Schwarz M.
Rickli C.

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Characterisation of the vegetation cover at the test site of Ruedlingen

1. General situation

The stand is located on a slope (37-40°) at circa 350 m altitude. The horizontal profile is slightly concave. The area is situated on the upper part of the Rhine river bank with a S-E exposition. The vegetation cover is basically composed of three layers: a single layer of trees (covertures of circa 80%, high from 5-20 m), a lower layer with shrubs (1-5 m) and finally a herb layer.
The species composition of each layer is quite heterogeneous. Following, a table of the most representative species is reported (Tab. 1).

Trees:	*Fraxinus excelsior, Fagus silvatica, Carpinus betulus, Quercus robur, Prunus avium (plus Acer pseudoplatanus, Tilia platyphyllos, Ulmus glabra)*
Shrubs:	*Corylus avellana, Viburnum lantana .*
Herbs:	*Merculiaris perennis*, *Clematis vitalba, (Hedera helix, Lamium galeobdolon, Stachys sylvatica, Paris quadrifolia,Galium sylvaticum, Lonicera xylosteum, Euphorbia amygdaloides, Circaea intermedia, Hepatica nobilis).*

Tab. 1: Floristic list.

Fig. 1: Overview of the slope.

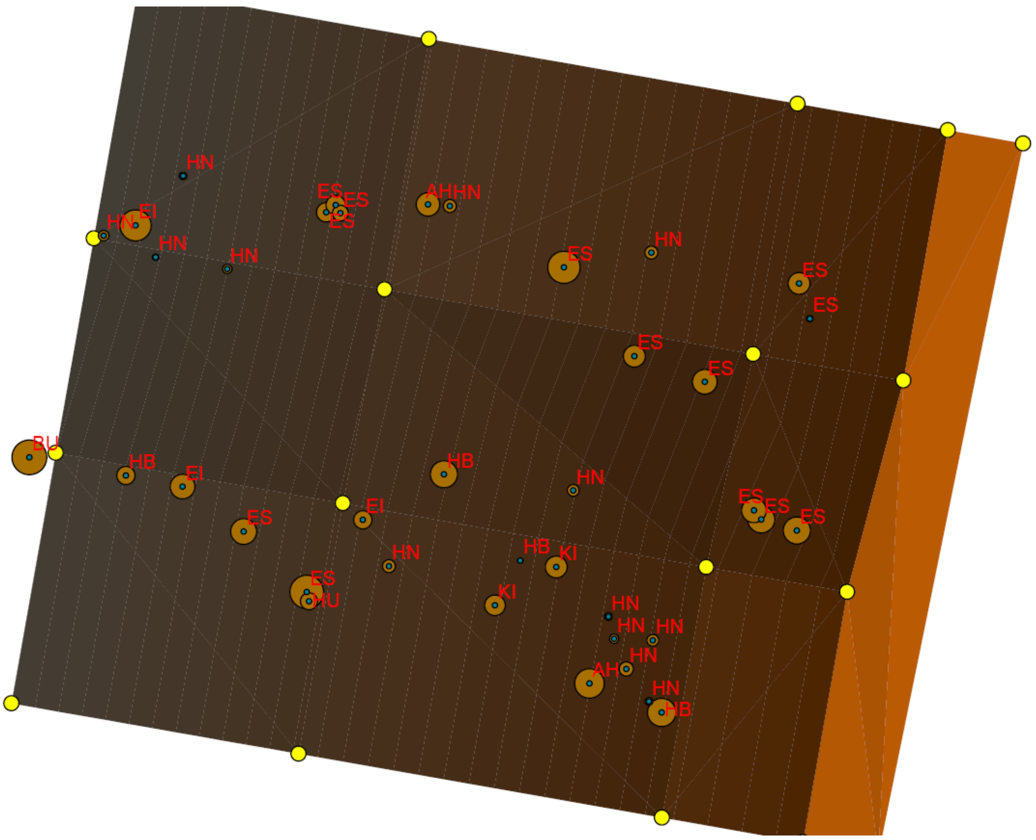

Fig. 2: Overview position and species of the trees (ES = *Fraxinus E.*, BU = *Fagus S.*, AH = *Acer P.*, HN = *Corillus A.*, HB = *Carpinus B.,* KI = *Prunus A.*)

Fig. 3: Soil profile for root analysis.

