Moving Overall Stability to the Strength Limit State

Tony Allen, T15 Chair

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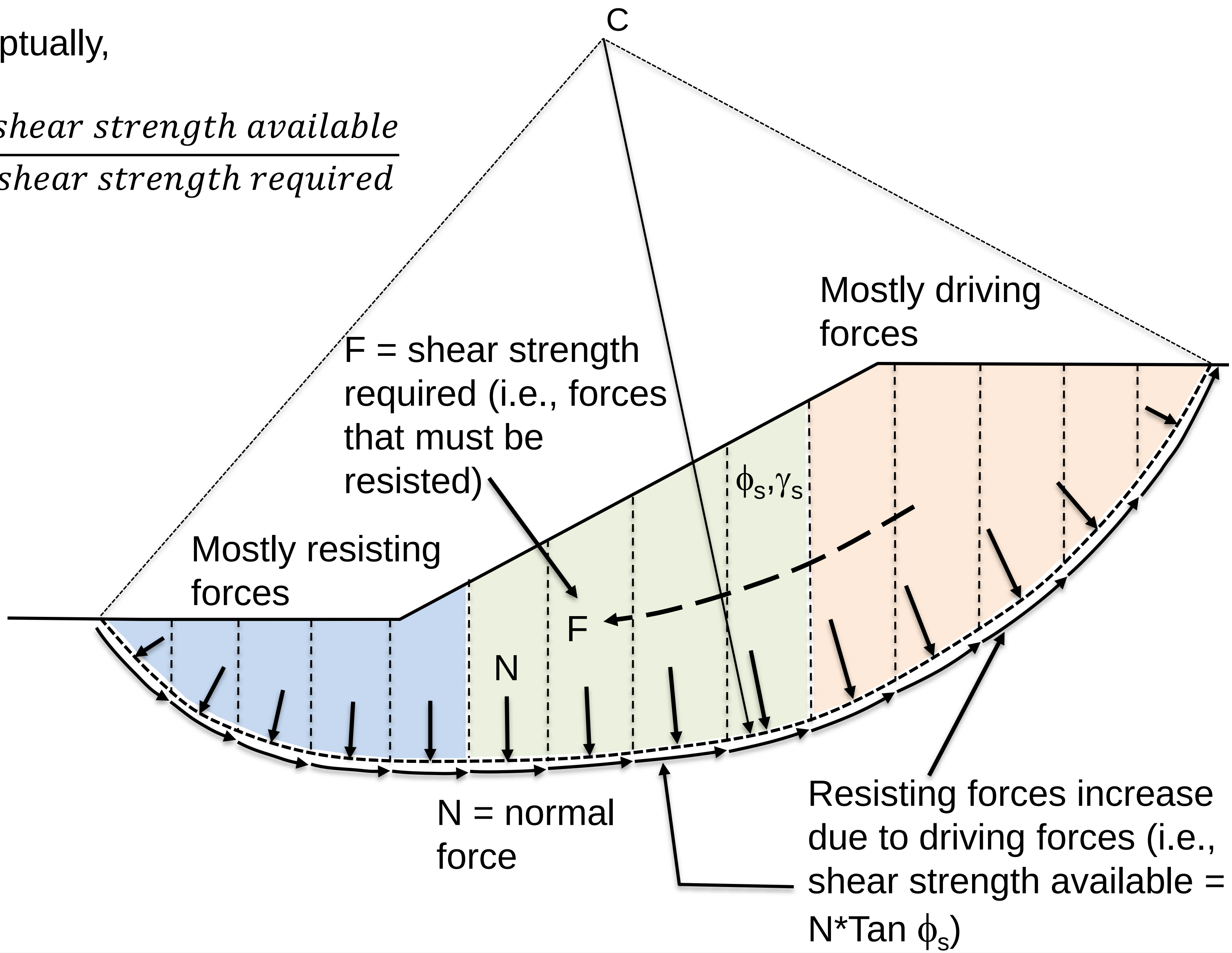
The History

