Comments by Editor:

Dear Authors,

You - as the contact author - are requested to individually respond to all referee comments (RCs) by posting final author comments on behalf of all co-authors no later than 13 Jan 2019 (final response phase) at: https://editor.copernicus.org/nhess-2018-192/final-response.

Comments by Anonymous Referee #1 (nhess-2018-192-RC1)

[Answers in blue]

GENERAL COMMENTS

(1) This paper deals with the ability to predict a landslide failure curve and the slope factor of safety with a terrain stability (TS) analysis. Overall it is written in a good English, but I believe it is not as innovative as claimed for considering rainfall infiltration in the calculation of the factor of safety**. I suggest focus on the ability to well-predict the landslide failure curve and surface area.**

(2) We appreciate your comments on our model and specifically the ability to predict well the slip failure curve and the area of the breakage surface. We continue to believe in the originality of our model, incorporating the rainfall infiltration in the calculation of the safety factor with a terrain stability, by means of the infiltration factor of the Spencer method and its treatment in the calculation model implemented in Matlab. The TS method is a simple, but versatile computational procedure that is suitable for a normal computer

In addition, we also re-focus the paper on the ability to well-predict the landslide failure curve and surface area. In the intro a new text has been added:

(3) *"The new developed software is fast and accurate in resolution of landslide failure curve and surface area, including the infiltration effects."*

(1) The literature of relevance has not been adequately cited. I recommend reviewing more methods for slope stability analysis.

(2) We have incorporated the references in the introduction section and in the specific comments, which we believe improve the application literature. In the revised final version of the paper, we include a brief description of the state-of-art in order to clarify the improvements of our work.

(1) Chapter 2 is very confusing and the paragraphs are disjointed. As is, it is not easily readable. In chapter 3, the test should be described more accurately and the center of the failure curves should be shown in, at least, the first figure (Figure 2).

(2) Chapter 2 has been improved by incorporating in specific comments clarifications and syntax improvements, the center has been incorporated in Figure 2 (a new figure 2 has been done).

(1) In chapter 4 there is the need to mention the date of the slide.

(2) The date of the landslide has been introduced, which we had not included in the text, but we had marked it in figure n. °7, in the histogram. See specific comments.

(1) Both chapter 3 and 4 miss the description of the calculation of the pore pressure parameter. Move lines 421-444 to chapter 2 because they describe the characteristics of the TS model compared to the STB 2010.

(2) In the specific comments section show the description of the calculation of the pore pressure parameter. We have clarified this question.

Following your suggestions, we have moved lines 421-444 to chapter 2 because they describe the characteristics of the TS model compared to the 2010 STB.

(1) Please, check references consistency with the journal guidelines. For other comments and technical corrections see the attached file.

(2) We have reviewed and verified the references of coherence with the guidelines of the journal.

SPECIFIC COMMENTS

SECTION 0: ABSTRACT

(1) These sentences seem unjointed. Please, try to make them more fluent for reading.

(2) The comment seems right to us and we introduce the change. In the original document line 23-26.

(3) *“This model is especially useful for predicting the risk of landslides in scenarios of heavy unpredictable rainfall. We have called it (TS) Terrain Stability and programmed in MATLAB, which it allows us a simulation of the slope stability in a 2D spatial distribution. As originality in our algorithm a hydrological assumption has been incorporated in steady-state.”*

(1) Be more specific: critical rainfall, critical point, critical surface..., I would suggest a keyword that refers to the model, such as: numerical model, 2D model, limit equilibrium model,..

(2) The comment seems right to us and we introduce the change.

(3) “Keywords: Landslides, critical rainfall, limit equilibrium model, 2D model, critical surface.”

SECTION 1: INTRODUCTION

(1) I believe you should start the introduction paragraph with a general description of the landslide hazard, as you did in the abstract.

After that, you may depict what is a stability analysis and its evolution over time.

(2) The comment seems right to us and we introduce the change.

(3) *“Landslides, one of the natural disasters, have resulted into significant injury and loss to the human life and damaged property and infrastructure*

throughout the world (Crozier and Glade, 2005; Dai et al., 2002; Parise and Jibson, 2000; Varnes, 1996).

