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General Report —Session IV: Dynamic Earth Pressures and Seismic Design of Earth Retaining Structures

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General Report - Session IV

Dynamic Earth Pressures and Seismic Design of Earth Retaining Structures

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CLASSIFICATION OF PAPERS

Of the seven papers that were received for this session, three papers deal with dynamic earth pressure on retaining walls. The remaining papers deal with earthquake-induced displacement of gravity retaining walls, lateral stress ratio on retaining structures after earthquake loading, soil-diaphragm wall interaction underneath a dam, and shaking table tests and numerical simulation of seismic response of seawalls.

DYNAMIC EARTH PRESSURE ON RETAINING WALLS

Matsuzawa, Hazarika, and Sugimura (Paper 4.12) perform a numerical study of the dependency of the dynamic earth pressure on a retaining wall on its mode of movement. They develop a special finite element in which localized shear strains occur along two shear bands. The element is denoted *cracked triangular element*. The Monobe-Okabe slip surface approximately coincides with the envelope of the failure zone predicted in the analyses. However, the dynamic earth pressure coefficient appears to be somewhat higher than K_{AE} from the Mononobe-Okabe equation (Fig. 1). The point of application of the resultant active thrust depends on the mode of wall movement and acceleration level (Fig. 2). This parameter cannot be obtained from the classical Mononobe-Okabe analysis.

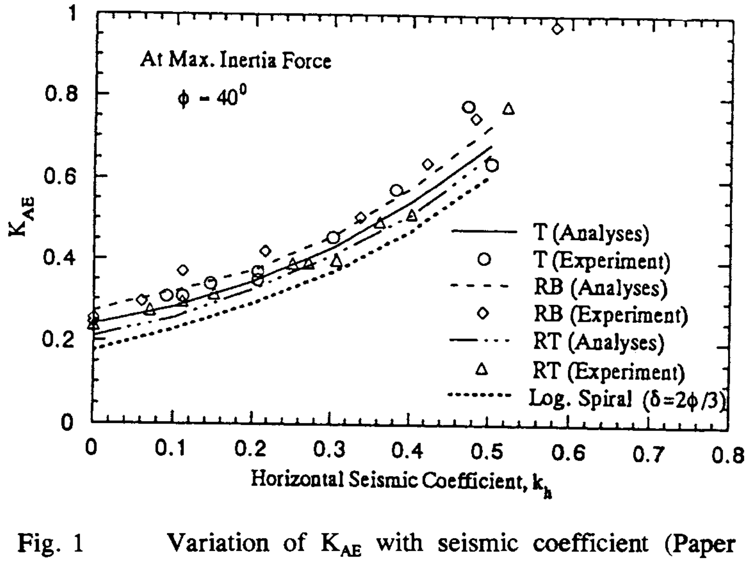

Fig. 1 Variation of K_{AE} with seismic coefficient (Paper 4.12)

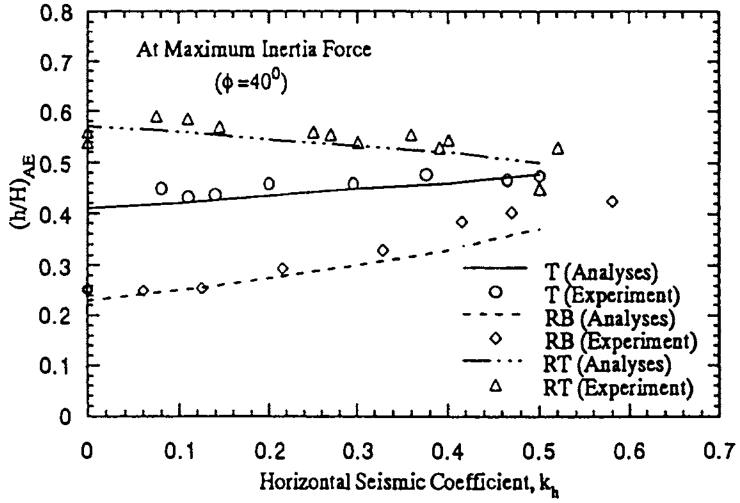

Fig. 2 Variation of $(h/H)_{AE}$ with seismic coefficient (Paper 4.12)

Anvar and Ghahramani (Paper 4.16) obtain static and dynamic active earth pressure coefficients for a dry, granular backfill by considering the equilibrium equations along the Zero extension Line (ZEL). This approach has been previously used by the second author and his co-workers to solve the dynamic passive earth pressure problem. The dynamic active earth pressure coefficient obtained by the ZEL theory is very close to K_{AE} from the Mononobe-Okabe analysis for ground accelerations up to 0.4g (Fig. 3).