The site can be classified as *Aceri-Fraxinetum*. It is humid (due to the vicinity of the river) and the reaction of the soil-stone substrate is basic. The presence of the *Fagus silvatica* and *Prunus avium* indicate that the site is not wet! Slpe inclination, grain size distribution and OCR conditions result in a good drainage of the entire profile (no signs of reduction). Soil activity is high and the type of humus layer is a mull (10-20 cm Ah). The soil is good aggregated in the upper layers (crumbs = high porosity; diameter aggregates circa 1-10 mm), but shows increased density at circa 50-70 cm depth.

The upper layers of the soil profile in this area are the deposit material of a recent shallow landslide. Damages on the tree trunks and the age of young trees growing on the sediment indicate that the event was about 6 years ago (2002-2003). No signs of that event are found in the soil profile.

Fig. 4: Sediment deposition on the upper side of a tree stem.

2. Root distribution

We characterised the root distribution considering root diameter classes and frequency. The lateral distribution was estimated using the model of Schwarz et al.(2008) and for the vertical distribution we used the probability distribution function used from Laio et al.(2006). We estimated a maximal rooting depth of 1.5 m. Literature data show that usually 70% of the roots biomass of ash trees is at a depth between 70 and 110 cm. The root systems of mature trees are usually a sinker (Fig. 5).

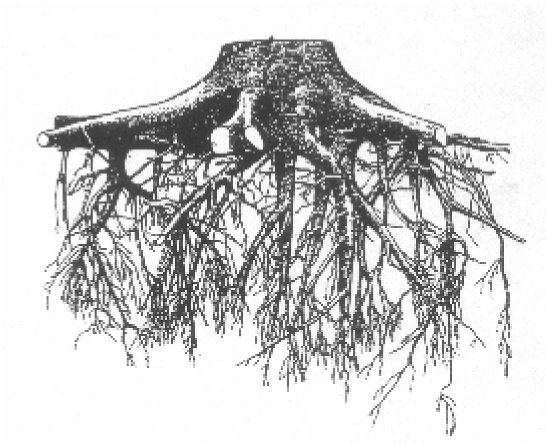

Fig. 5: Illustration of the root system of a mature ash tree.

For the calibration of the models we dogged two soil profiles (50 cm depth and 100 cm large) at two distances (1.5 m and 2.5 m) from the stem of a tree (*Fraxinus excelsior*) and we measured the frequency for each diameter class.

