

# Complex geology slope stability analysis by shear strength reduction



*Marek Cala, Jerzy Flisiak*

*Department of Geomechanics, Civil Engineering & Geotechnics  
AGH University of Science & Technology*

## Slope stability Shear strength reduction technique (SSR)

- The stability of slopes may be estimated using 2D limit equilibrium methods (**LEM**) or numerical methods.
- Due to the rapid development of computing efficiency, several numerical methods are gaining increasing popularity in slope stability engineering.
- The factor of safety (**FS**) of a soil slope is defined as the number by which the original shear strength parameters must be divided in order to bring the slope to the point of failure.

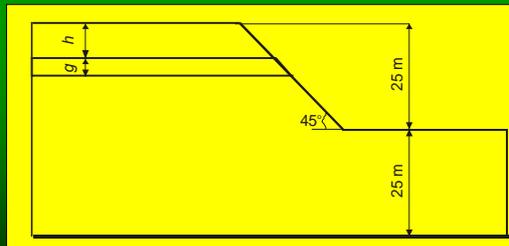
$$c_{trial} = \frac{c}{FS_{trial}} \quad \varphi_{trial} = \arctg\left(\frac{tg\varphi}{FS_{trial}}\right)$$

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## Shear strength reduction technique (SSR)

- It's well known fact that for simple slopes FS obtained from SSR is usually the same as FS obtained from LEM (Griffiths & Lane, 1999; Cala & Flisiak, 2001).
- However, for complex geology slopes considerable differences between FS values from LEM and SSR may be expected (Cala & Flisiak, 2001).

Several analyses for the slope with weak stratum were performed to study the differences between LEM and SSR.



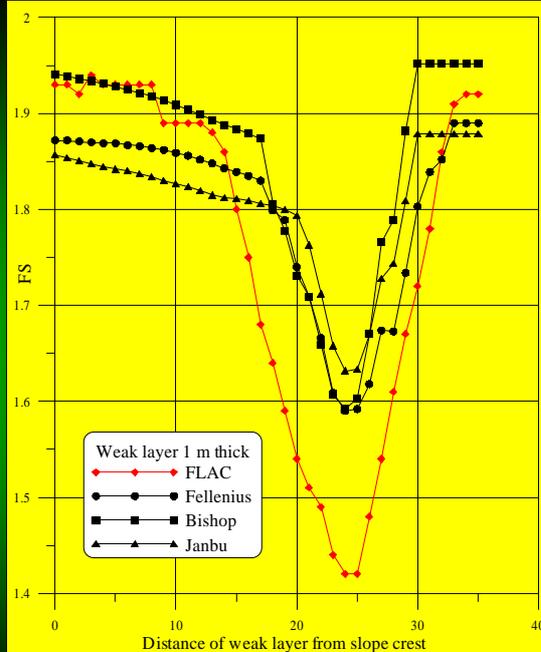
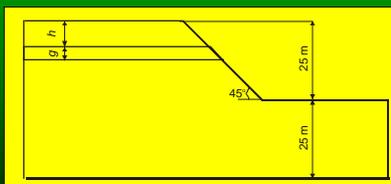
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## SSR versus LEM

Weak layer 1 m thick

Hard soil  $c=75 \text{ kPa}$ ,  $\phi=30^\circ$

Soft soil  $c=25 \text{ kPa}$ ,  $\phi=10^\circ$



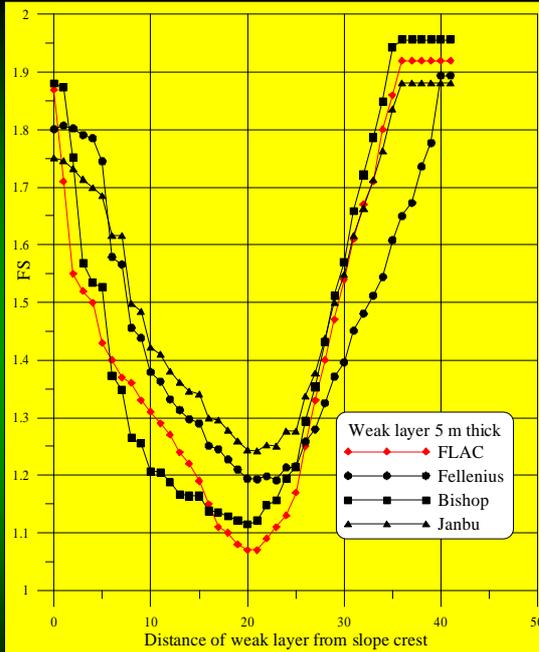
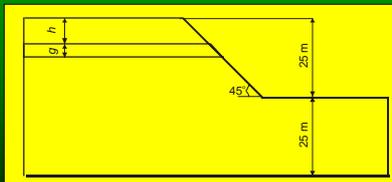
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## SSR versus LEM

