Finite Element Analyses in Geotechnical Engineering – *Part 3: An Indispensable Tool or a Mysterious Black Box?*

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This article is a continuation of the writer's contribution published in the November issue of JURUTERA Bulletin (pp. 28–31). It forms the second of three case studies that constitutes the full article.

Engineering experience and judgment, as well as the fundamental knowledge and understanding of theoretical soil mechanics are important ingredients in shaping a responsible and experienced FEA user. The benchmarking of FEA analyses is good practice to avoid or reduce carelessness in design. Ong (2006) highlighted that the responses from a typical simulated geotechnical analysis can be benchmarked quantitatively and qualitatively.

Quantitative benchmarking involves (i) software *vs.* software, (ii) software *vs.* reliable field data and (iii) software *vs.* reliable laboratory experimental data, which are often used to produce closed-form and analytical solutions, while qualitative benchmarking involves software vs. experience and judgment.

CASE STUDY 3: BENCHMARKING OF A SLOPE STABILITY AND SEEPAGE PROBLEM (SOFTWARE VS. FIELD DATA)

Appreciating and modelling the problem at hand

A 12m high hydraulic sand-filled embankment that forms part of the approaching section to a large span bridge structure was to be built. During construction, embankment toe failure occurred and construction had to be suspended. Detailed FE transient (time dependent) seepage and limit equilibrium slope stability analyses were carried out to investigate the causes of the toe failure using commercially available software SEEP/W and SLOPE/W.

Figure 1 shows the simulated embankment. The transient FEA analyses would generate the fluctuating phreatic surface when the hydraulic boundary conditions and time intervals are carefully and correctly specified. The required phreatic surface can be exported to SLOPE/W so that slope stability analyses can be performed on that particular phreatic surface as shown in Figure 2.

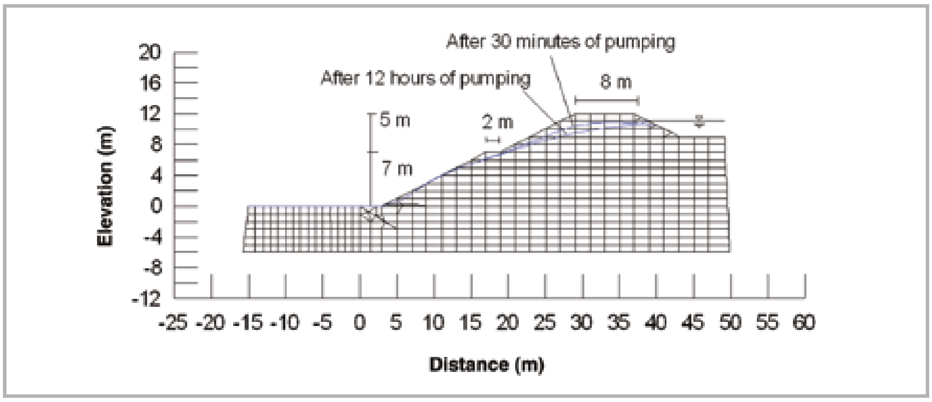

Figure 1(a): Development of phreatic surfaces due to hydraulic sand-filling after 30 minutes and after 12 hours respectively

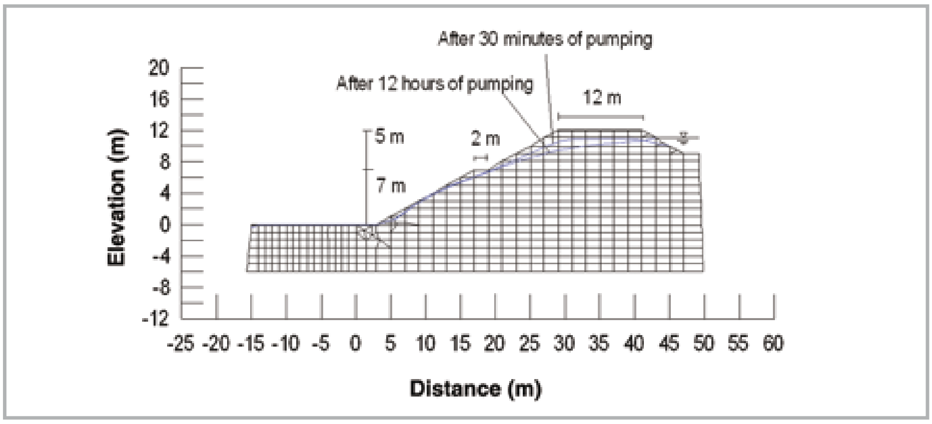

Figure 1(b): Development of phreatic surfaces due to hydraulic sand-filling after 30 minutes and after 12 hours respectively

Table 1 shows the summary of embankment factor of safety (FOS) when two types of embankment configurations and pumping conditions are modelled. It is evident that the FOS can be increased by lengthening the flow path (i.e. increase in dimension W) from the flow channel to the rock toe of the embankment.

