THE AUTOMATIC EARTHQUAKE PROCEDURE

Simple design formulations for the pseudo-static design of earth retaining structures are only available for two opposite wall behaviours.

In **very flexible** wall design, various methods based on limit analysis concepts are available, assuming that the all the soil interacting with the wall is essentially in yielding limits conditions, i.e. in a plastic state. Among such approaches, the most widely use is the M-O method, which, while, is conceptually applicable to both active and passive limit state conditions, it is actually employed just for the active seismic thrust estimate. As for seismic passive resistance, other approaches such as Chen e Liu (1990), Soubra (2000) methods and recent simple and safe formulation by Lancellotta (2007) are used.

On the opposite side, in **very rigid** wall design, soil interacting with the wall is currently assumed to be very far from some yielding state, even during seismic event. In such conditions, seismic soil thrusts are essentially computed based on "elastic" methods, among which the most widely adopted one is the Wood (1973) method, which is also included in Eurocode 8 , Part 5 recommendations. Recently, several alternatives have been proposed, aiming at improving the Wood method: reference can be made to the works by Wu & Finn (1999) and Veletsos & Younan (Veletsos & Younan (1994a), (1994b), (1997)), in which more general yet quite more complex analytical solutions are included.

The seismic thrust increment ΔP_E, due to an uniform pseudo-static horizontal acceleration k_h on a wall whose height is H, from a homogeneous dry soil backfill, with unit weight γ and a friction angle ϕ, assuming a wall-soil friction angle δ equal to ½ ϕ is given by the following equations:

$$\frac{\Delta P_E}{\gamma H^2} \cong 0.375 \cdot k_h$$ seismic active thrust increment , M-O method (Seed & Whitman (1970))

$$\frac{\Delta P_E}{\gamma H^2} = k_h$$ seismic thrust increment, Wood method (independent from ϕ and δ)

Corresponding with the same horizontal acceleration k_h, the very rigid wall assumption according to the Wood method yields to a seismic thrust increment which is almost three times greater than the M-O thrust. Such difference may even grow up further if, in the estimate of the k_h value to be considered in the M-O, an additional reduction factor is included to account for wall ductility: for example, by taking a reduction factor r=2 corresponding with the maximum factor allowed by Eurocode 8, the ratio of Wood thrust on M-O may exceed 5.

In reality, based on general criteria, it's usually very complex to deem whether a retaining wall may be considered very rigid or very deformable: we may just assert that quite limited, yet non-zero deformations (around some thousandths of the wall height) are sufficient to recover active conditions in the retained soil, thus allowing the M-O equations for the thrust estimate. However , when the wall rigidity is somehow higher, an intermediate thrust estimate in between Wood and M-O values is currently more realistic: for example, the Greek Guide for seismic bridge design (Regulatory Guide E39/93 (1998)) suggests the following equations for such intermediate circumstances:

$$\frac{\Delta P_E}{\gamma H^2} \cong 0.75 \cdot k_h$$

In a conventional retaining wall analysis, the seismic pressure increment distribution, that must be initially defined according to the selected applicable method, whichever it is, must be added to the static soil and water pressures, on the active side. In this case, the active soil coefficient must not be increased according to the seismic M-O value. On the passive, however, the passive coefficient must be reduced appropriately to account for seismic effects.

As an alternative to such conventional approach, in PARATIE a semiautomatic procedure is included aiming at automatically include intermediate seismic conditions , based on actual wall behavior.

Basic ideas are briefly reviewed in the following.

Consider a soil region in the uphill side on the retaining wall, in which equilibrium conditions exists at the completion of the excavation process , just before the seismic event to be modeled.

In a very short time lagging in between seismic wave initiation and the actual wall response, incremental wall deformations may be assumed to be negligible: i.e. the wall may be considered as very rigid, for a while. In such very transient conditions, the seismic thrust increment may be estimated by a rigid approach, such as the Wood method. Note that, due such incremental pressure raise up, neither internal nor external equilibrium condition no long hold.

Therefore, very shortly afterwards, additional wall deformations must develop, in order to reestablish overall equilibrium conditions, which are pursued by means of the usual iterative process, exactly as in any static stage.