- Moved from Strength to Service approximately 15 yrs ago (2003)
- Intended as a temporary work around
  - The use of service limit load factors (i.e., load factors equal to 1.0) was the best way (at that time) to fit overall stability calculations into the LRFD format
  - Loads and resistances in slope stability analysis cannot be easily separated resulting in unrealistic failure surface
- Overall stability is a collapse, not deformation, scenario and should therefore be considered a strength limit state

The Problem: Separation of Load and Resistance

Conceptually,

$$FS = \frac{shear\ strength\ available}{shear\ strength\ required}$$



Summary of What is Currently Required in the LRFD Specifications (2003 – 2018)

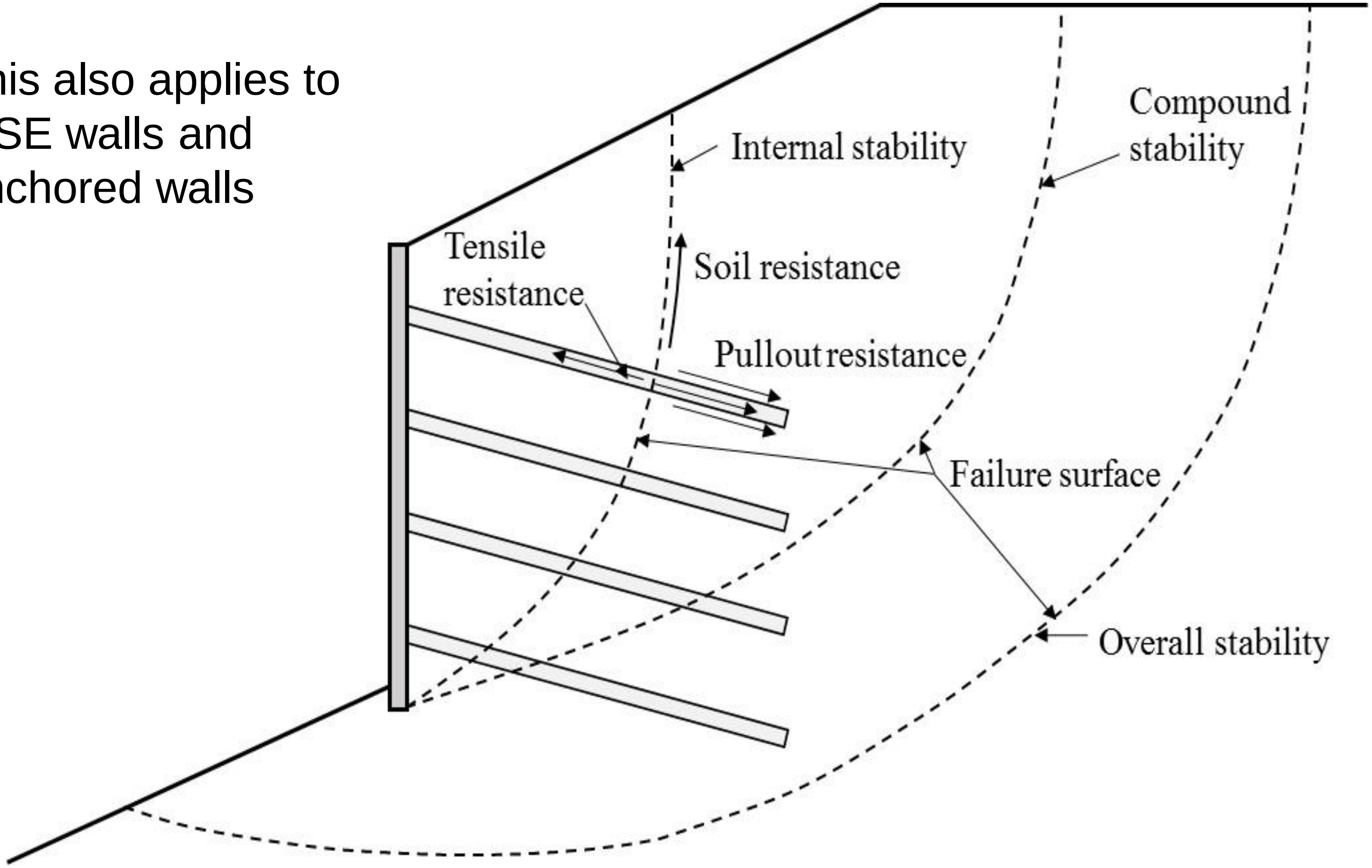
- Consider FS output by slope stability design programs to be a resistance factor
  - ϕ = 1/FS = 1/1.3 $\cong$ 0.75 (geotech. parameters well defined, does not support structural element)
  - ϕ = 1/FS = 1/1.5 $\cong$ 0.65 (geotech. parameters not well defined, or supports structural element)
- The analysis is based on Service I limit state
  - Focus of overall stability is on the soil shear strength needed for stability versus the soil shear strength available (i.e., $\Sigma F_v = \Sigma F_h = 0$, $\Sigma M_c = 0$)
  - This resistance factor ϕ for overall stability is combined with an overall stability load factor (γ_p, i.e., EV) of 1.0 (Table 3.4.1-2)
  - All other loads, including transient loads, have a load factor of 1.0
  - Therefore, external loads such as loads due to foundations are essentially unfactored