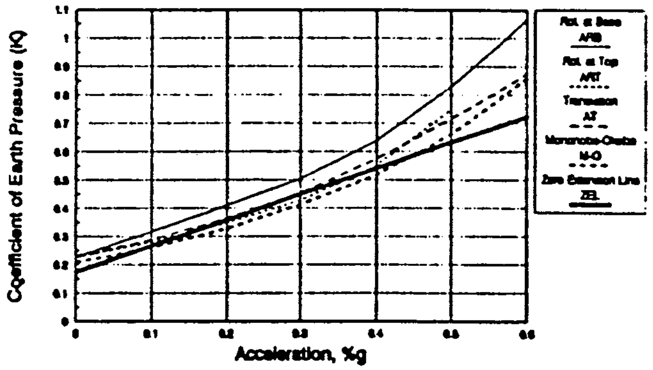

Fig. 3 Comparison of experimental and theoretical results (Paper 4.16)

Sun and Lin (Paper 4.17) present an analysis of dynamic soil pressures on a flexible, vertical retaining wall. The soil is assumed to be a linear elastic material with hysteretic damping and the wall is assumed to be a cantilever beam (Fig. 4). They obtain the solution to the problem by the boundary integral method. Figure 5 shows the frequency response of soil pressure on top of the wall. The soil Poisson's ratio is $\mu=0.3$, the mass density ratio is $\gamma=1.0$, and the material damping factor is $\delta=0.05$ in these solutions. The parameter $\xi=H^3G/EI$ represents the wall flexibility. The vertical axis $\Psi=Q/\rho H\ddot{u}_g$ is the normalized pressure at top of the wall, and the horizontal axis is normalized frequency w.r.t. frequency of backfill. The model used by Sun and Lin has similarities with the models proposed earlier by Scott (1973) and Wood (1973). A comparison with these earlier solutions would have strengthened the paper.

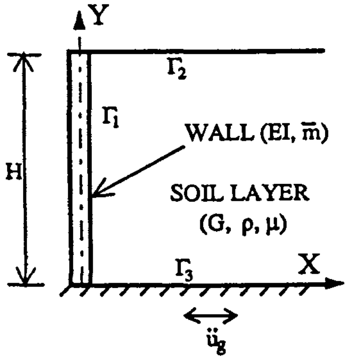

Fig. 4 Flexible retaining wall and soil system (Paper 4.17)

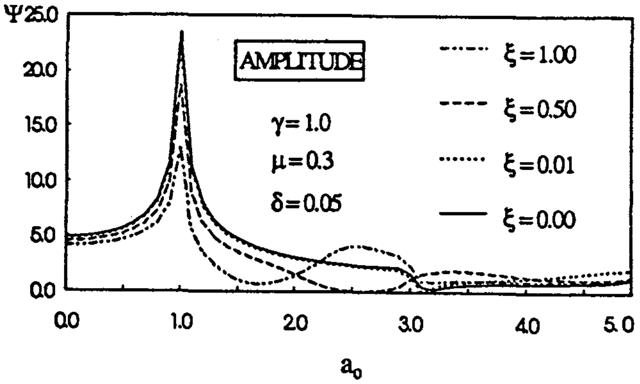

Fig. 5 Effect of wall flexibility on frequency response of soil pressure (Paper 4.17)

EARTHQUAKE-INDUCED DISPLACEMENT OF GRAVITY RETAINING WALLS

Zeng (Paper 4.14) presents the results of centrifuge tests conducted to study the displacement of gravity retaining walls during earthquakes. Numerical simulations based on Newmark's sliding block method were performed to analyze the data. For a gravity wall with dry backfill, sliding block method generates reasonable results. However, the method is difficult to apply for a retaining wall with saturated backfill. Zeng also suggests a method for estimating the permanent tilt of a gravity retaining wall with dry backfill.

Strangely missing from Zeng's paper is any reference to the pioneering work of Whitman and his co-workers, who have studied the same problems since late 1970's (see e.g. reference list in Nadim and Whitman, 1993).

EFFECT OF EARTHQUAKE LOADING ON LATERAL STRESS RATIO

Stamatopoulos (Paper 4.01) studies the earthquake-induced change in the permanent horizontal stress acting on a frictionless vertical wall with dry backfill. He uses the residual strain method to derive the relevant equations. The equations exhibit a limiting coefficient of lateral pressure that depends only on the slope of the critical state line and the Poisson's ratio of the backfill (Fig. 6). The lateral stress on the wall increases or decreases towards this limit after dynamic shaking. The expected values of the limiting lateral stress ratio lie between 0.5 and 0.7.

