Reprise of 52nd Rankine Lecture "Performance-Based Design in Geotechnical Engineering" by Professor Malcolm Bolton

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ON 10 December 2012, Professor Malcolm Bolton of the University of Cambridge delivered a reprise of his Rankine Lecture with the theme "Performance-Based Design in Geotechnical Engineering" to 125 participants at the Auditorium Tan Sri Ir. Professor Chin Fung Kee, IEM in Petaling Jaya. The lecture started at 5.30 p.m. His original Rankine Lecture was made in London on 12 March 2012.

Figure 1: Professor Malcolm Bolton giving his Rankine Lecture at IEM, Petaling Jaya

The lecture presented findings from centrifuge studies on steep slopes and use of the Mobilizable Strength Design method for braced deep excavations; both in clays to demonstrate that it is possible to evaluate the performance of earth structures. Professor Bolton argued that geotechnical engineering designs must strive to limit deformations to tolerable magnitudes instead of merely factoring down soil strengths.

1. SLOPES

Professor Bolton presented data from centrifuge tests on a physical model of a steep 36° slope in clay. The clay used possessed the critical state friction angle of 24° and the tests featured subjecting the slope to cyclical loadings (exposures) from wet and dry climatic seasons with detailed measurement of pore water pressures and soil particle movements. In each wet season, he pointed out that whenever the averaged shear strengths mobilized in the slope exceeded the critical state values as the result of diminished soil suctions, large strains developed which were mostly irrecoverable in the ensuing dry season whereas below the critical states these were small and recoverable. The irrecoverable strains led to creep in the slope. A critical state diagram is shown in Figure 2.

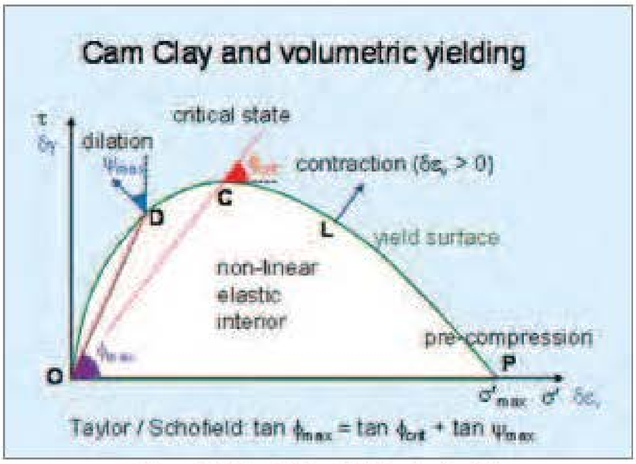

Figure 2: Critical States Soil Mechanics with the original Cam-Clay yield locus

Professor Bolton revealed that the strains associated with the mobilization of super-critical strengths resulted in dilation or swelling in the clay which grew cumulatively through successive wet seasons. Softening or strength degradation in the clay accompanied the cumulative slope swelling and creep, eventually leading to local failure at the toe of the slope after repeated wet seasons to inevitably trigger off progressive failure in the slope.

This has been provided as the mechanism for delayed failure of steep slopes in wet climatic regions.

Professor Bolton emphasised that limiting shear strengths mobilized in slopes to below critical state values would keep deformations in the ground small and recoverable to ensure freedom from first time slope failures; just as the late Professor Alec Skempton had advocated in 1970.

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2. EXTENDED MOBILIZABLE STRENGTH DESIGN METHOD FOR BRACED EXCAVATIONS

Professor Bolton demonstrated that with clays and silts, the mobilized strength factor (a proportion of the undrained shear strength value) variation with the shear strain parameter conforms reasonably well to a power law. He had chosen to normalize shear strains with the strain value at 50 percent undrained shear strength as the shear strain parameter for use in his power curve expression after a study of 115 laboratory tests reported on 19 different clays and silts. The expression fitted the test data well in the mobilized strength factor ranging from 0.2 to 0.8; a spread relevant to most field situations in service. (Please refer to a separate report on Professor Malcolm Bolton's short course on 9 December 2012 at IEM for further details on this.)

This permitted his development of the Mobilizable Strength Design (MSD) method to facilitate deformations of a geo-structure or geotechnical engineering construction under load to be made possible with 'simple' hand calculations to assess its performance in service. He then proceeded to describe the application of the MSD method to estimate the accompanying deformations in the retaining wall for varying excavation depths and supporting strut configurations.