Weak layer 5m thick

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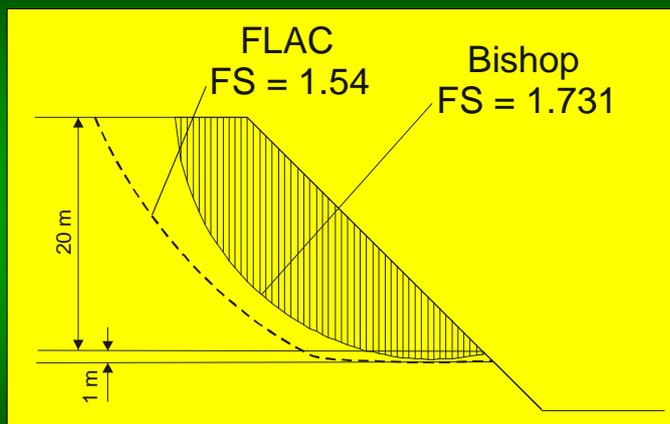
Soft soil  $c=25 \text{ kPa}$ ,  $\phi=10^\circ$



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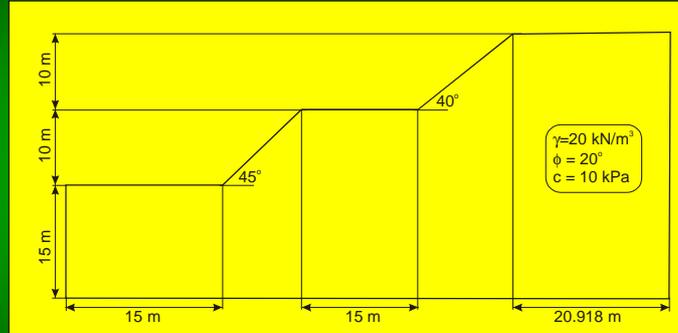
## SSR versus LEM



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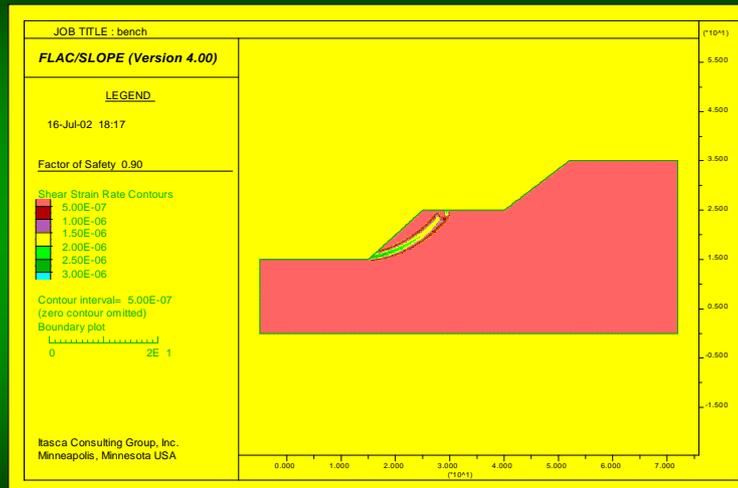
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## SSR versus LEM benched slope case



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## SSR versus LEM benched slope case