The equipotential lines of the sand-fill embankment are shown in Figure 3(a). From the results of the transient analyses, it is found that if the hydraulic sand-filling process is suspended for at least 12 hours, the phreatic surface would drop to a safer level, as illustrated in Figure 3 (b). By suspending the sand-filling process for 12 hours, the corresponding FOS is noted to have increased to 1.27 as shown in Table 1.

Therefore, during construction, it is proposed that a 12-hour interval of hydraulic filling-suspension is to be strictly enforced. This is also practical from the construction viewpoint. In comparison, if the hydraulic sand-filling process were to

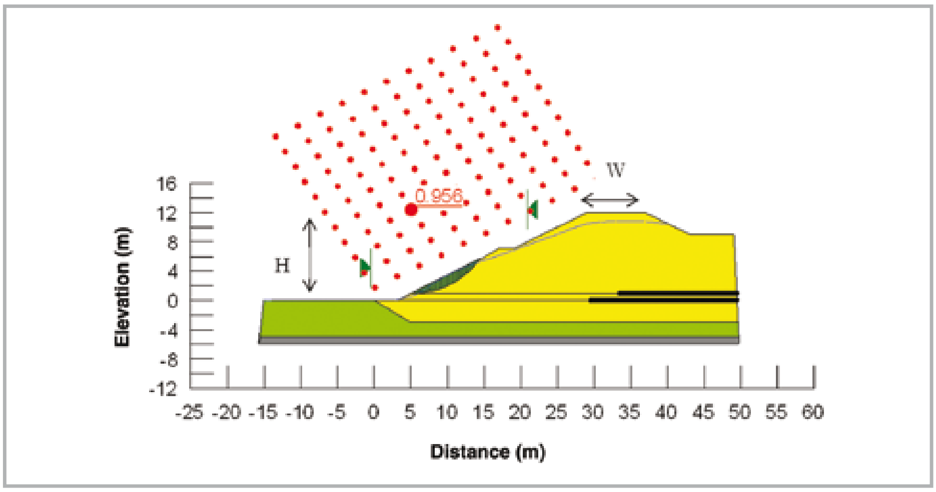

Figure 2(a): FOS after 30 minutes of hydraulic sand-filling (H=12m, W=8m)

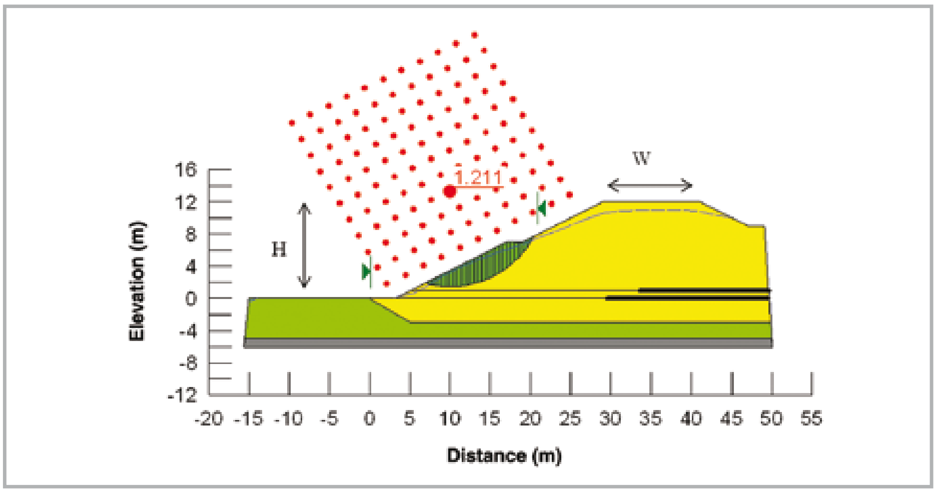

Figure 2(b): FOS after 30 minutes of hydraulic sand-filling (H=12m, W=12m)