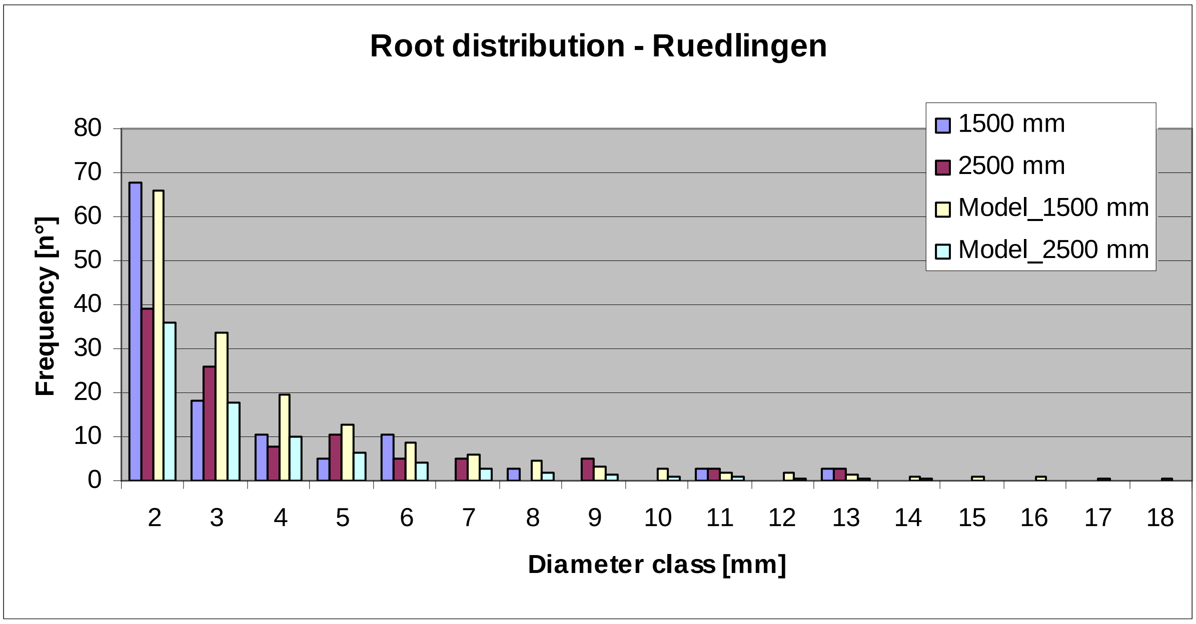

Fig. 6: Measured and simulated root distribution [N/m2] on a two profile at 1.5 and 2.5 m from an ash tree.

3. Root mechanical properties

We tested the maximal pullout force of 8 roots with a force gauge instrument (Fig. 7). The data obtained were used to calibrate the model for the quantification of the root-soil mechanical interaction. Roots bigger then 1-2 mm diameter tend to break instead slip out. Root-soil friction coefficient is estimated to be circa 0.005 MPa (without considering root branching effects).

Fig.7 : pullout tests of roots.

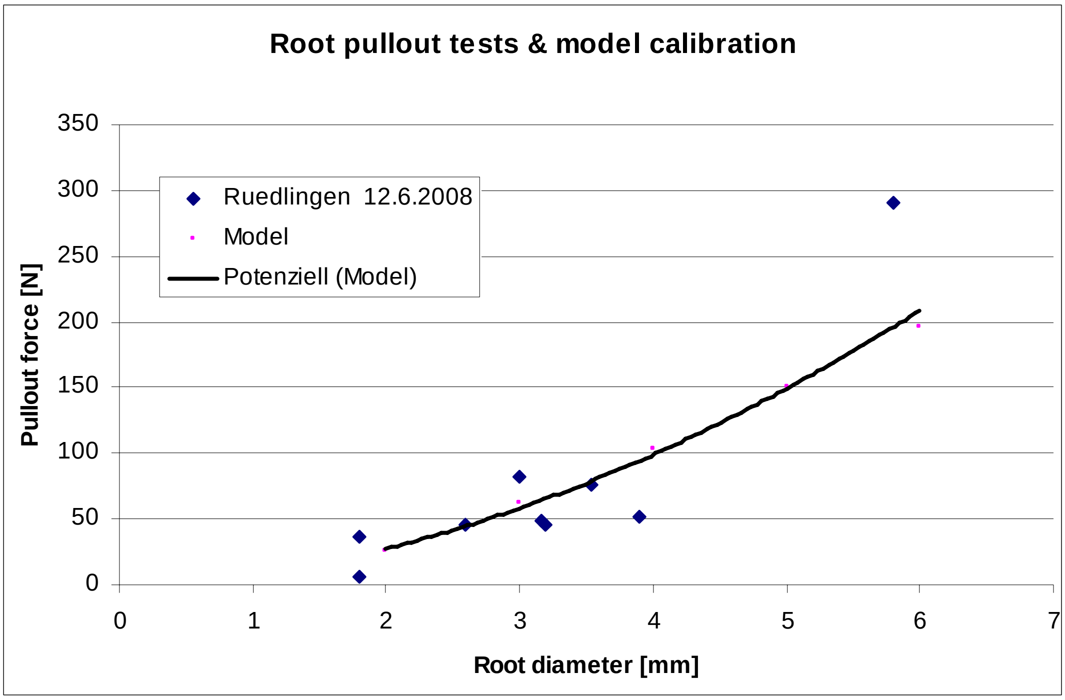

Fig. 8: Results of the pullout tests with ash tree roots. The line shows the modelled value after calibration.