Therefore, very shortly, the two-steps algorithm works as follows:

1. In the first iteration of the seismic stage, in any uphill soil element only, the effective lateral pressure is artificially increased by the rigid (Wood) pressure increment: note that such stress increase corresponds with no strain increase, thus it can be revised as an anelastic increment.

2. As for further iterations, the zero strain increments constraints is released and, at the same time, the active (or passive for downhill parts) ratio is modified according to the seismic value.

Through the iterative process, the initial seismic stress increment may consistently diminish or even vanish at all, but the appropriate seismic yield conditions are granted, at least.

In the figure some particular stress paths for up-hill soil elements are outlined, during such atomatic seismic procedure stage.

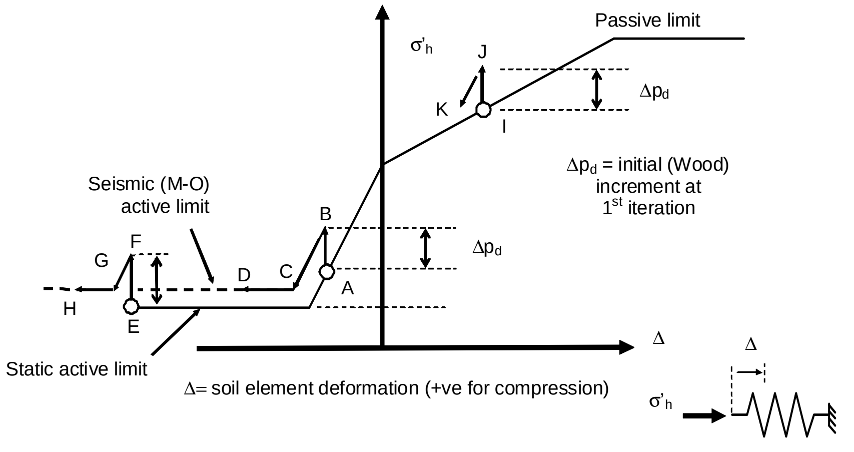

Figura 0-1: some relevant stress paths in uphill soil elements according to automatic seismic procedure

A-B-C-D path: it corresponds with an “elastic” uphill soil region in which the lateral stress was released, in a previous static stage, from at rest conditions, yet not sufficiently to reach active limit state (pt A). Initial rigid seismic stress increment is then represented by A-B segment. Further stress evolutions toward eventual seismic active conditions are represented by B-C-D path, in which B-C is the “elastic” release part, whereas C-D represents the development of seismic plastic strains. By the way, note that the seismic yield limit is currently higher than the static one.

E-F-G-H path: it represents an uphill soil region that reached active static conditions (pt.E) Initial rigid seismic stress increment is represented by E-F segment, corresponding with a temporary elastic reloading path. Subsequent elastic strain release is represented by F-G segment, whilst seismic plastic deformation development is associated to segment G-H

I-J-K path: an uphill soil element is represented, which was actually pushed rather than being released ($\Delta>0$, point I): initial rigid seismic stress increment is then represented by I-B segment, whereas subsequent unloading is J-K

Active and passive limit seismic conditions are computed according to general criteria reported in the other relevan sections of this manual. However it should be noted that for partially submerged soil, at depth $z > z_w$, with z_w = phreatic depth, active and passive seismic coefficients are computed based o the following equations:

$$K_{AE}^{equiv} = \frac{(1 \pm k_v)\left\{K^d{}_{A,E} \cdot \sigma_V^{'}(z_w) + K^w{}_{A,E} \cdot \left[\sigma_V^{'}(z) - \sigma_V^{'}(z_w)\right]\right\}}{\sigma_V^{'}(z)}$$

$$K_{PE}^{equiv} = \frac{(1 \pm k_v)\left\{K^d{}_{P,E} \cdot \sigma_V^{'}(z_w) + K^w{}_{P,E} \cdot \left[\sigma_V^{'}(z) - \sigma_V^{'}(z_w)\right]\right\}}{\sigma_V^{'}(z)}$$

where

$K^d{}_{A,E}$ = active thrust coefficient – dry soil

$K^w{}_{A,E}$ = active thrust coefficient – completely submerged soil

$K^d{}_{P,E}$ = passive thrust coefficient – dry soil

$K^w{}_{P,E}$ = passive thrust coefficient – completely submerged soil

Such values may be either directly specified by the User or internally computed. This special definition for partially submerged case is necessary to prevent unrealistic lateral pressure discontinuities at the phreatic depth as well as to recover a correct overall resultant value.

