

# The GeoStudio software in the context of the Eurocode and Limit States Design

## 1 Introduction

Eurocode 7 has adopted the use of Limit States Design (LSD) for geotechnical engineering. LSD in geotechnical engineering is primarily used in soil-structure interaction designs where both geotechnical and structural engineers are involved in the design process. A typical example of this type of design might include foundation and earth retaining structures. The method however can also be applied to conventional slope stability analysis.

This document discusses how GeoStudio can be used in the context of the Eurocode and Limit States Design.

## 2 Limit States Design

A fundamental feature of the LSD approach is that it clearly distinguishes between limiting deformations or serviceability and safety against failure or ultimate collapse. The former is referred to as the Serviceability Limit State (SLS) and the latter as the Ultimate Limit State (ULS).

The SLS aspect of design addresses the question: will the deformations of the structure be small enough such that the structure can serve its intended function? For example, will the building settlements be within limits such that the building's windows and doors function as intended?

The ULS conditions are checked using partial load and resistance factors. The term partial means that the resistance factor on the cohesive strength (cohesion) of the soil may be different than the resistance factor on the frictional strength (frictional angle). The load and resistance factors are specified by codes of practice like the Eurocode.

It is important to note that the GEO-SLOPE software packages are not intended to implement any particular design methodology. The primary use of the software is for analysis. SLOPE/W in particular is intended for analyzing stability or determining margins of safety against possible failure. In the context of LSD, SLOPE/W is used for checking the ULS. SLOPE/W can accommodate the partial load and resistance factors inherent in a ULS analysis as discussed in the next section.

SIGMA/W is devoted primarily to assessing deformations. In other words, it is intended for doing a SLS type of analysis. Deformation analyses are usually performed using un-factored soil strengths and deformation parameters such as the soil stiffness and working or service loads. However, the effects of factoring strength or deformation parameters could readily be studied with SIGMA/W.

## 3 ULS analyses with SLOPE/W

### 3.1 Resistance factors

The primary source of resistance to instability is the soil strength; that is, the strength properties  $c$  and  $\phi'$ . It is these parameters that should be factored. Let us assume that the resistance factor (RF) for cohesion and the friction angle are 0.5 and 0.8, respectively.

The cohesion specified in SLOPE/W would be calculated as follows:

$$C = c * RF \text{ or } c * 0.5$$

In a similar manner, the friction angle would be calculated as:

$$\phi = \arctan(\tan \phi * RF)$$

If the friction angle is 30 degrees, then the value specified in SLOPE/W would be

$$\phi = \tan^{-1}(\tan 30 * 0.8) = 24.79$$

A SLOPE/W computed *factor of safety of 1.0 or greater* would be deemed an indication of an acceptable design or an acceptable margin of safety against failure if factored strength parameters are used.

Partial factors of safety can also be specified for the pullout resistance and capacity of structural elements such as anchors, nails, geofabrics or piles in a SLOPE/W analysis. The reciprocal of the Eurocode resistance factor (1/RF) is equivalent to the partial factors of safety specified in SLOPE/W. The following SLOPE/W dialog box shows the data required for anchor reinforcement. Note the separate Bond Safety Factor, Bar Safety Factor, and Shear Safety Factor.

