[別紙１]

論　文　の　内　容　の　要　旨

論文題目　Simple and rational evaluation of soil deformation induced by faulting for estimating performance of pile foundations (杭基礎の挙動評価のための断層近傍の地盤変位の合理的な評価手法)

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In the central part of Taiwan (Chi-Chi), an earthquake with a local magnitude of 7.3 (moment magnitude 7.6) occurred at 1:47 AM (local time) on the 21st September 1999. Among the most shocking phenomena during this earthquake were the extraordinarily large displacements of the reverse fault ruptures along the 105-km long Chelungpu Fault and the high intensities of the ground shaking in the surrounding fault area.

At the time when the Chi-Chi earthquake stroke, the Nanto section (central Taiwan) of Freeway Route #3 (Fwy 3) was under construction. The alignment of Fwy 3 is along the boundary of the western plains and the foothills of Taiwan and was crossed by the fault's alignment in four locations: Bauweishan, Pinlinchi, Fuanglishan and Choshuihan (Chen et Al.,'01)

The attention will be focused on the severe damages inflicted to a viaduct's foundations in

Bauweishan, where 300 pile foundations were respectively deformed and cracked by large deformations of soils caused by the fault rupturing (Moh and Associates, ‘00). After the earthquake, a new viaduct was constructed 11m in south direction respect to the original plan, therefore there are still many piles embedded in the deformed soil mass. Since they are still preserving their deformed shapes in the soil, investigating these piles was considered to provide a clear perspective for designing pile-supported structures in vicinities of active faults. A discussion on this issue must be based on a quite different scenario from those for ordinary designs; in the ordinary design, ground accelerations and/or velocities are always crucial factors. Due attention should be paid to deformation build-up in soils that cover hidden faults. When the bedrock comes steadily up into a poorly consolidated soil deposit, strains can be distributed over wide zones. Consequently an embedded foundation can be shifted from its original location, and deformed even though it is located quite far from the rupture plane.

Thanks to field investigations, relative horizontal and vertical pile cap positioning (before and after earthquake), pile integrity investigations by boreholing, soil boreholing, SPT, electric resistivity tomography and PS waves logging were measured (Konagai, ‘07). The investigation of the underground soil characteristics have shown that the footwall is constituted by a very stiff ($N_{SPT}>30$) Quaternary soil (gravel-sand); the hanging wall by a poorly consolidated ($N_{SPT}<7$) Pliocene-Miocene soil (sand-clay). The evaluation of the pile induced mechanism of failure shows that there is evident difference when the pile were supporting or less their piers. According to the earthquake accelerographs, the piers must have encountered at first strong accelerations which brought the piles to fail beneath the pile caps (inertial effect); in a second stage the induced soil deformations brought failure in deeper zones (kinematic interaction).

The key parameters that influence the behavior of poorly consolidated soil deposits when subjected to bedrock displacements are highlighted thanks to numerical simulations (FEM), a simple analytical model (Konagai, ‘04) and compared with the available literature. The objective is to find out a “numerical control parameter” ($\gamma_{rupture}$) associated with concept of soil surface limit of inclination (i_{lim}) and over-all strain ($\gamma=\Delta_H/H$) (Bray, ‘90) for distinguishing the soil deposit state of deformation (when $\gamma \leq \gamma_{rupture}$) and rupture development (when $\gamma > \gamma_{rupture}$).

The key parameters that regard soil-structure interaction have been highlighted thanks to a study of how a pile (with similar dimensions to ones of the case of Bauweishan) displaces / deforms / fails when positioned at different locations on the hanging wall of a reverse fault. It has been developed a nonlinear soil-pile interaction model, thanks to the Thin Layered Element Method (TLEM) (Tajimi and Shimomura ’76, Ahsan et Al. ’07, Tahghighi et Al. ’07), nonlinear features of the reinforced concrete according to the Eurocode 2 (ENV 1992) and elasto-perfectly plastic behavior of the horizontal (Broms ’64) and vertical soil springs stiffness (soil-pile friction considerations). After a *critical distance* from the primary surface failure trace on the soil deposit surface, as soil strains become irrelevant and soil behaves like a rigid mass, piles don’t suffer anymore relative displacements respect to the soil deposit surface and their induced stress / strains are far beneath the pile’s limit of failure.

The understanding that piles behave like soil strain gauges, the attention returns to the soil deposit numerical simulations and literature review (Cole and Lade ’84, Ueta ’03) regarding the study of the location of the *primary surface failure* ($\gamma/\gamma_{rupture} > 1$) in a homogenous soil deposit which can be successfully localized with a linear approximation (*linear approximation method with dip* α^*) based on the following few key parameters: the initial fracture dip angle at the bedrock (□ and it’s relation with the soil friction angle (ϕ), the height of the soil deposit (*H*) and the dilatancy (ψ).

From numerical simulations it has been observed that the primary surface failure and the critical distance have the following correlation: if primary failure surface has shallow dip angles, the critical distance is extending till a maximum of 20 times the soil deposit depth *H*; oppositely, if it has steep dip angles, the critical distance has an extent closed to the soil deposit depth. Some laboratory test results available in literature (Cole and Lade, ’84; Ueta and Tani, ’99; Panien et Al. ’05; Lee ’05, Hardy et Al. ‘07) are showing the same trend of results.

As a pile can be safely built outside the critical length, the *critical distance method* can be extended as setback criterion to all generic structures. A structure can be located within its extension just if it can be demonstrated that induced strain / displacements are compatible with the structure’s admissible ones.