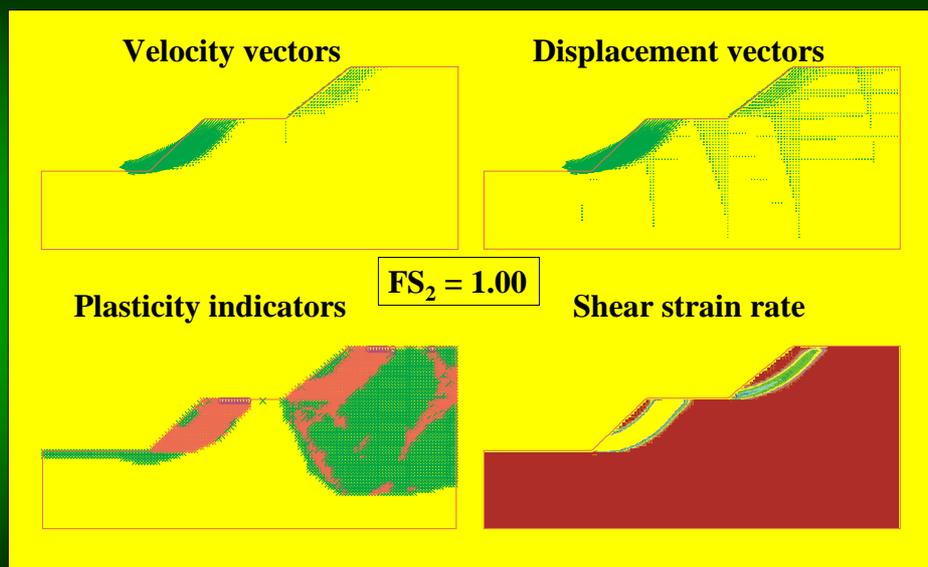
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## Modified shear strength reduction technique

1. Apply classic SSR technique to calculate  $FS_1$  (FLAC/Slope).
2. Export \*.dat file to FLAC. Calculate the initial, stable situation by increasing  $c$  and  $\phi$ .
3. Find the representative number of steps ( $N_r$ ) which characterises the response time of the system. Use  $1.1N_r$  for further calculations.
4. Calculate situation for  $FS_1$  (check out for communication between FLAC and FLAC/Slope and elimination of any mistakes).
5. Reduce  $c$  and  $\phi$  to find further  $FS_i$  (prepare \*.dat file manually or using Excel; each time start from the initial, stable \*.sav file).

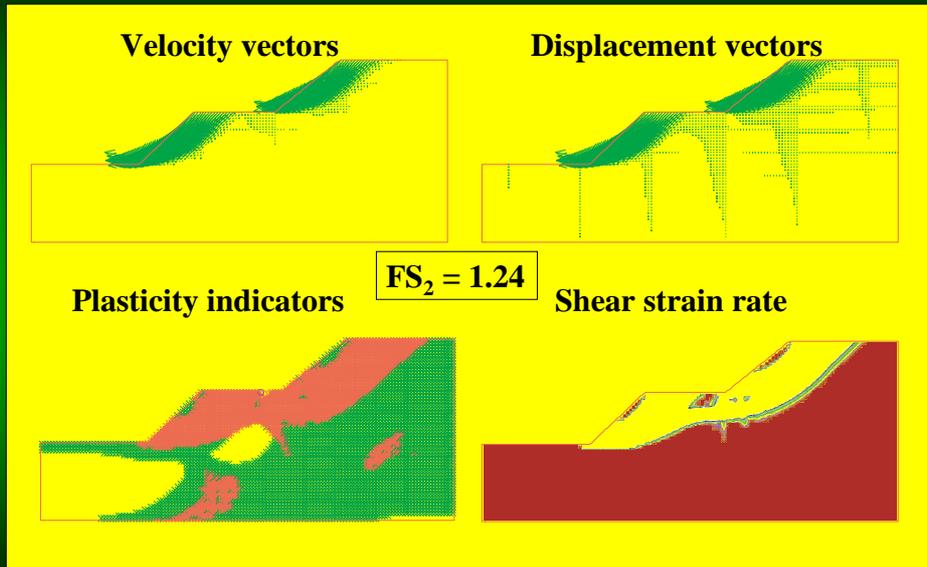
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## Modified shear strength reduction technique



