Paper No. 217, Bull. ISET, Vol. 18, No. 3, Sept. 1981, pp. 125–130

SEISMIC DISPLACEMENT ANALYSIS FOR SURFACE HYDEL POWER STATIONS IN COHESIONLESS SOILS

V.H. Joshi[1] and S. Mukerjee[1]

INTRODUCTION

Structures founded on sloping ground have different depths of earth fill on either side of the structure, in the plane of the slope. Surface hydel power stations have earth fill on three sides. On the tail race side the depth of earth fill is relatively small. I.S. 4227, Part III (1970) recommendes a pseudostatic analysis with equivalent static forces to obtain a factor of safety. But this factor of safety does not account for the magnitude of displacements undergone, which is important in defining the failure. Moreover, the passive pressure mobilized to resist this movement also depends on the magnitude of the displacement undergone, which is not considered in the analysis suggested by the code.

Detailed elastoplastic two or three dimensional finite element method of analyses are very costly for many problems. As such, reliable displacement analyses at reasonable costs are desirable. New mark (1965) initiated the concept of displacement analysis for cohesionless soils. This idea was further explored by Seed and Goodman (1964), Goodman and Seed (1966), Mitra (1970) and Lavania (1972) for stability analysis of cohesionless slopes.

ANALYSIS PROPOSED BY NANDAKUMARAN AND MUKERJEE (1978)

This was proposed for surface hydel power stations with different levels of earth fill on the head race and tail race sides. (Figure 1). The passive soil resistance on the tail race

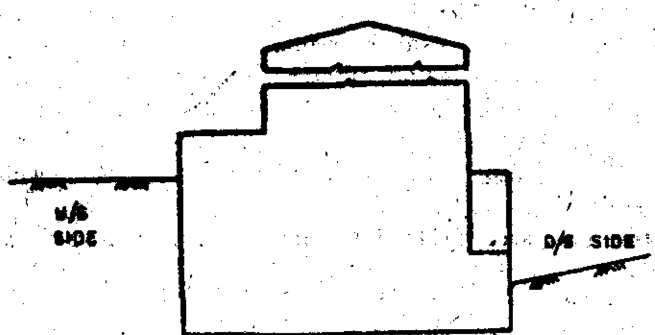

Fig. 1. - Schematic layout of a surface hydel power station

side was idealized by a trilinear function as shown in the Figure 2. The resisting forces due to the passive soil resistance on the tail race side and the frictional resistance at the base of

1. Department of Earthquake Engineering, University of Roorkee, Roorkee, India, 247 672.

the foundation were considered. The yield acceleration was defined as the acceleration which would just overcome the base frictional resistance. The portion of the design accelerogram for the site outside the threshold of the yield acceleration acting towards the head race side, is integrated to obtain the velocity curve (damage potential). The peak velocity is assumed

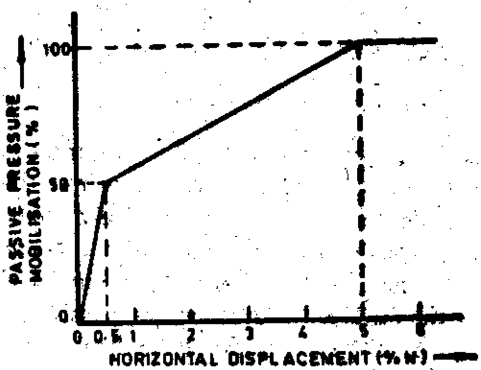

Fig. 2. Passive pressure mobilisation vs displacenent (Lambe and Whitman, 1969)

to decay to zero value due to the passive resistance of the earth fill on the tail race side. The displacement for a pulse is evaluated by equating the work done by the passive resistance to the maximum kinetic energy of the foundation block. The net displacement is obtained as the algebraic sum of all such displacements. Since the passive resistance on the head race side is considerably larger when compared to that on the tail race side, the slippage takes place towards the tail race side only intermittantly.