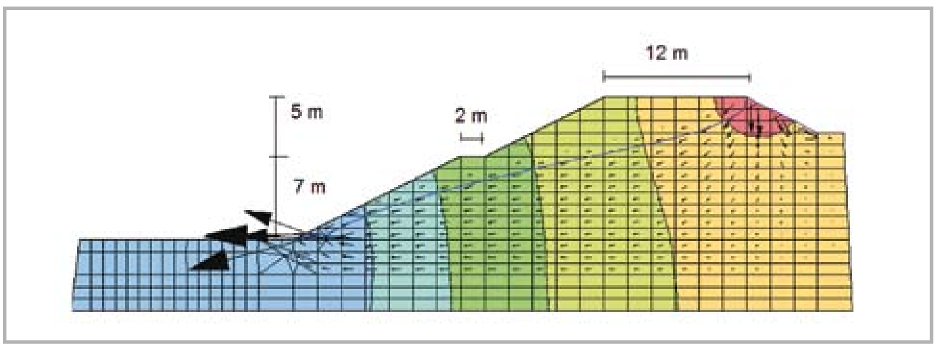

Figure 3(a): Equipotential lines, associated phreatic surface and exit gradient in analysed embankment

Table 1: FOS of embankment shoulder against failure during hydraulic sand-filling

Embankment	Quantity per linear m of wall as output by PLAXIS	Conversion to quantity per pile
H=12, W=8	30 mins	0.96
	12 hours	0.84
H=12, W=12	30 mins	1.21
	12 hours	0.98
	After suspension for 12 hours	1.27
	After suspension indefinitely	1.82

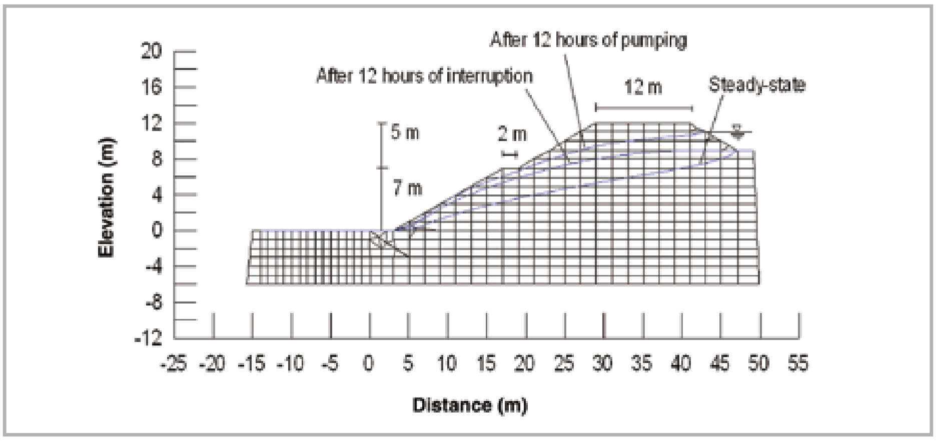

Figure 3(b): Drop of phreatic surface due to the suspension of sand-filling for 12 hours

be suspended 'indefinitely', the phreatic surface would approach 'steady-state' condition as shown in Figure 3(b).

Results, interpretation and discussion

Based on the detailed analyses, an improved embankment design as shown in Figure 4 was implemented. An instrumentation program that included water standpipes was also implemented to assist in monitoring the stability of the embankment to prevent further incidents. Figure 5(b) shows the computed and measured drop in phreatic levels. It is observed that the computed data for distances 7m and 22m away from the embankment toe generally provides values that are about the average of the measured values. However, at 11m from the embankment toe, the computed drop in phreatic level is slightly higher than the average measured values.

From Figure 5(b), it is also noted that the drop in phreatic levels increases with the distance away from the embankment toe, which is similar to the prediction made by SEEP/W as discussed earlier. The discrepancies between the computed and measured values could be due to the persistent rainfall that might have prevented the phreatic surface from dropping further.