Why a Change in How We Handle Overall Stability is Needed

- Slope stability limit equilibrium techniques are:
  - Used for internal, compound, and overall stability for soil nail walls, and
  - Used for compound and overall stability for MSE walls
- Since especially for soil nail walls all three types of stability are evaluated in one continuous design process, having overall stability in the Service Limit state is problematic

Illustration of the Different Types of Slope Stability

This also applies to MSE walls and anchored walls



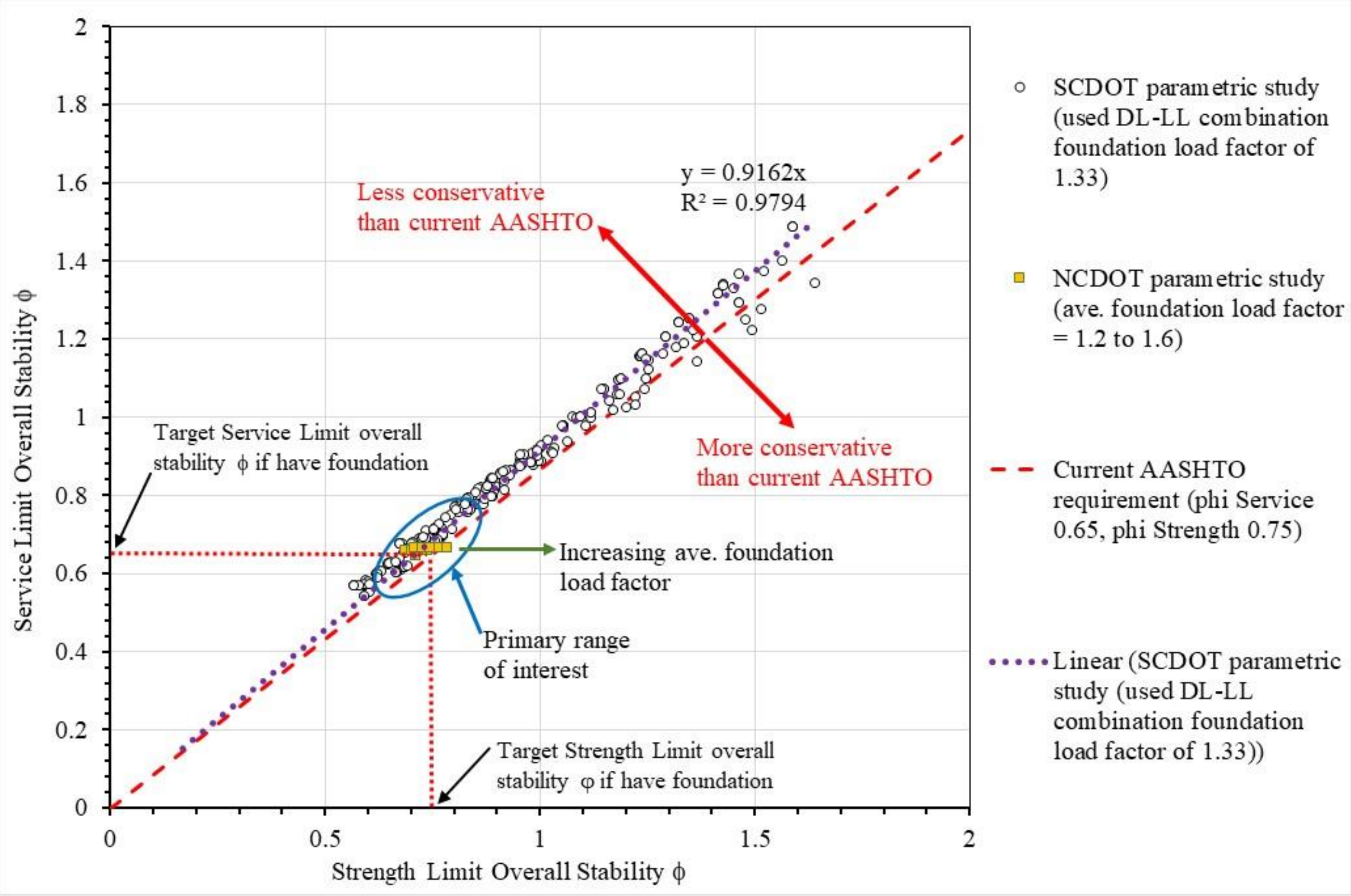
Proposed Solution Reflected in Agenda Item