A dynamic excess pore pressure coefficient r_u can be assigned, as the ratio of the pore pressure increment u_e to the effective vertical pressure. In this case, $\sigma'_V(z)$ at seismic step is computed by including u_e based on the effective vertical stress at previous step, i.e. $\sigma'_{V,0}(z)$. In other words, the following procedure is adopted:

$$\begin{cases} u_e(z) = r_u \cdot \sigma'_{V,0}(z) \\ u(z) = u_0(z) + u_e(z) \\ \sigma'_V(z) = \sigma_v(z) - u(z) \end{cases}$$

Which is equivalent to:

$$\sigma'_V(z) = \sigma'_{V,0}(z) \cdot (1 - r_u)$$

It should be noted that the vertical effective stress decrease $\Delta\sigma'_V(z) = -r_u \cdot \sigma'_{V,0}(z)$ also induces a horizoltal stress decrease, according to the standard solution procedure.

However, Westergaard hydrodynamic overpressures, if any, are not automatically included at all, but they must be explicitly added by the Users as external loadings.

Seismic inertia loading due to the wall mass should also be applied as external loadings.

If some clay layers exist that are modeled by the CLAY option, the automatic seismic procedure can by used only if undrained conditions are assigned for such soil layers: is such circumstances, the initial Wood pressures are added to total lateral stress components; therefore the pore pressures increments are computed according to the overall CLAY model procedures, exactly as in a static stage. **In current version, however, the automatic seismic procedure is not yet available if some CLAY elements exist.**

As for downhill soil elements, according to this automatic procedure, just the passive limit is redefined, taking into account the passive coefficient reduction due to seismic acceleration. Also for such elements, eventually Westergaard hydrodynamic effects should be applied as external loadings, in such a way to maximize instabilizing effects on the wall stability. In next figure, the overall procedure is summarized.

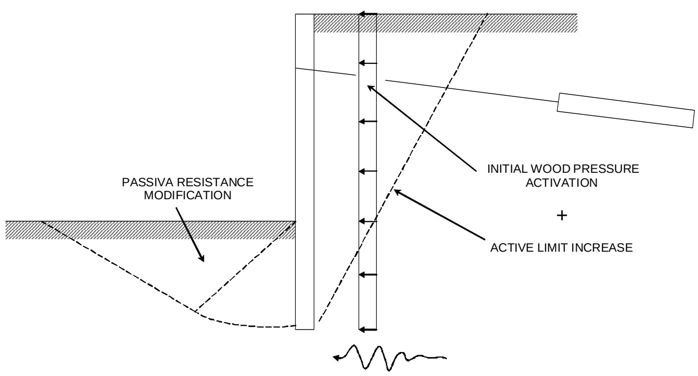

Figura 0-2: Automatic seismic procedure overview

It's worth noting that by this procedure all wall typologies may be analyzed without preliminary and arbitrary assumptions on their mechanical behavior: the algorithm will rationally select the actual wall response in between the two extreme assumptions; as for very flexible walls, the M-O seismic thrust is ensured at least, thus complying with most widely used design approaches. As for non-yielding wall in static conditions, by this method a seismic overstress is obtained as well.

The initial Wood stress release based toward final intermediate seismic pressure distribution is performed base on the static wall flexibility. However, the User is allowed to somehow tune the elastic response at this stage, by simply changing the initial soil stiffness.

At the moment, it is not possible to impose a position on the overall seismic resultant different form the static one.

It is highly recommended to activate the automatic seismic procedure at the last step the analysis, in a stage in which no other modifications are included in the model.

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