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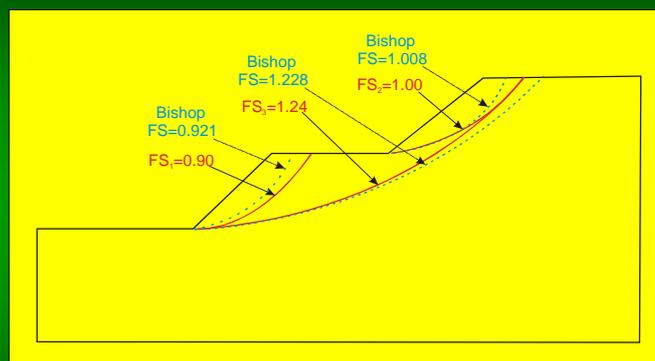
## Modified shear strength reduction technique



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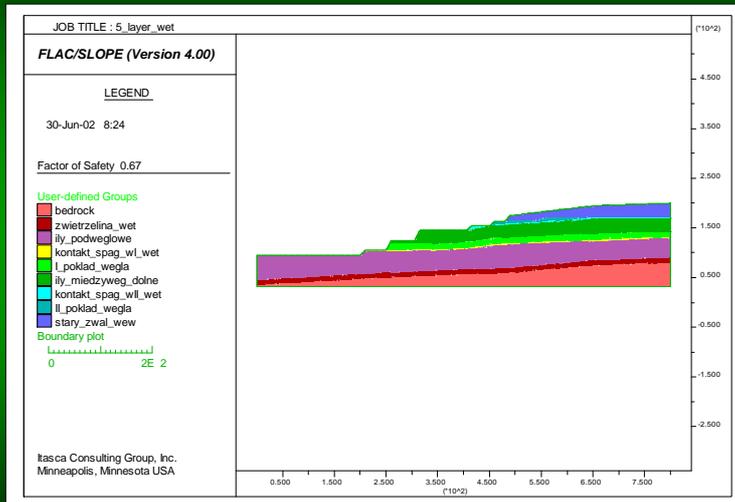
## MSSR versus LEM benched slope case



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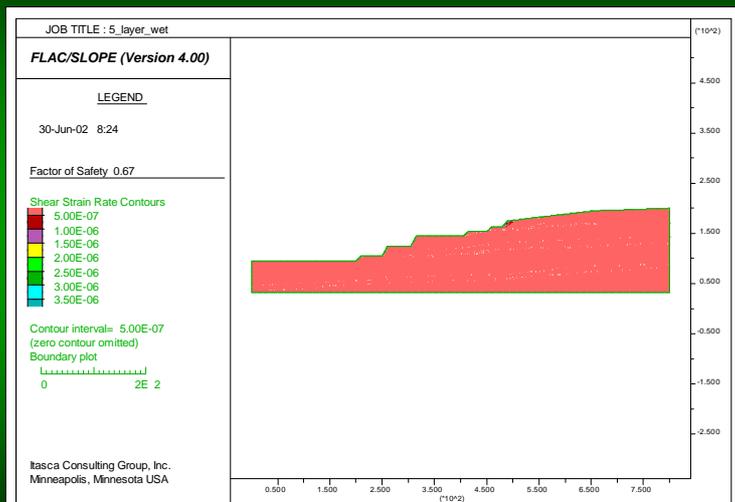
# Shear strength reduction technique Large, complex geology slope case



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# Shear strength reduction technique Large, complex geology slope case



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## Modified shear strength reduction technique

Displacement vectors



Shear strain rate

$$FS_2 = 0.87$$

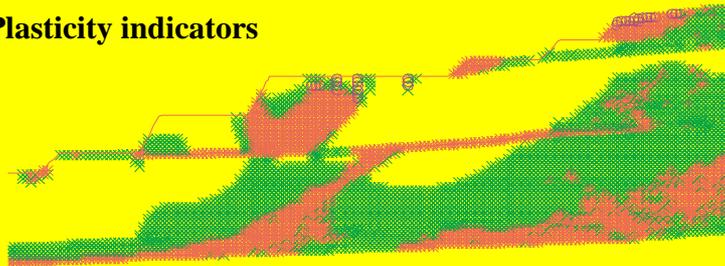


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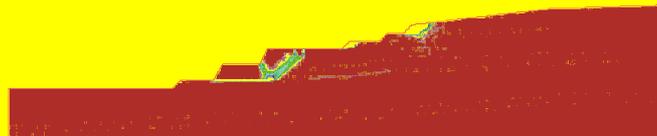
## Modified shear strength reduction technique