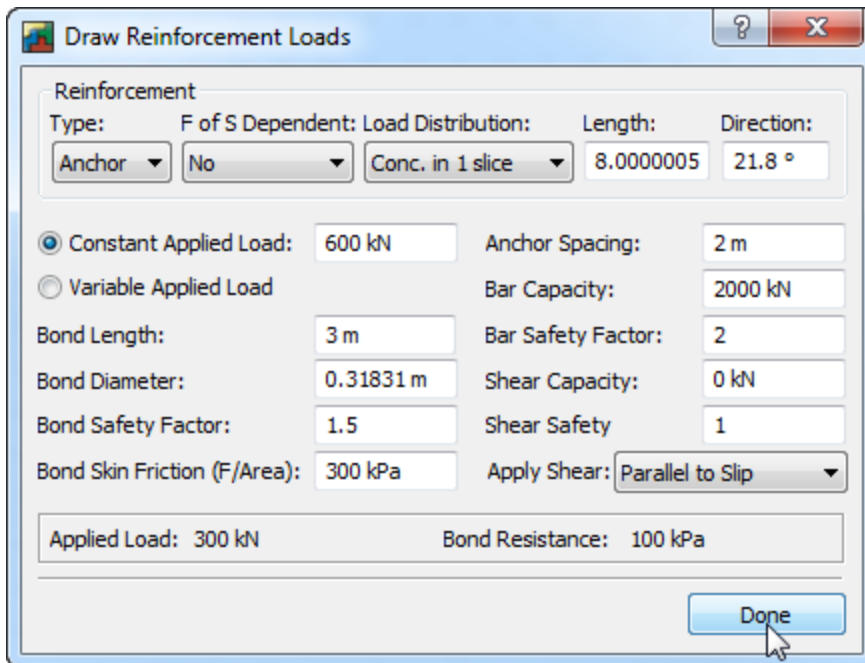
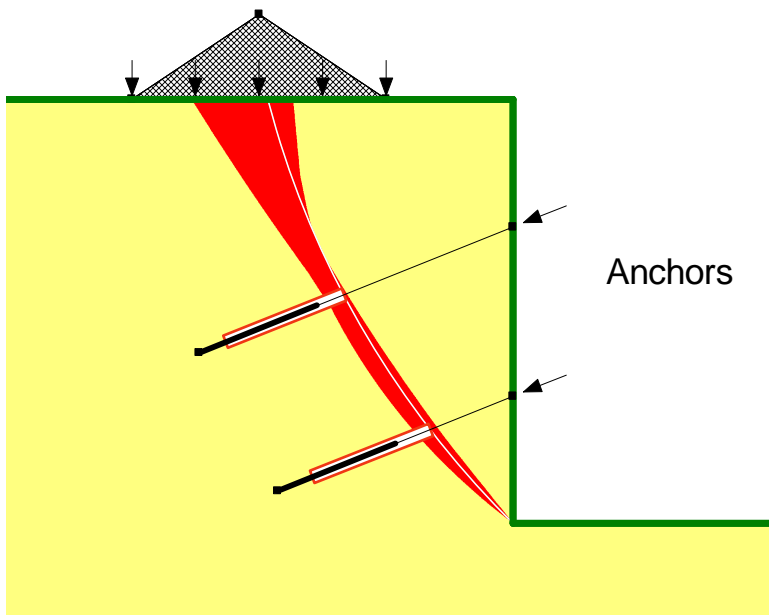


Figure 1 – Draw Reinforcement Loads Key-in Menu

### 3.2 Load factors

Load factors can also be included in a SLOPE/W analysis. Consider the simple case illustrated in Figure 2 below. The primary driving force arises from the weight of the soil. A load factor can be applied to the unit weight of the soil. Once again, the unit weight specified in SLOPE/W would be the most-likely design-selected unit weight times the code-specified load factor. A separate load factor could be applied to the surcharge if desirable.



**Figure 2 – Illustration of Load Factoring in Slope/W Analyses**

In more general slope stability analyses, gravity loads are usually unfavorable with regard to stability in part of the sliding mass, but favorable in others. As such, it may be difficult to assess the appropriate partial factors. The use of partial factors in such a case may not be appropriate.

The Eurocode allows for an alternative approach. One approach involves dealing with the overall activating and resisting moments and forces separately. SLOPE/W lists these values as shown in Figure 3. These values are conveniently available if the designer selects to make use of them in an ULS assessment.

Parameter	
Method	Morgenstem-Price
Factor of Safety	1.37
Total Volume	250.29 m <sup>3</sup>
Total Weight	5005.9 kN
Total Resisting Moment	39451 kN-m
Total Activating Moment	28832 kN-m
Total Resisting Force	1510.2 kN
Total Activating Force	1096.1 kN

Buttons: Copy, Print..., Done

**Figure 3 - Total potential sliding mass parameters**

### 3.3 Important concept

A central concept for conducting a ULS SLOPE/W analysis is that a computed factor of safety of unity or greater is an indication of an acceptable margin of safety against failure.

