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DYNAMIC EARTH PRESSURE SIMULATION BY SINGLE DEGREE OF FREEDOM SYSTEM

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SUMMARY

The theory of static and dynamic earth pressure by the method of zero extension line developed by the authors is extended to the plain strain solution of a smooth vertical wall retaining sand backfill subjected to horizontal dynamic excitation. The pressure exerted on an element of the wall for the static and dynamic case is shown to be a function of rotation of the element of the wall. It is shown that this pressure resulting from the combined effect of static and dynamic loading can be simulated by a single degree of freedom system. The stiffness and mass characteristics of this single degree of freedom is evaluated and presented here. It is shown that with the angle of internal friction being a function of shear strain of the sand, the parameters of the single degree of freedom system is a function of rotation of the wall element.

INTRODUCTION

The theory of zero extension line was developed by Roscoe [1] and his coworkers. This theory was extended by the authors [2] and by Ghahramani and Clemence [3] for the evaluation of the static and dynamic earth pressure on a retaining wall with sand backfill. This theory is used to evaluate the response history of a smooth vertical retaining wall subjected to horizontal excitation . The theory will be explained and the derivation will be presented. The results are used to simulate the motion by a single degree of freedom system. Expressions are developed for the stiffness and the mass of the single degree of freedom system as a function of rotation of the element of the wall.

THEORY

The full explanation of the theory can be found in [2] and [3]. Only a summary will be presented here. Consider the retaining wall shown in Figure 1. The presentation is for the passive case, but the formula will also be given for the active case.

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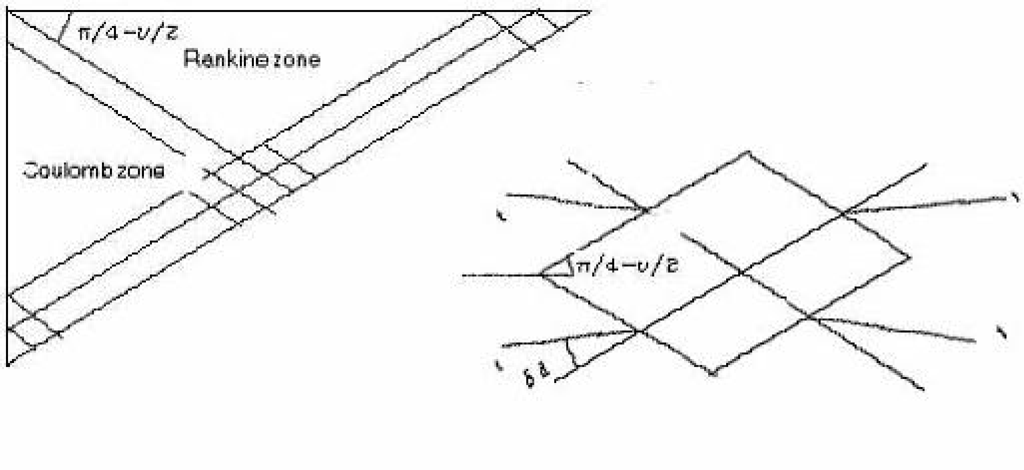

Figure 1. The simple zero extension line field and its element.

The simple zero extension line field for the smooth wall is composed of two zones; a Rankin zone and a Coulomb zone. The angle is π/4 – υ/2 where υ is the angle of dilation of the soil. The angle of dilation is evaluated from the friction angle ϕ by the following formula which is proposed in the computer program Plaxis [4].

$$\phi = \nu + 35 \qquad (1)$$

The angle dd is the angle that traction force t makes with the direction of the zero extension line as shown in Figure 1. As explained in [3] this angle is related to angles of internal friction and dilation by the following formula

$$\tan \delta d = (\sin\phi - \sin\nu)/\cos\nu \qquad (2)$$

The pressure at depth *h* can be evaluated by[2]

$$P_P = k_{P\gamma}\gamma h + k_{Pe}\rho a h \qquad (3)$$

where P_P is the passive pressure , $k_{P\gamma}$ is the passive pressure coefficient , γh is the unit weight multiplied by the depth of the wall element *h*, k_{Pe} is the dynamic passive pressure due to acceleration *a* of the wall element at depth *h,* and ρ is the soil density. Expression similar to equation (3) can be written for the active case where the subscripts *p* is changed to *a.*