LIMITATIONS OF THIS ANALYSIS

The analysis considers the frictional resistance at the base only and neglects the contribution of the soil resistance on the d/s side in evaluating the yield acceleration; and hence in the assessment of the damage potential obtained by integrating the acceleration curve, say from time t_1 to t_2 (Figure 3). In evaluating the displacement, the kinetic energy due to the peak velocity, V_p, at the time t_2, is presumed to be resisted by the soil resistance alone. In reality, the frictional resistance at the base also provides some resistance which is not accounted for and this base resistance could be significant. When the passive soil resistance on the d/s side is negligible, this analysis tends to over-estimate the computed displacements leading to a conservative design.

The method does not explicitly perform the integration of the velocity curve to obtain the displacements. As such, the displacement contributed by the integration of each velocity lobe upto the peak velocity is not included in the computed displacements. This tends to underestimate the displacements which is undesirable.

Thus, the error in neglecting the passive soil resistance in estimating the yield acceleration and in neglecting the base friction in obtaining the net displacement tends to compensate that due to the commission of the integration of the initial portion of the velocity curve. It is difficult to estimate the net error introduced, which depends on the nature of the problem being analyzed. A rational method considering more realistic actuating and resisting forces is proposed.

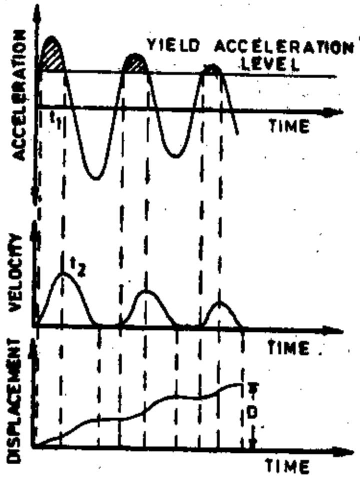

Fig. 3. Acceleration/velocity/displacement vs time (Nandakumaran and Mukerjee, 1978)

PROPOSED METHOD

A schematic diagram for the foundation system considered is shown in the Figure 1. The disturbing forces due to the inertia of the mass of the structure and its contents, the earth force towards the tail race side due to the earth fill and the surcharge resting on it, the inertia forces due to structures not resting on the foundation directly but their inertia forces act on the structure and all other forces with components in the tail race direction are computed for various values of horizontal acceleration coefficients. The net disturbing force, F_d, is expressed as a function of the acceleration coefficient, α, as is shown in the Figure 4.

To determine the initial yield acceleration, the value of F_d at $\alpha=0$ is read from the Figure 4. Assuming the earth pressure due to at rest condition on the tail race side, the normal reaction on the foundation is calculated considering all forces acting on the foundation, for $\alpha=0$ condition. From this, the resisting force, F_r, due to the frictional resistance at the base and the at rest earth pressure resistance on the tail race side, can be obtained. The yield acceleration (initial), A_{y1}, is obtained by reading the value of α from the Figure 4, for which the driving force, F_d, equals the resistance force, F_r.

Using this value of A_{y1}, the peak velocity for the first pulse of the damage potential is obtained by integrating the design accelerogram outside the threshold of A_{y1} acting towards the u/s side. This velocity pulse upto the instant of the peak velocity, V_p, is further integrated with respect to the time to get the displacement at that instant. Using this value of displacement, the corresponding passive earth force on the tail race side is obtained from the Figure 2 and thus obtained is the corresponding new value of the resisting force, F_r, which dissipates the peak velocity, V_p, completely in the time interval, δt. The time interval, δt, may be obtained from the impulse momentum equation:

$$m\ dV = F\ dt \qquad (1)$$

The mass term in this equation includes the mass of the structure and its components as well as the mass of the soil in the active failure wedge on the u/s side and the surcharge resting on it. The term F and dV in this expression are the resting force, F_r, and the peak velocity, V_p, respectively. Substituting these values, δt may be expressed as:

$$\delta t = mV_p/F_r \qquad (2)$$

The resisting forces may be presumed to be constant over the time period, δt, even though they may actually vary. The assumption envisages a linear variation of the velocity from the peak value, V_p, to zero. The velocity curve for the duration, δt is integrated to obtain the incremental displacement and hence the net displacement. Using this value of the displacement new values of the resting force and the corresponding yield acceleration are determined from the Figure 4.