4. Root reinforcement

Using the root distribution measured in the area (just tree plants) and the standard model for the quantification of root reinforcement (Wu, 1976) we obtain values between 40 and 50 kPa. These values represent the total reinforcement along the profile and they decrease exponentially with the soil depth. Reinforcement can be considered to be 0 bellow 2 m of soil depth.
Using an extension of the FBM approach we obtain value of root reinforcement between 0 and 40 kPa (in nearly saturated condition of the soil).
The stress-strain behaviours of such a kind of root bundle is represented in Fig.9.
Maximal root reinforcement at circa 2-3 m from trees is reached after 3-5 cm of displacement (much more after the suction effects which take place at few millimeters of displacement).

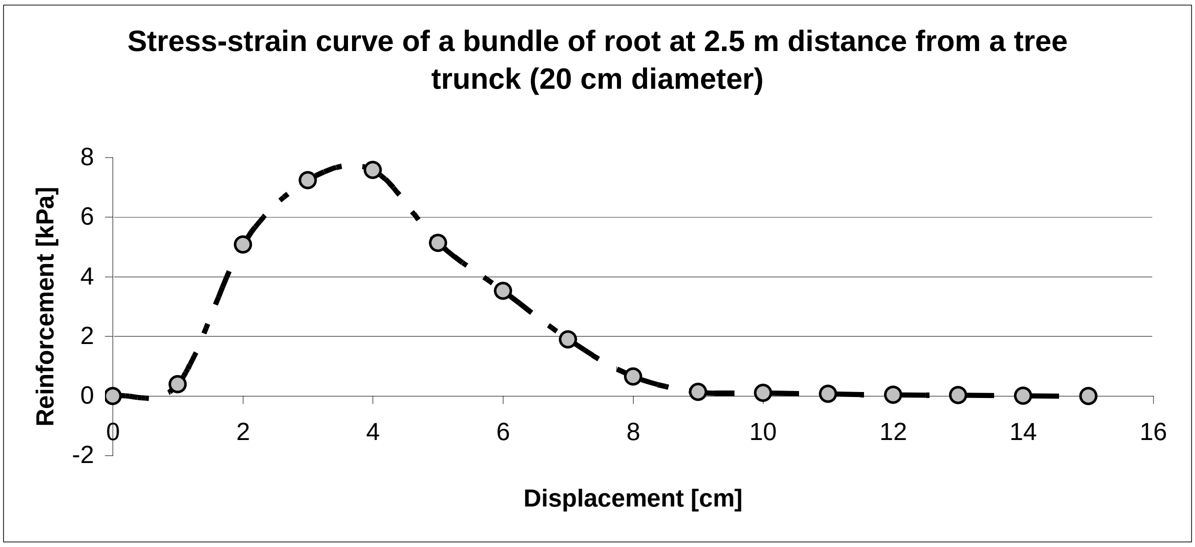

Fig. 9: stress-strain curve of a bundle of ash tree roots at 2.5 m distance from a tree with 20 cm diameter at burst height.

Using a new model for the spatial quantification of root reinforcement we obtain a distribution on the slope show in Fig. 10 .
This model takes in consideration tree distribution, soil water content and soil type.
For slope stability calculation we suggest to use a minimal average value of additional root reinforcement of 5kPa (<u>not</u> to be added to soil cohesion or suction in the case of lateral reinforcement!!!!).
The absolute values range from 0 to 70 kPa (distance less then 1 m from tree are not considered).

