}{N_{max,tot}} = \frac{1.00\times 50}{1834} = 0.0273, \quad (|\overline{V}| < 1, \text{ thus OK!}) \qquad (9)$$

The dimensionless soil inertia force, $\overline{F}$, for a purely cohesive soil is given by:

$$\overline{F} = \frac{\rho\cdot\gamma_I\cdot a_{gR}\cdot S\cdot B}{c_u} = \frac{1837\times 1.1\times 0.5\times 9.81\times 1.4\times 4.08}{30000} = 1.885 \qquad (10)$$

Putting these numbers altogether, the LHS of Equation (6) can now be evaluated:

$$\frac{(1-0.21\times1.885)^{2.0}\times(2.57\times0.0273)^{2.0}}{0.534^{0.7}\left[(1-0.21\times1.885^{1.22})^{1.0}-0.534\right]^{1.29}}+0-1=-0.018\approx0$$

Thus, 4.08 m is the minimum dimension that could make the design "safe" according to EC8-5. However, such verification of safety is very irresponsible, in that Equation (6) is an over-simplified inequality that fails to address any ULS or SLS design requirements or methodologies explicitly, such as:

- Maximum allowable (differential) vertical displacement
- Maximum allowable horizontal displacement
- Maximum allowable tilting
- Method to evaluate the equivalent overall factor of safety (OFS)
- Maximum allowable damage, and the evaluation method of such

To illustrates how sensitive Equation (6) actually is, numerical simulations were run for four design widths, 3.96 m (97%), 4.08 m, 4.20 m (103%), and 4.49 m (110%), using the Plaxis2D^{tm} Dynamic^{tm} software package. The earthquake applied is a simple sine wave that gives a maximum acceleration of 0.5g, or 4.9 ms^{-2}. The foundation is restricted to move in the vertical plane only and rotate about a single axis though this vertical plane. The seismic loading parameters, N_{Ed}, V_{Ed}, and M_{Ed}, are chosen as 980 kN, 50 kN and 0 divided by each foundation width respectively (i.e. the case is simplified to a strip foundation design for 2D analysis) in accordance with the previous example. The seismic response of each design is summarised in Table 4. Note that all these designs have satisfied EC7's ULS requirements (> 3.51 m, which is slightly higher than the previous 3.42 m due to the introduction of a fixed horizontal force of 50 kN). The foundation is assumed to remain rigid during the earthquake.

Although these results are of indicative nature, it is clear that a mere 3% reduction from the critical foundation width would push the LHS value of Equation (6) from –0.018 to infinity. The associated maximum vertical and horizontal displacement, on the other hand, only increases by 4 mm (4.3%) and 2 mm (4.5%) respectively. At the same time, a tiny step upwards from the critical would reduce the LHS value dramatically, but offers little corresponding improvements in seismic performance.

Table 4. *Summary of Plaxis results for 4 foundation designs using Mohr-Coulomb Soil Model,* $\varphi' = 30°, c' = 2$ *kPa,* $E = 22{,}000$ *kPa,* $k = 1 \times 10^{-8}$ *ms*$^{-1}$.

Design Width (m)	LHS Value of Equation (6)	Max. Vertical Displ. (mm)	Max. Hori. Displ. (mm)
3.96	∞	96	46
4.08	- 0.018	92	44
4.20	- 0.700	89	41
4.49	- 0.903	75	31

A clear conclusion from these data is that Equation (6) of EC8-5 cannot offer a specific "cut-off" point for a "safe" seismic bearing capacity design. The word "safe" itself should also be re-defined, as a few more millimetres may not justify a fundamental difference between seismically "safe" foundations and seismically "unsafe" foundations. In fact, from a philosophical point of view, a large enough earthquake can always make a "safe" foundation unsafe. Thus any seismic design code should, perhaps, not emphasis entirely on safety, but places its focal point on deformation and damage cost minimisation. It is possible to expand the Damage Limitation State (DLS) concept of EC8-1, and find a way to transform settlements, deformations, or even injury and mortality probabilities into financial terms, so that the performance of seismic designs can be evaluated comparably and quantitatively.

CONCLUSIONS

This paper compared and contrasted the design concepts of EC 7 & 8 with BS. A simple design example was used to highlight the EC7, EC8 and BS design methods. Seismic performance for simple foundation designs were analysed using PLAXIS dynamic package. Results showed the sensitiveness of the seismic foundation design equation presented in "*informative*" annex of EC8. It is therefore important to note that assessment of deformation of the foundation under design earthquake loading is vital. It is hoped that EC8 will incorporate seismic performance assessment as an essential part. The ISO concept of total life cycle costing may also be incorporated into EC8-5, which not only adds an environmental perspective to design, but can make it a truly performance based earthquake design code as well.

REFERENCES

1. British Standards Institution. EN 1997-1:2004. *Eurocode 7: Geotechnical Design – Part 1: General Rules.* Code of Practice. BSI, London, 2004.
2. British Standards Institution. BS 8004:1986. *Code of Practice for Foundations – (Formerly CP 2004)*. Code of Practice. BSI, London, 1998.
3. Frank R et al. *Designers' Guide to EN 1997-1. Eurocode 7: Geotechnical design – General rules*. Eurocode Expert, ICE and Thomas Telford, 2004.
4. Simpson B and Driscoll R. *Eurocode 7: A Commentary*. IHS BRE Press, Watford, 1998.
5. British Standards Institution. EN 1998-1:2004. *Eurocode 8: Design of Structures for Earthquake Resistance – Part 1: General rules, seismic actions and rules for buildings.* Code of Practice. BSI, London, 2004.
6. British Standards Institution. EN 1998-5:2004. *Eurocode 8: Design of Structures for Earthquake Resistance – Part 5: Foundations, retaining structures, and geotechnical aspects.* Code of Practice. BSI, London, 2004.
7. Fardis MN et al. *Designers' Guide to EN 1998-1 and EN 1998-5. Eurocode 8: Design of Structures for Earthquake Resistance. General rules, seismic actions, design rules for buildings, foundations and retaining structures*. Eurocode Expert, ICE and Thomas Telford, 2005.

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