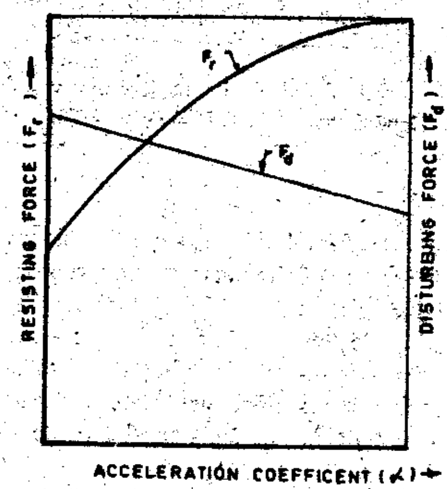

Fig. 4. Resisting force vs acceleration coefficient

The procedure is repeated for the entire duration of the design accelerogram. The acceleration, velocity and the displacement curves will be similar to those shown in the Figure 5.

ADVANTAGES OF THE PROPOSED METHOD

The base frictional resistance as well as the passive earth resistance on the tail race side are included in the estimation of the yield acceleration and the time, and hence the incremental displpcement, in which the peak velocity is dissipated. This is a more rational and logical approach. The inclusion of mass of the active wedge and the surcharge on it is yet another improvement. If these quantities are not included in the calculation for the mass term in the Equation (2), unsafe estimates of the computed displacements will result. Similarly obtaining displacements by integrating the velocity curve is a more appropriate method than computing the same from the passive resistance alone.

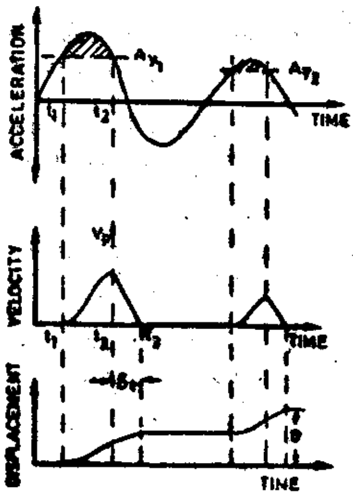

Fig. 5. Acceleration/velocity/displacement vs time

CONCLUSIONS

Though the concept of displacement analysis was initiated by Newmark (1965), not much work has been done on the plastic displacement analysis of foundations. The method proposed by Nandakumaran and Mukerjee (1978) does not consider an increase in the resisting forces within the velosity pulse duration. It also neglects the constribution of the base friction in dissipating the peak velocity. Nor does it account for the mass of the soil in the active wedge on the u/s side or the surcharge resting on it in estimating the kinetic energy, based on which the displacements are evaluated. The exact nature of the influence of these errors on the final value of the computed displacement would be difficult to assess because it depends on the nature of the particular problem.

The proposed method rationalizes all these short comings of the above cited method. Estimation of a modified resisting force at the instant of the peak velocity, consideration of the frictional as well as the earth pressure forces in the velocity disspation and the inclusion of the mass of the active wedge and the surcharge resting on it improves the quality of the analysis.

BIBLIOGRAPHY

1. Goodman, R.E. and Seed, H.B., (1964) "Earthquake Induced Displacements in Sand Embankments", Journal of ASCE, Soil Mech. and Fdn. Div., SM-2, pp 125–146.

2. IS. Code 4227 (1970) "Indian Standard Code of Practice for Structural Design of Surface Hydel Power Station, Part III, Substructure".

3. Lavania, B.V.K., (1972) "Seismic Stability of Cohesionless Soils", M.E. Thesis, Deptt. of Civil Engg., University of Roorkee, Roorkee.

4. Mitra, P.K., (1970) "A Model Study on Cohesionless Slope During Vibration", M.E. Thesis, Dept. of Earthquake Engg., University of Roorkee, Roorkee.

5. Nandakumaran, P. and Mukerjee, S., (1978) "Seismic Stability of Surface Hydel Power Station Substructure", VI Symp. on Earthquake Engg., University of Roorkee, Roovkes Vol. I, pp 289–293.

6. Newmark. N.M., (1965) "Effects of Earthquakes on Dams and Embankments", Geotechnique, Vol. XV, pp 139–160.

7. Seed, A.B. and Goodman, R.E., (1964) "Earthquake Stability of Slopes in Cohesionless Soils", Journal of ASCE, Soil Mech. and Fdn. Div., SM-6, pp 43–73.