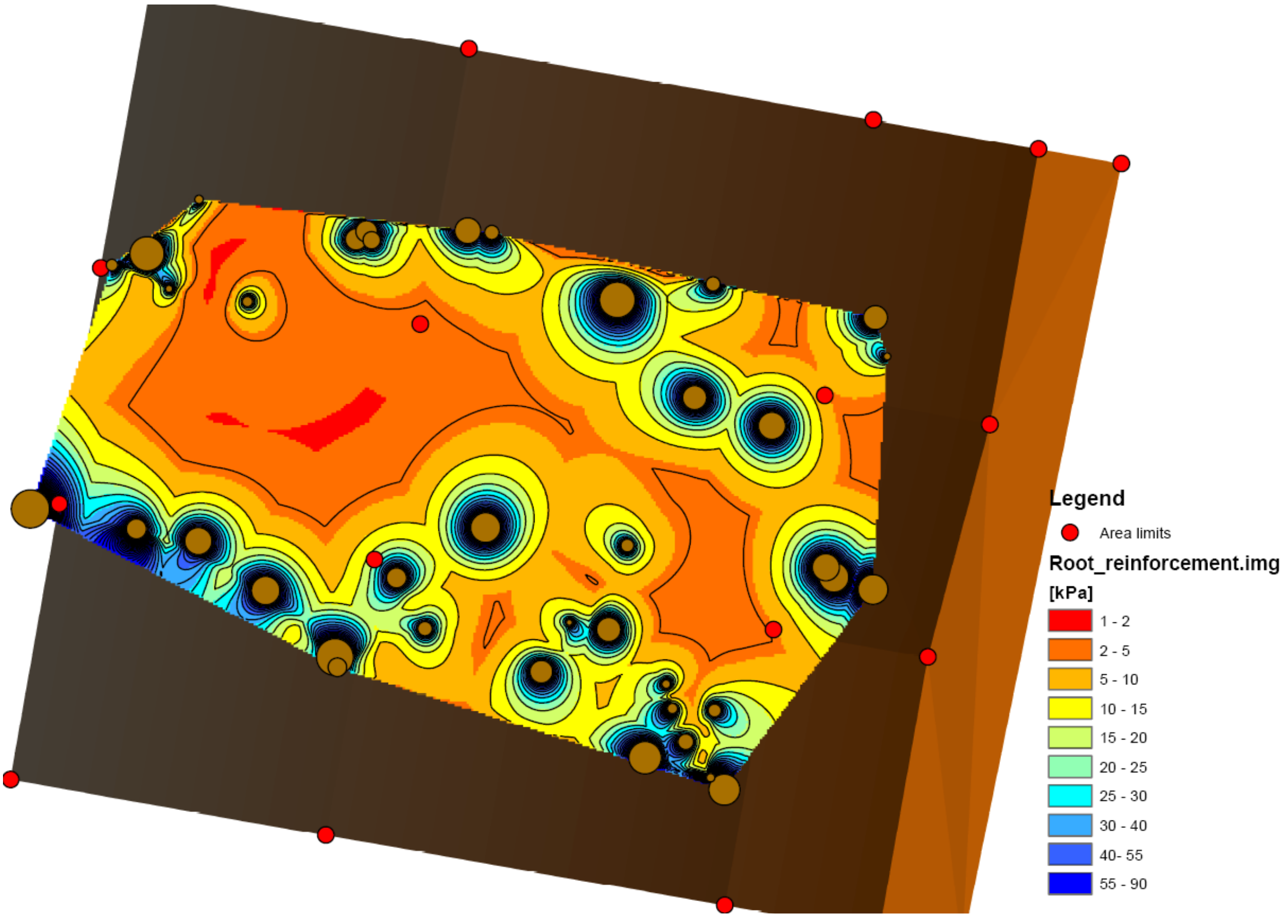

Fig. 10: Tree positions and root reinforcement distribution on the slope (white zone indicate the road). The visualisation is not completely representative (wrong tessellation and just 2D calculation) but it helps to get an idea!!!

