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Efficient analytical approach for stability analysis of infrastructure slopes

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Geotechnical area: Slope stability

Research background

- Infrastructure asset owners manage a large portfolio of earthworks (e.g., Network Rail manage 191,000 earthworks; Highways England manage 49,000 earthworks).
- The key challenge is to identify the earthworks which need most urgent attention.
- Automation tool which is more efficient than FEM/LEM is needed for a large portfolio of earthworks.

Research objective

✓ Develop an efficient analytical approach for the analysis of a large portfolio of earthworks.

Efficient analytical approach for infrastructure slopes

Stability charts
(Bishop and Morgenstern, 1960)

$$F = m - n\, r_u \qquad (1)$$

Analytical stability equation
(Huang, 2018)

$$F = A\left(\frac{c'}{\gamma H \tan\phi'}\right)^{B} \tan\phi' + \frac{\tan\phi'}{\tan\beta} - \left(\frac{c'}{\gamma H}\frac{1}{\tan\beta} + \frac{\tan\phi'}{\sin\beta\cos\beta}\right) r_u \qquad (2)$$

$$A = 10.50\exp(-0.009\beta) \qquad B = 0.72 - 3.5\times10^{-5}\beta^2 + 0.0031\beta$$

- Use of stability charts require checking the coefficients m and n in Eq. (1), which is tedious and not efficient.
- Eq. (2) calculate F explicitly as a function of slope geometry (β, H), soil properties (γ, c', ϕ') and r_u.
- Eq. (2) can be extended to comply with Eurocode 7, and probabilistic analysis using FOSM (Huang, 2021).
- Eq. (2) can easily be incorporated into modern digital design workflow (e.g. Excel via user-defined functions).
- Application of Eq. (2) for infrastructure slopes is illustrated in Fig. 1 for back analysis of first-time failures in railway cuttings. The failures are reasonably explained by low F and high probability of failure (P_f).
- Fig. 1 demonstrates the high efficiency of the analytical approach, and shows that the most critical assets can be identified by ranking the factor of safety (F) or probability of failure (P_f).

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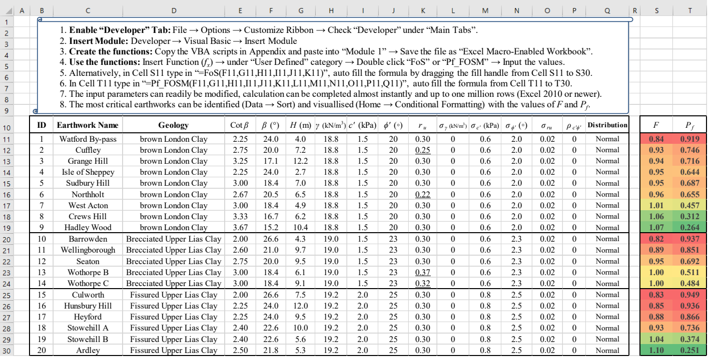

1. **Enable "Developer" Tab:** File → Options → Customize Ribbon → Check "Developer" under "Main Tabs".
2. **Insert Module:** Developer → Visual Basic → Insert Module
3. **Create the functions:** Copy the VBA scripts in Appendix and paste into "Module 1" → Save the file as "Excel Macro-Enabled Workbook".
4. **Use the functions:** Insert Function (f_x) → under "User Defined" category → Double click "FoS" or "Pf_FOSM" → Input the values.
5. Alternatively, in Cell S11 type in "=FoS(F11,G11,H11,I11,J11,K11)", auto fill the formula by dragging the fill handle from Cell S11 to S30.
6. In Cell T11 type in "=Pf_FOSM(F11,G11,H11,I11,J11,K11,L11,M11,N11,O11,P11,Q11)", auto fill the formula from Cell T11 to T30.
7. The input parameters can readily be modified, calculation can be completed almost instantly and up to one million rows (Excel 2010 or newer).
8. The most critical earthworks can be identified (Data → Sort) and visuallised (Home → Conditional Formatting) with the values of F and P_f.