The method was then improved by invoking the principle of energy conservation where the loss of potential energy in the deforming ground is balanced by the sum of work dissipated in plastic shearing of the soil and elastic energy stored in bending the bracing wall. It employs a sine wave function to represent the incremental displacement profiles in the ground and the wall below the lowest support prop for the stage of prop deployment. It is called the extended MSD method. In solving for energy conservation incrementally, the deformations in the ground and wall would be obtained for each increment. The resultant deformation at each propping stage is simply the summation of the incremental deformations up to that stage. This extended MSD method is still executable manually though the calculations have become considerably more involved to accommodate the required number of propping stages and undrained shear strength variation in the ground.

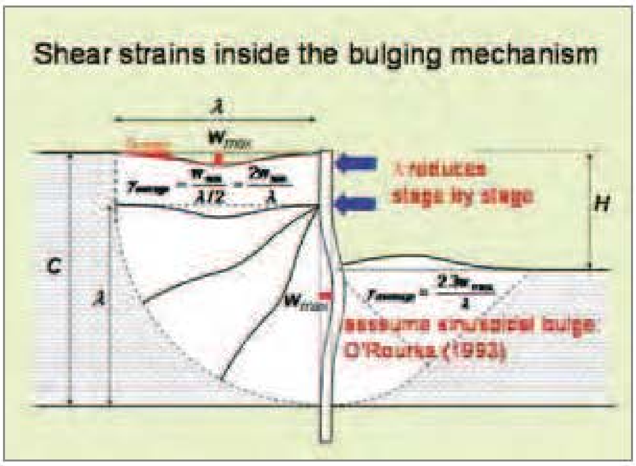

Figure 3: Deformation Mechanisms for Braced Excavation in Clay

Figure 3 illustrates the mechanisms involved for the extended MSD method. The wave-length, λ, for the sine function, representing the width of the incremental subsidence trough behind the braced wall at each excavation stage, had been observed in centrifuge tests to approximate the depth of clay below the lowest prop for that stage. Professor Bolton pointed out that this runs counter to the long-held position that the distance for ground deformations outside a deep excavation is a function of the total depth of the excavation. Only in the case of an unpropped embedded retaining wall does the lateral extent of ground deformation depend on the total excavation depth.

Professor Bolton presented deformations obtained using the extended MSD method for a great variety of excavations and ground conditions which compared very favourably to results from evaluations conducted with the finite element analysis employing a very sophisticated constitutive soil model. The method calibrated within an error factor of less than 1.4 against documented performances for 110 excavations in 9 cities across the world! He stated that safe excavation depths in normally consolidated clay should have the mobilized strength factor in excess of 1.25.

The extended MSD method permits the mobilized strength factor in the ground to be determined from measured deformations. Using data available in the report on the public enquiry into the collapse of the Nicoll Highway tunnel's braced excavation in Singapore in 2004, Professor Bolton demonstrated the extended MSD method's ability to 'predict' the excavation's collapse.

3. ON PERFORMANCE-BASED DESIGN

Professor Bolton concluded his lecture with an impassioned plea for geotechnical engineers to examine if current design methods dominated by safety factors are appropriate when it is deformations that cause problem. He reiterated that the performance of soil structures can be predicted by designers using the MSD method as a matter of routine to prevent both ultimate limit state and serviceability limit state failures. As long as the shear strain parameter is measured and known, MSD calculations are no more complicated than conventional design methods.

He pleaded for performance-based design to be adopted since it satisfies performance requirements of strength, deformation and durability in a set of design situations that define "worst credible conditions".

After graciously fielding a number of questions from the floor, Professor Bolton ended his lecture at 7.30 p.m. He was given a warm round of applause from the floor before being presented with an IEM momento by the Chairman of IEM's Geotechnical Engineering Technical Division. ■

In 1994, Ir. Yee set up his own practice, Geo.Consult, to support the construction industry with both expert and specialist consultancy, in particular on geotechnical engineering aspects. He has authored/co-authored more than a dozen technical papers in local and international conferences. Ir. Yee is an expert witness and accredited checker for design of geotechnical engineering works registered with the Board of Engineers Malaysia.