- Move overall stability into the strength limit state
- Consider FS output by slope stability design programs to be a resistance factor. This is not a change other than what is shown below.
  - $\phi = 1/FS = 1/1.3 \cong 0.75$ (geotech. parameters well defined~~, does not support structural element~~)
  - $\phi = 1/FS = 1/1.5 \cong 0.65$ (geotech. parameters not well defined~~, or supports structural element~~)
- Continue to use γ_p (i.e., EV) for overall stability equal to 1.0
- Use standard load factors for Strength I if have foundation load on top of slope
  - For example, for Strength I, load group is EV = 1.0 for soil loading, DC = 1.25 for foundation dead load, LL = 1.75 for live load acting on foundation, etc.
  - For soil resistance, $\phi = 1/FS = 1/1.3 \cong 0.75$ whether or not slope supports external loads such as a foundation (i.e., rather than decreasing ϕ to 0.65 if foundation load is present), since foundation loads will now be factored using Strength I values

Parametric Analyses to Assess Effect of Moving Overall Stability to Strength Limit

- Analyses conducted by NCDOT and SCDOT
- NCDOT analyses assessed effect of ratio of factored footing load to nominal footing load acting on slope ranging from 1.2 to 1.6
- SCDOT used their typical ratio of factored footing load to nominal footing load acting on slope (i.e., ratio of 1.33) and did parametric analyses for several actual bridge projects
- Goal: compare slope stability FS obtained when designing the example in Service I versus the FS obtained for the same foundation loading when factored in accordance with Strength I
  - For the Service I limit, target FS was 1.5 (i.e., ϕ = 1/FS =0.65)
  - For the Strength I limit, target FS was 1.3 (i.e., ϕ = 1/FS = 0.75)
  - The question: are FS = 1.5 (i.e., ϕ = 0.65) and unfactored footing loads in Service I approximately the same as FS = 1.3 (i.e., ϕ = 0.75) and factored footing loads in Strength I?