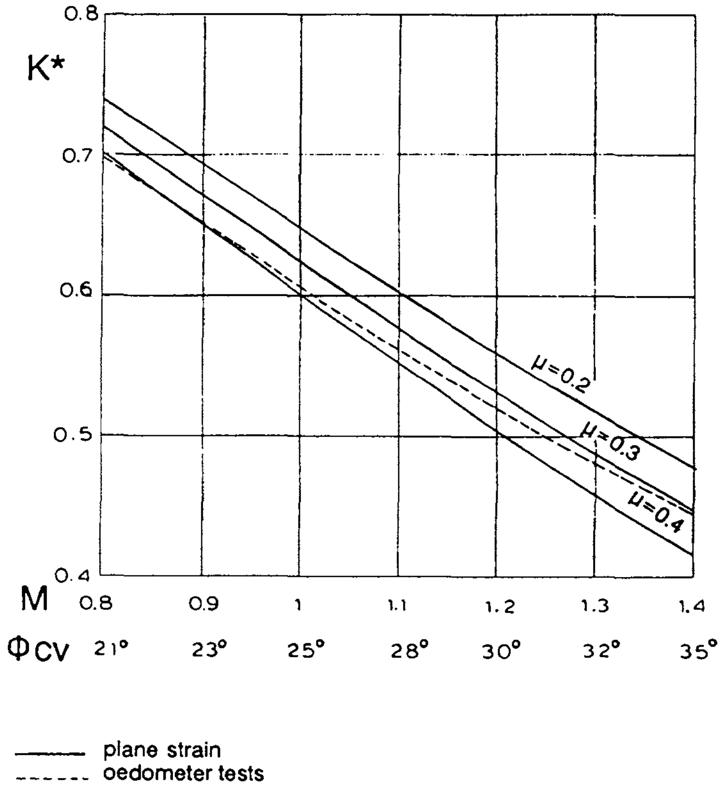

Fig. 6 Limiting value towards which the coefficient of lateral earth pressure changes after dynamic loading (Paper 4.01)

SOIL-DIAPHRAGM WALL INTERACTION

Watanabe and Kanazawa (Paper 4.02) study the interaction of soil with the diaphragm cutoff wall underneath an embankment dam (Fig. 7). The stability of an embankment dam with diaphragm cutoff wall constructed on riverbed sediment depends on the local structural behavior of the wall top. Watanabe and Kanazawa develop a modified joint element to evaluate the concentration of earth pressures on the top of the diaphragm wall.

Using the TADAMI dam (Fig. 7) as the target structure of the study, the computed and measured earth pressures on the diaphragm wall agree throughout the staged construction of the dam. The earthquake response analysis shows that the amplification of accelerations along the diaphragm cutoff wall is insignificant. However, some permanent displacements (sliding and separation) take place between the wall and soil on the lower stream side. Watanabe and Kanazawa conclude that they have developed a rational design method for an embankment dam with a diaphragm cutoff wall.

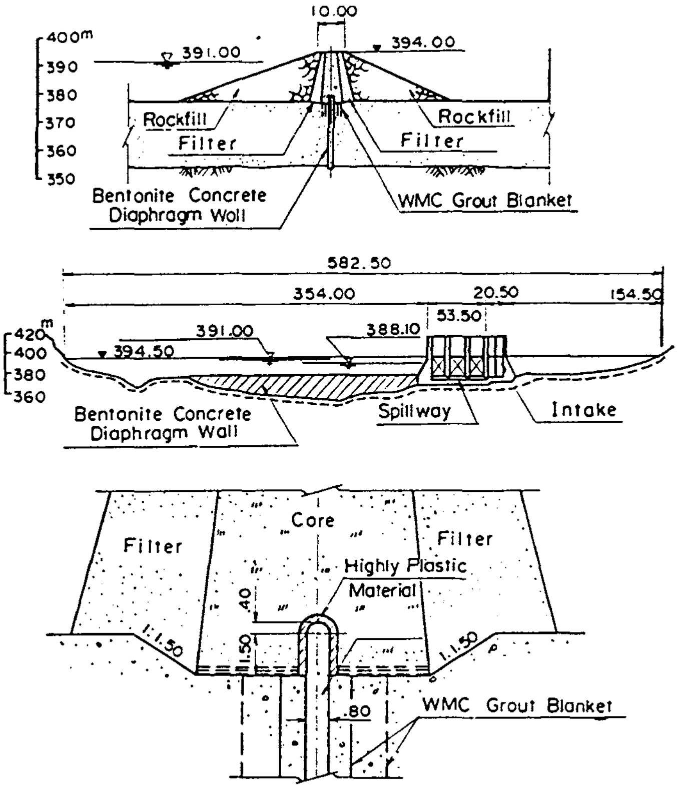

Fig. 7 Outline of TADAMI Dam (Paper No. 4.02)

