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Closure to "Kinematic Framework for Evaluating Seismic Earth Pressures on Retaining Walls"

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by Scott J. Brandenberg, M. ASCE[1], George Mylonakis, M. ASCE[2], and Jonathan P. Stewart, F. ASCE[3]

The Authors thank the Discusser for his insightful extensions to the kinematic framework for evaluating seismic earth pressures, and for supporting the overriding principle that seismic earth pressures form as a result of relative displacements between the wall and free-field soil profile. This displacement-based approach is fundamentally different from assigning an acceleration-proportional pseudo-static seismic coefficient to an active wedge, regardless of wall kinematics and wave propagation in soil, which has been common practice since the work of Okabe (1926) and Mononobe and Matsuo (1929) nearly a century ago.

The Discusser's solutions for the case of a rigid base (i.e., $K_y = K_{xx} \rightarrow \infty$) are a useful application of the original equations for cases where the base slab is large and/or founded on soil or rock that is significantly stiffer than the retained soil. Furthermore, the introduction of damping within the backfill for the case of rigid media below the wall foundation provides interesting insights, as it prevents development of zero seismic thrusts that otherwise occur at certain frequencies. This can be interpreted as imperfect destructive interference of the impinging seismic waves on the wall, due to phase differences in pressures at different elevations caused by damping.

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The Discusser's solutions for vertically inhomogeneous soil stiffness are important since many soil profiles exhibit an increase in stiffness with depth. The constant stiffness assumption in our original paper was acknowledged as a limitation, and the Discusser's solutions help address this limitation for the rigid base condition.

The Discusser accurately points out that for a given ground surface displacement amplitude, the kinematic framework predicts that seismic thrust approaches zero as frequency approaches zero. He then presents pseudo-static solutions involving constant horizontal body forces in the soil for which the seismic thrust is non-zero. Although these solutions are interesting and mathematically consistent, Fourier amplitudes of earthquake ground accelerations decay logarithmically as frequency decreases. As a practical matter, there is no acceleration at zero frequency, hence this pseudo-static solution may not reproduce the interaction that occurs during an earthquake. The Authors maintain that consideration of the frequency content of the ground motion is essential for obtaining accurate kinematic earth pressure solutions, which pseudo-static solutions cannot provide.

The Authors acknowledge that simplifying assumptions were made in the paper to facilitate the presentation of relatively simple closed-form solutions. We are actively engaged in research to facilitate relaxation of these assumptions by incorporating into the solution wall flexibility, soil nonlinearity, vertical inhomogeneity in soil stiffness for flexible base conditions, gap formation at the soil-wall interface, improvement of impedance functions, and inertial interaction effects associated with the wall itself and attached structures. These extensions will improve model accuracy for situations in which relative wall-soil displacements are expected to be significant (i.e., when $\lambda/H < \sim$ 8-10). However, for the relatively common case of larger λ/H ratios, the physics of the problem will continue to dictate very low earth pressures, as predicted by the framework presented in our paper. In short, the Authors posit that our framework can effectively distinguish cases where kinematic earth pressures are and are not likely to be important. Where they are significant, current procedures provide an admittedly rough estimate, but one that is much more strongly rooted in the physics of the problem than pseudo-static methods associated with an effective acceleration of a soil wedge. We respectfully suggest that this long-held paradigm be gently moved toward retirement.