5. Stability of the vegetated slope

The big heterogeneity in the species composition contributes to increase the stabilising effect of roots. Trees of different species living in concurrence optimise the uptake of resources in function of their ecological strategy. Concerning root distribution, for example, there are species that tend to develop deeper root systems while other species occupy the upper layer of the soil. On the site of Rüdlingen water is not a limiting factor and it is difficult to say which species root deeper then the other. Generally ash tree, in mixed forest, tend to root deeper than other species.
For the first 50 cm of soil profile fine roots (1-2 mm diameter) are distributed homogeneously on the entire slope, thus we consider a minimal value of lateral and basal root reinforcement of 5 kPa.
In deeper layers the heterogeneity of the reinforcement increases. In a depth of 2 m, basal root reinforcement could be considered equal to 0 every where.
First stability calculations considering the centre of instability to be in the middle of the cover gap, show that even with pore water pressure corresponding to 80 cm of water table, the security factor still be over 1 for landslide areas smaller then 100 m^2 (this in the worse conditions – full staturation!) (Fig. 12).

We estimated 32° of internal friction angle to be representative for the residual shear strength; labor tests would be useful for a better estimation. Table 1 report the parameter used for the 3D stability calculation.
Preferential flow paths due to soil aggregation, animals and roots could play an important role concerning slope stability. Generally the superficial soil layers are well drained and we can assume a strong vertical infiltration and subsurface drainage parallel to slope (low or zero pore water pressure). The decrease in suction and the building up of a pore water pressure in deeper soil layers will depend on the permeability and structure of those layers.

Weight of vegetation [t/m^2]	0.1	Friction angle [°]	32
Weight of wet soil [g/cm^3]	2.07	Root lateral reinforcement [kPa]	5
Pore water pressure on slip surface [kPa]	8	Root basal reinforcement [kPa]	0
Soil cohesion [kPa]	0	Soil depth [m]	1

Tab. 2: parameters for the slope stability in calculations wet condition.