Normally, heavy rainfall, high relative relief and complex fragile geology with increased manmade activities, have resulted in increased landslide (Gutiérrez-Martin, 2015). It is essential to identify, evaluate and delineate landslide hazard prone areas for proper strategic planning and mitigation (Bisson et al., 2014). Therefore, to delineate landslide susceptible slopes over large areas, landslide hazard zonation (LHZ) techniques can be employed (Fall et al., 2006; Casagli et al., 2004; Guzzetti et al., 1999; Anbalagan, 1992).

Landslides are resulted because of intrinsic and external triggering factors. The intrinsic factors are mainly; geological factors, geometry of the slope (Wang and Niu, 2009; Ayalew et al., 2004; Anbalagan, 1992; Hoek and Bray, 1981).

The external factors which generally trigger landslides are rainfall (Dai and Lee, 2001; Collison et al., 2000; Anderson, 1985). Several LHZ techniques have been developed over the past and these can be broadly classified into three categories; expert evaluation, statistical methods and deterministic approaches (Canili et al., 2018; Zhang et al.; 2018; Lari et al., 2016; Raia et al., 2014; Rossi et al., 2013; Lu and Godt, 2008; Fall et al., 2006; Casagli et al., 2004; Crosta and Frattini, 2003; Inverson, 2000; Guzzetti et al., 1999; Leroi, 1997; Wu and Sidle, 1995). Within these models, we want to highlight the empirical models that are based on rainfall thresholds (Matelloni et al., 2011; Gruzzetti et al., 2007; Aleotti, 2004; Wilson, 1997).

Each of these LHZ techniques has its own advantage and disadvantage owing to certain uncertainties on account of factors considered or methods by which factor data are derived (Carrara et al.,1995).

"Limit equilibrium types of analyses for assessing the stability of earth slopes have been in use in geotechnical engineering for many decades. The idea of discretizing a potential sliding mass into vertical slices was introduced in the 20th century. During the next few decades, Fellenius introduced the Ordinary method of slices (Fellenius, 1936) . In the mid1950s Janbu and Bishop developed advances in the method (Janbu, 1954; Bishop, 1955). The advent of electronic computers in the 1960's made it possible to more readily handle the iterative procedures inherent in the method, which led to mathematically more rigorous formulations such

as those developed by Morgenstern and Price and by Spencer (Morgenstern and Price, 1965; Spencer, 1967).”

(1) There are plenty of free software (see for example TRIGRS model of USGS). You should cite them too and specify the differences with your model. Line 36-38.

(2) To address this question the following text (including new references) has been added into the introduction section:

(3) *“Limit equilibrium types of analyses for assessing the stability of earth slopes have been in use in geotechnical engineering for las year. Currently, the vast majority of stability analyses using **this method of equilibrium limit** are performed with commercial software like SLIDE V5, SLOPE/W, Phase2, GEO-Slope, GALENA, GSTABL7, GEO5 and GeoStudio, entre otros [Mousavi, 2017; Acharya et al., 2016a; Acharya et al., 2016b; Jiao et al., 2013; Gonzalez de Vallejo et al., 2002). Other models of slope stability based on the theory of limit equilibrium are still being studied, as is the case of the SSAP model (Borselli, 2016), but in this case a General equilibrium method model is applied.”*

“There are other types of software based on the modeling of the probability of occurrence of shallow landslides LHZ, in more extensive areas using GIS technology and MDE, as is the case of deterministic software TRIGRS ,SINMAP, SHALSTAB, GEOtop/GEO-FS, R-Slope.stability among others (Tran et al., 2018; Alvioli and Baum, 2016; Reid et al., 2015; Mergili et al., 2014a; Mergili et al., 2014b; Mergili et al., 2014c; Baum, 2008; Simoni et al., 2008; Rigon et al., 2006; Pack, 2001). They are widely used models for calculating the time and location of the occurrence of shallow landslides caused by rainfall at the territorial level; some even in three dimensions, in order to obtain a probabilistic interpretation of the factor of safety.
Currently other approaches / theoretical studies for landslide prediction are used (for triggering and / or propagation) (Matelloni et al., 2017; Martelloni and Bagnoli, 2014).