ID	Earthwork Name	Geology	Cot β	β (°)	H (m)	γ (kN/m³)	c' (kPa)	ϕ' (°)	r_u	σ_γ (kN/m³)	$\sigma_{c'}$ (kPa)	$\sigma_{\phi'}$ (°)	σ_{ru}	$\rho_{c'\phi'}$	Distribution	F	P_f
1	Watford By-pass	brown London Clay	2.25	24.0	4.0	18.8	1.5	20	0.30	0	0.6	2.0	0.02	0	Normal	0.84	0.919
2	Cuffley	brown London Clay	2.75	20.0	7.2	18.8	1.5	20	0.25	0	0.6	2.0	0.02	0	Normal	0.93	0.746
3	Grange Hill	brown London Clay	3.25	17.1	12.2	18.8	1.5	20	0.30	0	0.6	2.0	0.02	0	Normal	0.94	0.716
4	Isle of Sheppey	brown London Clay	2.25	24.0	2.7	18.8	1.5	20	0.30	0	0.6	2.0	0.02	0	Normal	0.95	0.644
5	Sudbury Hill	brown London Clay	3.00	18.4	7.0	18.8	1.5	20	0.30	0	0.6	2.0	0.02	0	Normal	0.95	0.687
6	Northholt	brown London Clay	2.67	20.5	6.5	18.8	1.5	20	0.22	0	0.6	2.0	0.02	0	Normal	0.96	0.655
7	West Acton	brown London Clay	3.00	18.4	4.9	18.8	1.5	20	0.30	0	0.6	2.0	0.02	0	Normal	1.01	0.457
8	Crews Hill	brown London Clay	3.33	16.7	6.2	18.8	1.5	20	0.30	0	0.6	2.0	0.02	0	Normal	1.06	0.312
9	Hadley Wood	brown London Clay	3.67	15.2	10.4	18.8	1.5	20	0.30	0	0.6	2.0	0.02	0	Normal	1.07	0.264
10	Barrowden	Brecciated Upper Lias Clay	2.00	26.6	4.3	19.0	1.5	23	0.30	0	0.6	2.3	0.02	0	Normal	0.82	0.937
11	Wellingborough	Brecciated Upper Lias Clay	2.60	21.0	9.7	19.0	1.5	23	0.30	0	0.6	2.3	0.02	0	Normal	0.89	0.851
12	Seaton	Brecciated Upper Lias Clay	2.75	20.0	9.5	19.0	1.5	23	0.30	0	0.6	2.3	0.02	0	Normal	0.95	0.692
13	Wothorpe B	Brecciated Upper Lias Clay	3.00	18.4	6.1	19.0	1.5	23	0.37	0	0.6	2.3	0.02	0	Normal	1.00	0.511
14	Wothorpe C	Brecciated Upper Lias Clay	3.00	18.4	9.1	19.0	1.5	23	0.32	0	0.6	2.3	0.02	0	Normal	1.00	0.484
15	Culworth	Fissured Upper Lias Clay	2.00	26.6	7.5	19.2	2.0	25	0.30	0	0.8	2.5	0.02	0	Normal	0.83	0.949
16	Hunsbury Hill	Fissured Upper Lias Clay	2.25	24.0	12.0	19.2	2.0	25	0.30	0	0.8	2.5	0.02	0	Normal	0.85	0.936
17	Heyford	Fissured Upper Lias Clay	2.25	24.0	9.5	19.2	2.0	25	0.30	0	0.8	2.5	0.02	0	Normal	0.88	0.866
18	Stowehill A	Fissured Upper Lias Clay	2.40	22.6	10.0	19.2	2.0	25	0.30	0	0.8	2.5	0.02	0	Normal	0.93	0.736
19	Stowehill B	Fissured Upper Lias Clay	2.40	22.6	5.6	19.2	2.0	25	0.30	0	0.8	2.5	0.02	0	Normal	1.04	0.374
20	Ardley	Fissured Upper Lias Clay	2.50	21.8	5.3	19.2	2.0	25	0.30	0	0.8	2.5	0.02	0	Normal	1.10	0.251

Fig. 1. Back analysis of first-time slides reported by Chandler and Skempton (1974) using the proposed analytical approach (Huang, 2021)

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- Chandler, R. J., & Skempton, A. W. (1974). The design of permanent cutting slopes in stiff fissured clays. *Géotechnique*, 24(4), 457–466.
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