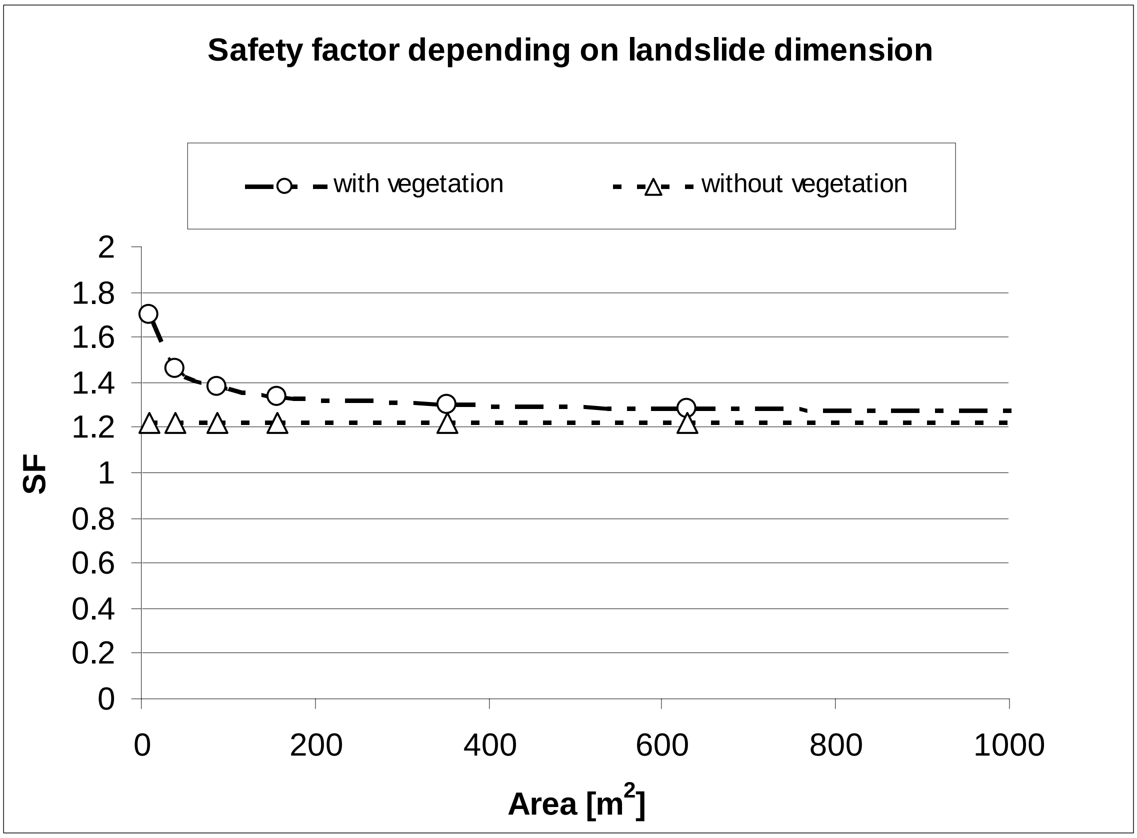

Fig. 11: Changes of safety factor vs dimension of landslide in dry condition (considering homogeneous topography).

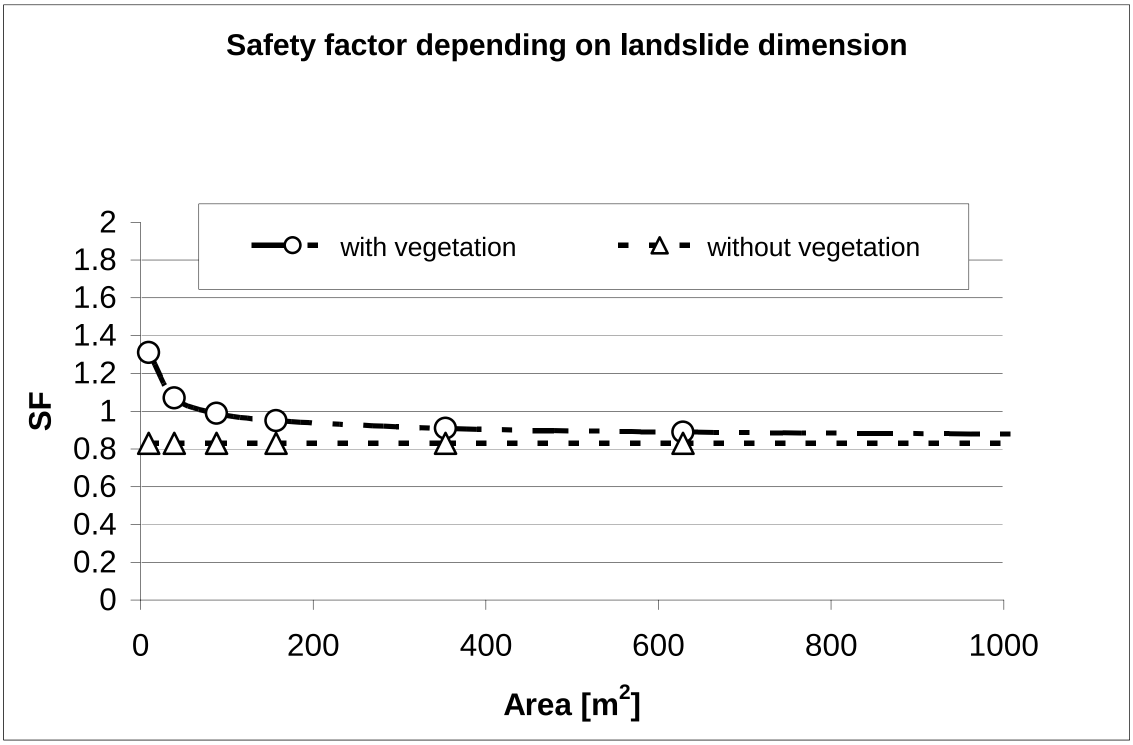

Fig. 12: Changes of safety factor vs dimension of landslide in saturated condition (considering homogeneous topography).