This is in sharp contrast to traditional Working Stress Designs for which the global factors of safety must be considerably greater than unity. For example, a typical design bearing capacity factor of safety for a footing might be as high 3.0.

## 4 Serviceability Limit States

As noted above, the Serviceability Limit State analysis addresses whether or not the deformation will be tolerable. This aspect of the design can be assessed with SIGMA/A, which is part of the GeoStudio suite of geotechnical engineering software.

The most important point here is that SIGMA/W can be used to model soil-structure interaction designs. SIGMA/W can accommodate structural elements like beams and bars. Stated another way, the stiffness of the structural components can be included when evaluating the deformation response of the soil due to some particular loading.

The following diagram (Figure 3) illustrates a case of a braced diaphragm wall in soft marine clay. The structural characteristic of the wall and the braces were included in the SIGMA/W analysis. The graph in Figure 4 compares the SIGMA/W computed wall deflection with the actual measured deflection. This illustrates the type of serviceability analyses that can be performed with SIGMA/W.

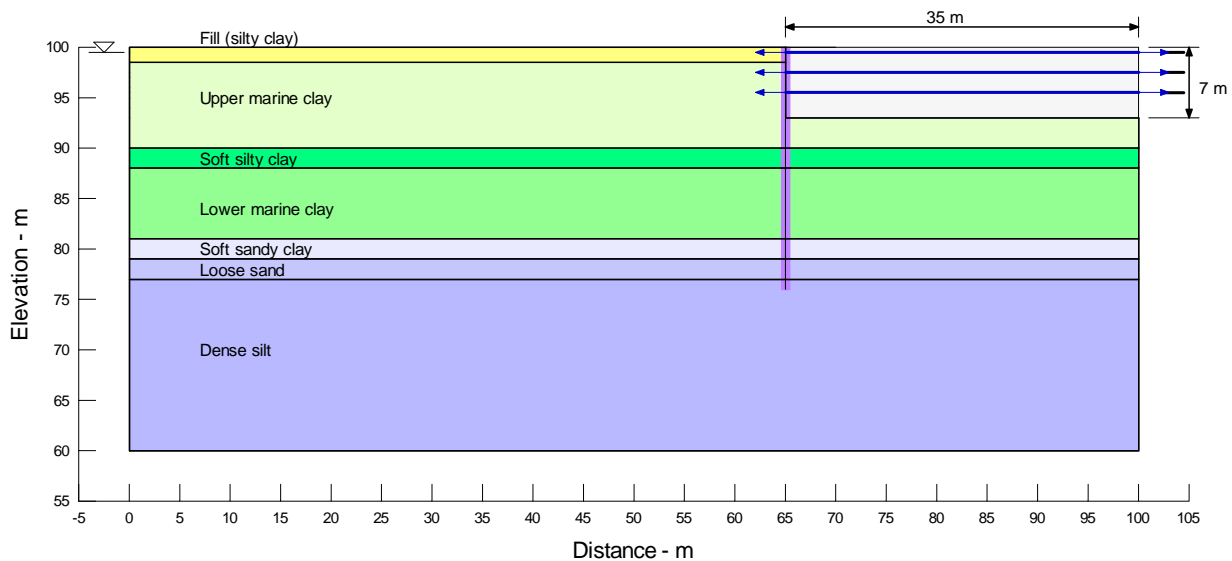
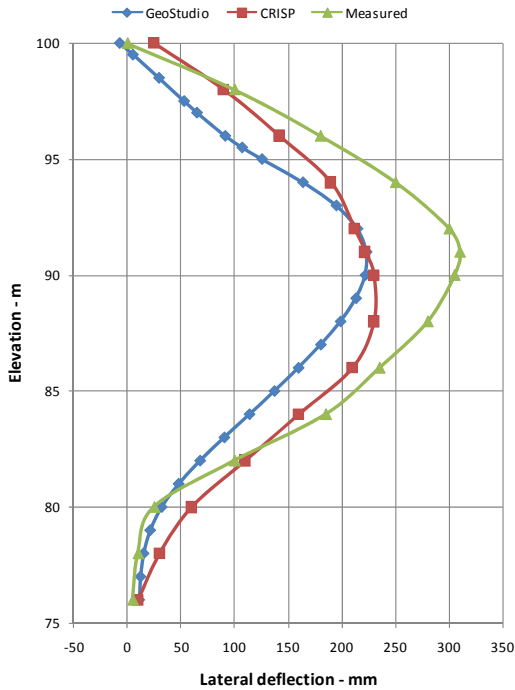