$$P_a = k_{a\gamma}\gamma h + k_{ae}\rho a h \qquad (4)$$

For the present case where the boundary is fixed , refer to Figure 3, $a = \ddot{\Delta}$. Expressions for $k_{P\gamma}$, k_{Pe} , $k_{a\gamma}$ and k_{ae} are given by the following formulas

$$k_{P\gamma} = \tan(\pi/4 + \nu/2 + \delta d)\tan(\pi/4 + \nu/2) = \frac{1+\sin\phi}{1-\sin\phi} = \tan^2(\pi/4 + \phi/2)$$

$$k_{Pe} = 2\frac{\tan(\pi/4 + \nu/2)}{1-\sin\phi} \tag{5}$$

$$k_{a\gamma} = \tan^2(\pi/4 - \phi/2)$$

$$k_{ae} = 2\frac{\tan(\pi/4 - \nu/2)}{1+\sin\phi}$$

It is to be noted that the zero extension line theory gives exactly the same formulas for the static passive and active pressure coefficients as those given by the Rankin formula but has different formulas for the dynamic passive and active pressure coefficients.

SINGLE DEGREE OF FREEDOM SIMULATION

It is well known that for soil *sinΦ* is a function of the shear strain γ. The test result of such correlation reported by Cole [5] for dense sand is shown in Figure 2. He also showed that the angle of dilation remains almost constant during shearing..

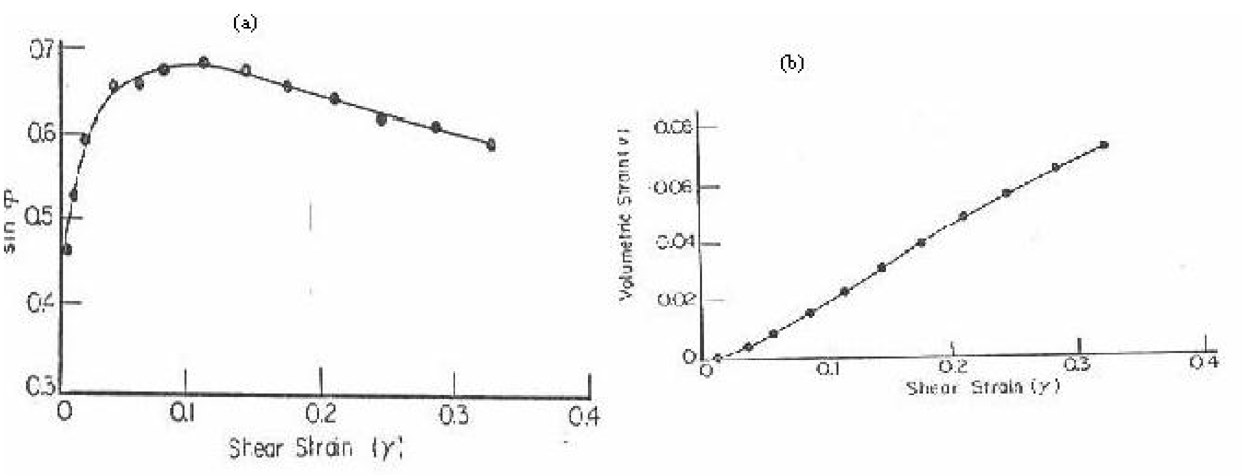

Figure 2. (a) *sinΦ vs* shear strain *γ* and (b) dilation vs shear strain γ[5].

Now if a unit element of the wall at depth *h* is moved into the sand and if the displacement of the element of the wall is D , then by zero extension line theory the displacement in the Coulomb zone and in the Rankin zone are given by the following formulas

Coulomb zone: $U_C = \Delta/\cos(\pi/4 + \nu/2)$

Rankin zone: $U_R = \Delta/\cos(\pi/4 + \nu/2)$ (6)

Likewise the rotation angle of the unit element, θ ,can be calculated from the relative displacement of the element by

$$\theta = \frac{\partial \Delta}{\partial z} \tag{7}$$

This means that at depth h the zero extension line translates into the sand. The shear strain for the slice of zero extension band at depth h with rotation θ will then be

$$\text{Shear strain:} \qquad \gamma = \frac{2\theta}{\cos\nu} \tag{8}$$

This indicates that the unit band of zero extension line undergoes shear related to the rotation of the element of the wall at depth h and thus different bands do not affect each other; see Figure 3.