From both the computed and measured data, it is evident that if the toe of the embankment is not strengthened and proper drainage paths are not provided, the embankment toe can easily fail due to pore water pressure build-up. Therefore, when the pore water pressure build-up was reduced by introducing an improved embankment design and proper construction method, the embankment was successfully constructed without any further incidents as shown in Figure 6. The importance of benchmarking using reliable field results is thus highlighted.

Concluding remarks for Case Study 3

The toe failure of the hydraulic sand-fill embankment was believed to be caused by wash water transporting the hydraulic sand-fill at the top of the embankment at that stage of the construction, seeping downwards through the embankment sand-fill. Detailed seepage and slope stability analyses based on FEA and limit equilibrium methods have been performed to determine the proper construction method and to establish an improved embankment design so that the construction of the embankment can be continued to its maximum height of 12m.

A field instrumentation program consisting of water standpipes was implemented during the construction stage to consistently monitor the fluctuations of the phreatic surface so that the

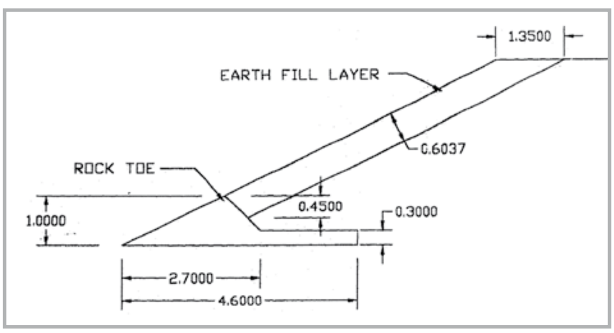

Figure 4: Improved design of embankment toe

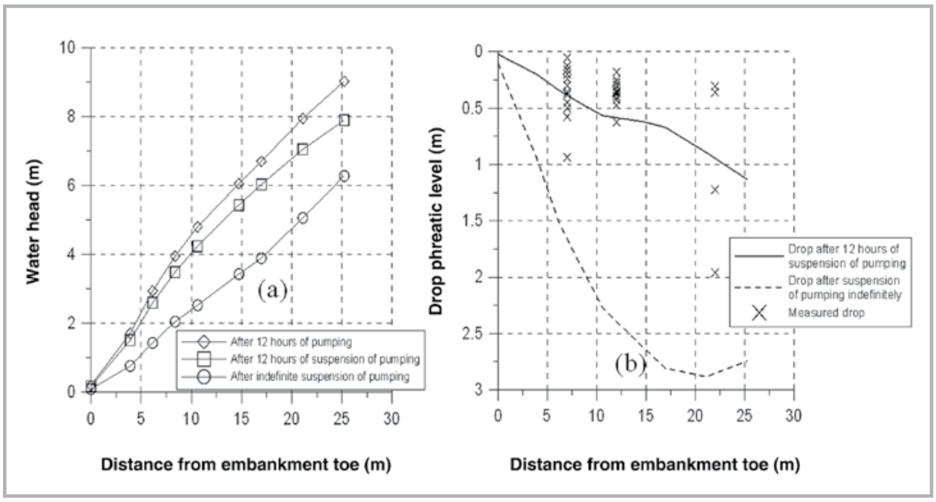

Figure 5: (a) Extracted water head data from SEEP/W analysis and (b) comparison between computed and measured drop in phreatic level

construction method derived based on the computer simulation were within working limits to prevent further failure. The 12m high hydraulic sand-fill embankment had been successfully constructed without any further incidents after the proposed revised construction method had been strictly adhered to.

Overall conclusion for Case Studies 1, 2 and 3

When commercial software is used in complex geotechnical problems, there is a clear and present danger that engineers using such a program may not be aware if a gap exists in their knowledge. One of the reasons could be due to the complex nature of the study of soil mechanics and the need to use very simple concepts in basic education to explain these concepts. While these simple concepts are useful in illustrating ideas, they may cause major flaws in a design when extrapolated to complicated real life problems.

Three case studies based on FEA have been discussed and it is to be realised that benchmarking forms an integral part of numerical modelling in order to increase the confidence level so that any potential numerical errors can be minimised, if not eliminated. If used effectively, finite element modelling can indeed be an indispensable tool to provide an insight into complex geotechnical soil-structure interaction problems. ■

Figure 6: (a) Flow channel for material transport at the crest of the embankment and (b) construction of rock toe wrapped with geotextile

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