DISCUSSION

A method for the design of embedded cantilever retaining walls under static and seismic loading

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Contribution by Kaustav Chatterjee and Akshay Pratap Singh
Conte *et al.* (2017) presented the variation of bending moment and net pressure on a cantilever sheet pile wall subjected to both static and seismic loadings. The coefficients of active and passive earth pressure were calculated by using the lower-bound theorem and included shearing resistance angle of soil and soil wall friction angle in a static condition, and in addition a term called obliquity of body force per unit volume in the presence of seismic action under an earthquake loading condition. Conti & Viggiani (2013) obtained the net pressure and bending moment distribution using a finite-difference-based computer program Flac. With reference to Figs 7(a), 7(b) and 12(a)–12(d) in the paper by Conte *et al.* (2017), the solutions of Conti & Viggiani (2013) were found to be in very close agreement. The centrifuge test results published by Madabhushi & Zeng (2006) also match the proposed method by Conte *et al.* (2017). The solutions of Conte *et al.* (2017) are expected to be better than that of Conti & Viggiani (2013) due to the consideration of coefficients of active and passive earth pressure based on the lower-bound theorem of plasticity (Lancellotta, 2002, 2007), which presumably is of importance in engineering practice as a result of its conservative nature and also permits the wall roughness to be taken into consideration, therefore avoiding unreasonably pessimistic assumptions. In their proposed method, coefficients of active and passive earth pressure were taken from Lancellotta (2002, 2007) based on the lower-bound theorem and assumption that a rectilinear distribution of net pressure is maintained to develop a method which is simple to use.

The discussers seek the following clarifications from the authors.

- (a) It seems that there is an error in equation (15a) and the correct expression may be written as

$$K_{pE} = \left[\frac{\cos \delta_2 \left(\cos \delta_2 + \sqrt{\sin^2 \phi'_2 - \sin^2 \delta_2} \right)}{\cos \psi - \sqrt{\sin^2 \phi'_2 - \sin^2 \psi}} \right] e^{2\vartheta_{pE} \tan \phi'_2}$$

- (b) Soil–wall friction angle is assumed in coefficients of active and passive earth pressure, which necessitates that force should be reflected in the vertical direction in the equation of equilibrium.

- (c) The details of ϑ_{pE} and ψ are not given in the notation, and should be as follows

ψ = obliquity of the body force per unit volume in the presence of seismic action (Lancellotta, 2007)

ϑ_{pE} = angle of rotation of principle stress direction (Lancellotta, 2007).

Authors' reply

The authors thank the discussers for their interest in the paper and their positive comments on the proposed method. Discussion focuses essentially on the seismic passive earth pressure coefficient derived by Lancellotta (2007) using the lower-bound approach of limit analysis. Although different methods could be used to calculate this coefficient, the authors have recommended using Lancellotta's solution because this solution provides conservative values of the passive earth pressure coefficient and is completely analytical and simple to use. The authors have also ascertained that the values of the active earth pressure coefficient provided by Lancellotta's solution are very close to those calculated using other existing methods. That said, the authors will try to clarify the issues raised by the discussion contributors.

- (a) Following Lancellotta (2007), for a vertical wall embedded in cohesionless soils with horizontal ground surface, the seismic passive earth pressure at depth ζ (see Fig. 1 in the paper by Lancellotta (2007)) can be calculated using the following equation (see equations (5) and (6) in the paper by Lancellotta (2007))

$$\sigma'_{xx} = \left[\frac{\cos \delta_2 \left(\cos \delta_2 + \sqrt{\sin^2 \phi'_2 - \sin^2 \delta_2} \right)}{\cos \psi - \sqrt{\sin^2 \phi'_2 - \sin^2 \psi}} \right] \times e^{2\vartheta_{pE} \tan \phi'_2} \bar{\gamma} \zeta \cos \psi \quad (23)$$

where ϑ_{pE} and ψ are provided, respectively, by equations (15b) and (17) in the paper by Conte *et al.* (2017), and

$$\bar{\gamma} = \frac{\gamma(1 \pm k_v)}{\cos \psi} \quad (24)$$

with k_v denoting the seismic coefficient in the vertical direction. The parameters δ_2 and ϕ'_2 appearing in equation (23) are also defined by Conte *et al.* (2017). Taking into account equation (24) and using the initial variable $z = \zeta \cos \psi$, equation (23) can be written as

$$\sigma'_{xx} = K_{pE} \gamma (1 \pm k_v) z \quad (25)$$

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where

$$K_{pE} = \frac{1}{\cos \psi} \left[\frac{\cos \delta_2 \left(\cos \delta_2 + \sqrt{\sin^2 \phi'_2 - \sin^2 \delta_2} \right)}{\cos \psi - \sqrt{\sin^2 \phi'_2 - \sin^2 \psi}} \right] \times e^{2\vartheta_{pE} \tan \phi'_2} \quad (26)$$

This latter is exactly equation (15a), which is hence correct. In other words, following Lancellotta (2012), the authors have included the term $1/\cos \psi$ in the expression of K_{pE} , in order to put the seismic passive earth pressure in the classical form usually adopted.

- (b) In several design regulations, vertical equilibrium is recommended for embedded retaining walls supported by very inclined anchors to ascertain whether a failure mechanism occurs at the wall base owing to the vertical component of the anchor forces. However, this equation is usually disregarded for the design of embedded cantilever walls.
- (c) As asserted by the discussers, angles ϑ_{pE} and ψ are defined in the paper by Lancellotta (2007). The authors were limited to reporting the expressions of these angles in their paper (i.e. equations (15b) and (17)).

NOTATION

K_{pE}	seismic passive earth pressure coefficient
k_v	seismic coefficient in the vertical direction
z	depth in the initial geometry

γ	unit weight of soil
$\bar{\gamma}$	unit weight of soil in the transformed geometry
δ_2	soil-wall friction angle for portion of the wall below excavation level
ζ	depth in the transformed geometry
ϑ_{pE}	angle of rotation of the principal stress direction
σ'_{xx}	seismic passive earth pressure
ϕ'_2	shearing resistance angle of soil below the excavation level
ψ	obliquity of the body force per unit volume in the presence of seismic action

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