Plasticity indicators



Shear strain rate

$$FS_3 = 1.02$$

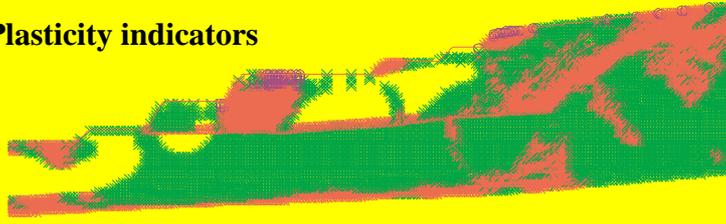


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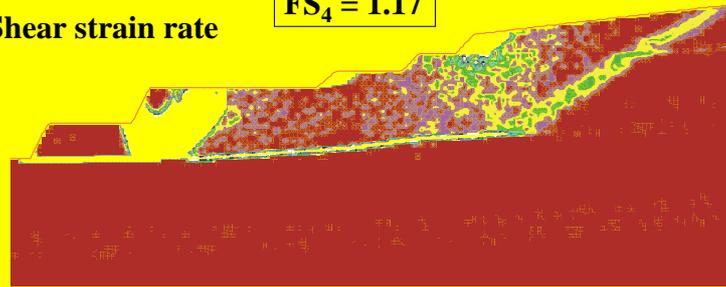
## Modified shear strength reduction technique

Plasticity indicators



Shear strain rate

$$FS_4 = 1.17$$

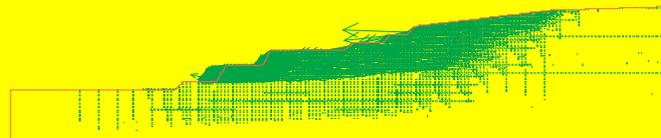


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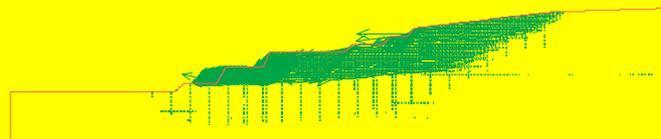
## Modified shear strength reduction technique

Displacement vectors



Velocity vectors

$$FS_5 = 1.29$$



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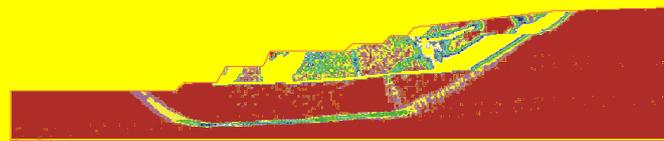
## Modified shear strength reduction technique

Plasticity indicators



Shear strain rate

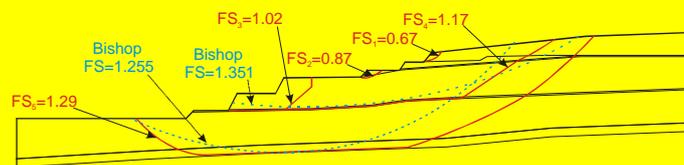
$$FS_5 = 1.29$$



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## MSSR versus LEM large, complex geology slope case



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## Conclusions

- For a **simple, homogeneous slope**, FS calculated with SSR are usually the same as FS obtained from LEM.
- In the case of a **simple geometry slope consisting of two geological units**, FS calculated with SSR may be considerably different than FS from LEM.
- In the case of complex geometry and geology slopes SSR technique is much more “sensitive” than LEM.
- Another step forward is the modified shear strength reduction technique – MSSR.
- Application of SSR/MSSR with FLAC may be recommended for the large-scale slopes of complex geometry.
- Such a powerful tool as MSSR with FLAC gives the opportunity for the **complete stability analysis for any slope**.
- Limitations: visibility, interpretation.
- **Verification !!!**

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