SEISMIC RESPONSE OF A SEAWALL

Nishimura, Fukui, Sato, Kurose, and Fujitani (Paper 4.13) present the results of shaking table tests and numerical simulations of a caisson seawall model under earthquake loading. A 1/40 scale model of a caisson seawall consisting of a caisson, a mound, wave breaking works and a backfill, was placed in a steel frame box of 6.0m length, 1.0m width, and 1.3m height, which was fixed to a shaking table. Six series of experiments were carried out. The shaking table test results are utilized to validate a two-dimensional FEM analysis method with joint elements. The numerical model with fine mesh division and joint elements shows fairly good agreement with the test results (Fig. 8). The angle of the failure plane in the backfill agreed well with the active failure angle estimated from the Mononobe-Okabe formula. The dynamic earth pressure acting on the caisson was greater than the hydrodynamic pressure on the seaside. This hydrodynamic pressure was in reasonably good agreement with Westergaard's formula. The presence of water in the backfill increased the dynamic earth pressure significantly. The numerical model used by Nishimura et al. is apparently based on a total stress formulation, and they make no attempt to measure or predict the pore pressures in the backfill.

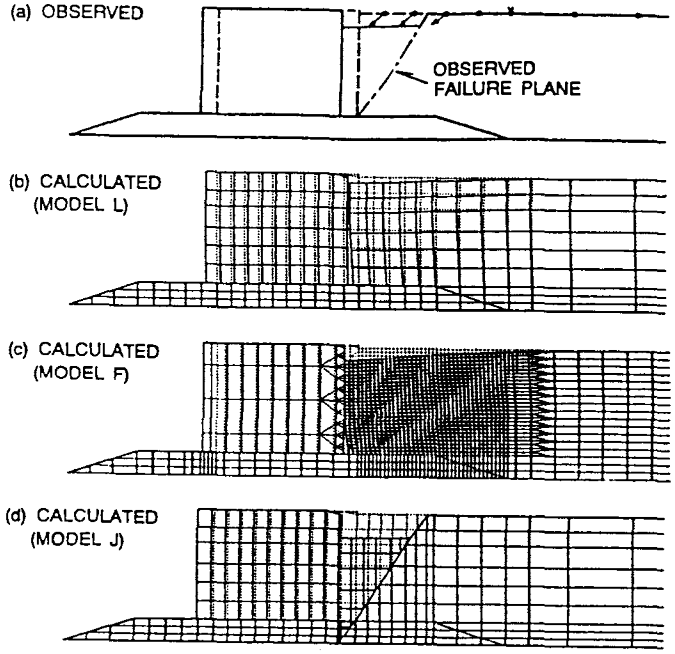

Fig. 8 Comparison of deformations between observations and calculations for a seawall (Paper 4.13)

GENERAL REPORTER'S COMMENTS

The behavior of retaining structures during earthquakes remains only imperfectly understood. This situation exists in part because of the great difficulties attending field studies of actual performance during earthquakes, where useful data are often lacking and the evidence of the details of any failure is usually marred by the action of water. Experimental and theoretical studies also face many problems of mechanical, constitutive and computational complexity.

Despite these difficulties, several useful design techniques have evolved. First among these is the Mononobe-Okabe theory. Although there are many theoretical and practical objections to it, its central results have been generally confirmed by research, and it remains the basis of most methods for determining dynamic lateral pressures.

Methods for determining the earthquake-induced permanent displacement of gravity walls with dry backfill have been elaborated by several researchers. Theoretical studies using a sliding block approach, augmented by finite element simulations and experimental methods using shaking tables and centrifuges, have led to reasonably accurate predictions of the sliding displacement. Methods to predict the earthquake-induced tilt are still unreliable.

Field observations of the performance of earth retaining structures during earthquakes show that retaining walls at waterfronts, where the backfill inevitably is in large measure saturated, have performed poorly during earthquakes. On the other hand, walls away from waterfronts have generally performed well during earthquakes. Obviously the culprits are water and build-up of excess pore pressures, which in unfavorable circumstances may lead to liquefaction of the backfill. Unfortunately, none of the papers presented in this session tackle this challenging problem directly.

The following topics for discussion in this session are suggested:

- Do we need to improve upon the Mononobe-Okabe equation for the estimation of dynamic active earth pressures on a wall with dry backfill?
- Are we satisfied with the existing models for estimating the permanent earthquake-induced wall displacements?
- Do we have any good models for predicting the earthquake response of a saturated backfill and the resulting pressures on the retaining structure?
- Are the existing finite element models good enough for analyzing the interaction of a flexible wall with soil under dynamic loads? What if the soil is saturated?
- The post-earthquake lateral pressure on the wall may be different from the pre-earthquake pressure. Is this a factor that should be considered in design?
- Many researchers interchange the words "design" and "analysis" freely. Is it correct to do so?

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