Summary of SCDOT & NCDOT Parametric Studies

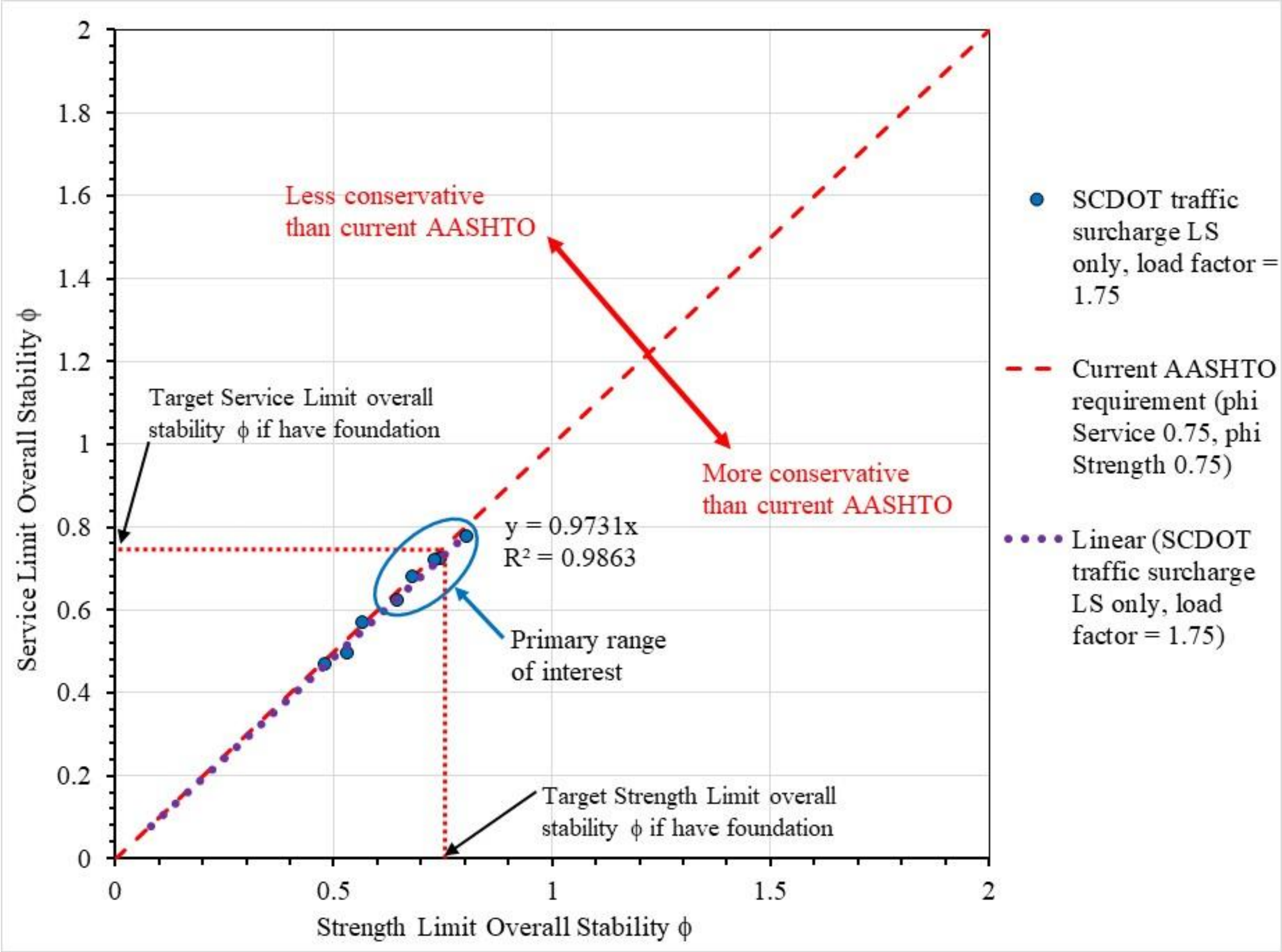


Results of Parametric Analyses when Foundation Loads are Present

- Moving overall stability to the Strength Limit is slightly less or slightly more conservative than current AASHTO, depending on load combination used (generally within 5%)
- The amount of the difference is affected by the average load factor for the foundation loads (i.e., factored footing loads/nominal footing loads) – break even point is when

$$\frac{\text{factored footing loads}}{\text{nominal footing loads}} \approx 1.4 \text{ to } 1.5$$

Summary of SCDOT Parametric Studies (LS)



Conclusions

- Moving overall stability to the Strength Limit from Service will have little or no effect on the design outcome if:
  - Overall stability load factor (i.e., EV) remains at 1.0 (Table 3.4.1-2)
  - Strength Limit State foundation load factors (Tables 3.4.1-1 and 3.4.1-2) or traffic live load surcharge (LS) load factors are used (Table 3.4.1-1)
  - A resistance factor for overall stability 0.75 is used with or without the presence of a foundation or traffic live load surcharge near the top of the slope
- If a foundation load is present, the result in the Strength Limit will be within approximately 5% of what would be obtained currently to address overall stability in the Service Limit
- If a traffic surcharge is present, the result in the Strength Limit will be within 2 to 3% of what would be obtained currently to address overall stability in the Service Limit