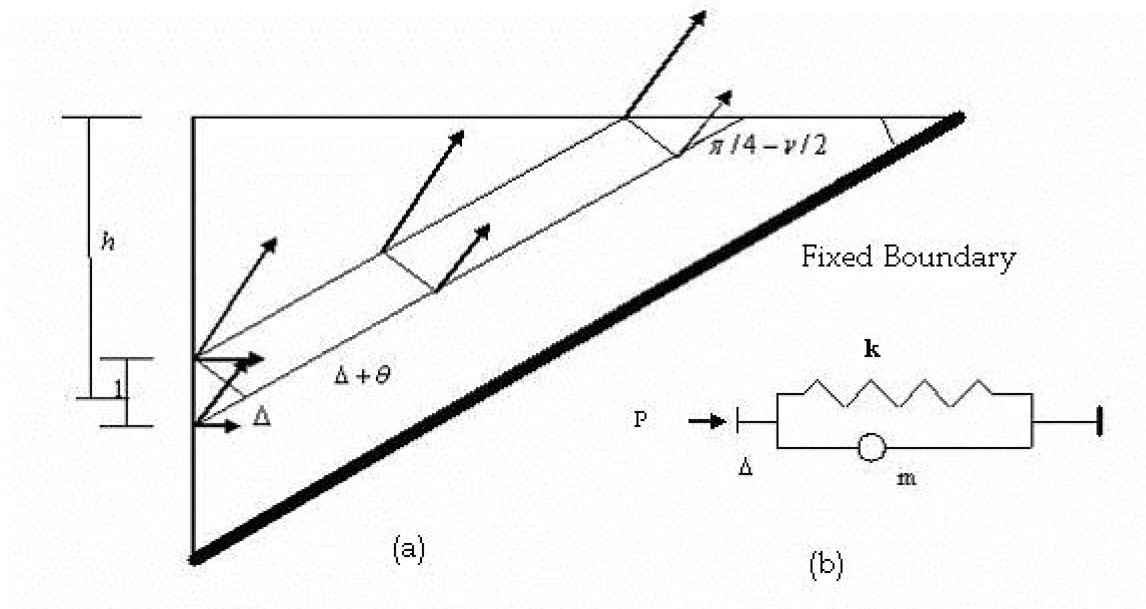

Figure 3. (a) Band of Zero Extension Line at depth *h* undergoing shear strain due to wall element rotation θ and displacement Δ, and (b) single degree of freedom system at depth *h*

It should also be noted that the translation without rotation of the element of the wall at depth h does not produce shear in the zero extension line band and it is the relative translation or rotation θ of the element of the wall at depth h which produces shear in the zero extension line band.

Considering the above findings, a single degree of freedom system can then be used to simulate the motion of the unit element of the wall at depth h. The stiffness k and the mass m for the single degree of freedom system is evaluated by the following formulas from the results of the static and dynamic pressure on the element of the wall at depth h. For the passive case

$$\begin{aligned} k_P &= k_{P\gamma}\gamma h / \Delta \\ m_P &= k_{Pe}\rho h \end{aligned} \tag{9}$$

and for the active case

$$k_a = k_{a\gamma}\gamma h / \Delta$$
$$m_a = k_{ae}\rho h \tag{10}$$

Dynamic property calculation procedure for single degree of freedom system

The wall will be divided into elements of unit height. Knowing the state of the wall at time *t,* it is intended to find the state of the wall at time $t + \delta t$. The calculation procedure for evaluation of stiffness, *k*, and mass , *m*, for each unit element of the wall is then as follows:

For any unit element of the wall at depth *h*, the wall displacement Δ and acceleration *a* are known at time t , and the rotation θ can be calculated by equation (7). Then the shear strain can be calculated from equation (8). Knowing the shear strain, $\sin\phi$ and ν can be determined by using graphs like that of Figure 2(a) and (b), respectively. Knowing $\sin\phi$ and ν, the passive and active pressure coefficients for the static and dynamic case can be calculated from equation (5). Finally *k* and *m* can be calculated from equation (9) or (10) for the passive or active case, and these single degree of freedom parameters can be used to calculate displacement at time $t + \delta t$ by using the incremental form of equations (3) and (4). This procedure results in the response history of the wall. It is to be noted that *k* and *m* can be quite nonlinear depending on the relation between $\sin\phi$ and shear strain of the soil γ.

CONCLUSIONS

From the discussion presented it can be concluded that using the zero extension line theory and with relation between $\sin\phi$ and γ being know, the dynamic parameters of the single degree of freedom system, *k* and *m,* can be calculated as function of wall displacement Δ and rotation θ.

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