Figure 3 – Illustration of Diaphragm Wall Model in SIGMA/W



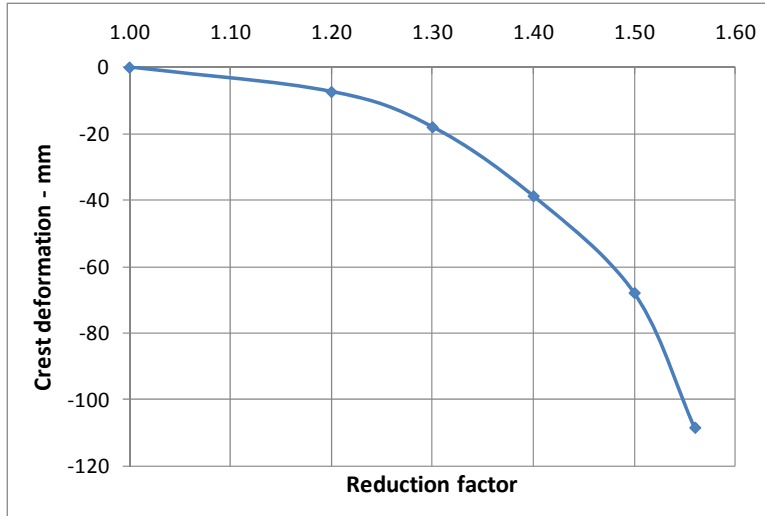
**Figure 4 – Actual and simulated deflection profile for the Diaphragm Wall**

The soil properties and loads are usually not factored for a serviceability type of analysis. The soil properties used in the analysis are considered representative of field conditions and the loads represent the working or service loads.

## 5 Combined approach

The ULS and SLS can be assessed within the same analysis by what is known as the strength reduction procedure. SIGMA/W can readily handle this type of approach.

Generally the strengths in this type of analysis are reduced by a factor and then the stresses in the ground are re-distributed. The stress re-distribution is accompanied by deformations. Reducing the strength in steps makes it possible to produce a graph of deformation at a point versus the reduction factor such as illustrated in Figure 4. The rapid increases in displacement at the higher reduction factors are deemed to be an indication of imminent failure.



**Figure 4 - Crest deformation verses reduction factor**

Moreover, the SIGMA/W computed stresses from the strength reduction analysis can be used in SLOPE/W to compute a ratio of the total shear resistance to the overall mobilized shear along a potential slip surface. The overall ratio is presented in SLOPE/W as a global factor of safety.

## 6 Commentary

The GeoStudio geotechnical engineering software does not have distinct edit boxes for specifying Resistance and Load factors required for a Limit State Design approach. However, this does not preclude the use of GeoStudio for a Limit State type of analysis. This document demonstrates that GeoStudio can readily be used to perform a Limit State Design analysis, including the approach required by the Eurocode.

Further discussion on the use of analytical software, such as SLOPE/W and SIGMA/W, within the Eurocode design methodology is provided in:

*Designers' Guide to EN 1997-1. Eurocode 7: Geotechnical design. General rules. ISBN 0 7277 3154 8. Thomas Telford, London.*

This Designer's Guide discusses the problems associated with uncertainty in whether permanent gravity loads are favorable or unfavorable in ULS design and suggests analytical approaches to accommodate this uncertainty. It is important to note that this issue is generic to the design method and not an artifact of any particular analysis software.