The idea of discretizing through this tool proposed (TS), the potential slip mass in the critical profile of the slope, once we have detected through the HZD programs unstable areas, is one of the achievements of this model. This calculation tool is not limited to shallow landslides and debris flows, but allows analysis of deep and rotational landslides, which others do not allow. Using the infiltration factor of Spencer r_u we introduce the *hydrological variable by infiltration to the stability calculation of the slope."*

(1) Please, clarify this sentence (line 41-42).

(2) We rewrite the sentence, with another clarifying development

(3) *"Second, sometimes in these commercial software, the introduction of the parameters to perform the calculations, are not very interactive."*

(1) Add citations in support of this sentence (line 48-49).

(2) Reference is added

(3) *"These methods allow us to analyse almost all types of landslides, such us translational, rotational, topple, creep and fall, among others (Zhou and Cheng, 2013; Wan et al, 2016).*

(1) Make the acronym explicit the first time it is introduced (line 58)

(2) FOS, is the safety factor, it is simplified and denominated throughout the text as Fs (safety of factor).

(3) *"Software such as the programmes mentioned above provide useful tools for determining the stability through the **F_S (safety of factor)**….."*

(1) Are these software free or commercial? It would be better to add them also in the first paragraph of the introduction, among others (File 60).

(2) It is a commercial calculation software on Slide V5 and the STB 2010 is free. The suggested change is done and the reference is entered on line 49 of the introduction. I introduce a new free software. Is removed from line 60.

(3) *"For the stability analysis, different approaches can be used, such as the limit equilibrium methods [Cheng et al., 2007; Liu et al., 2015], the finite elements method [Griffiths et al., 2007; Tschuchnigg et al., 2015; Griffiths, 2015] and the dynamic method [Jia et al., 2008], among others (Slide V5, STB 2010 and SSAP 2018)"*

(1) I believe this is not true, Please, verify this statement with more literature review. (line 62-64)

(2) The sentence has been deleted.

(1) For consistency I suggest referring to the factor of safety as FOS or Fs. (line 75)

(2) The suggestion is accepted and Fs is taken as the factor of safety and we remove from the text the term FOS.

(3) *"The primary result of this model was a stability index, namely the minimum Fs,........"*

(1) **Please, explicit in the text the meaning of R and alpha. (Line 98).**

(2) The text now is as follows:

(3) "In the equation 3, R is the radius of the curvature and α is the angle of the slope referred to each slice"

(1) Please, describe also the meaning of alpha, b and h.

(2) The suggestion is done.

(3)*"α is the angle of the slope referred to each slice, b is the slice width and h is the mean height of slice (if the height is not constant)."*

(1) Make the acronym explicit the first time it is introduced in the text, remove (lines 120-121).

(2) TS, is the proposed model (terrain stability), but I think it is convenient to delete the line as the reviewer indicates.
(3) Remove: *Spencer's method [Spencer, 1967] is more precise and simple in the TS model.*

Add reference. (line 122).

(1) It is done as follows:

(2) *"Taking into account these elements, the Fs is then obtained from the following expression (Spencer, 1967)."*

(1)The terms of this equation must be explicited. (line 123)
(2) It is accepted.
(3) *"Where ϕ' is the friction angle at the fracture surface, **u** is the pore pressure at the fracture zone, c´ is the soil cohesion, α is the angle at the base of the slice, W is the external vertical forces and b the width of the slice.*

(1)Please, check the use of talus here. Do not use it as a synonym of slope.
(2) It is accepted.
(3) *"As mentioned, the minimum Fs to consider a slope stable is equal to 1."*

(1)Why is the pore pressure mentioned just now?
(2) I have made a change at the proposal of the reviewer 3 and in view of its indication.

(3) Enter on line 155:

"When solving the normal and parallel forces at the base of the slice of the five acting forces, we obtain (Q), resulting from the forces between slices:

$$Q = \frac{\frac{c'b}{F}\sec\alpha + \frac{\tan\phi'}{F}(W\cos\alpha - ub\sec\alpha) - W\sin\alpha}{\cos(\alpha-\theta)[1+\frac{\tan\phi'}{F}\tan(\alpha-\theta)]}$$

In this expression, u is the pore pressure (permanent interstitial pressure) at the base of the slice and the weight of the slice is determined by W. If we assume that the soil is uniform and its density (γ) also, the weight of a slice of height h and width b can be written:

$$W = \gamma bh$$ "

Enter on line 164-172:

The factor r_u is a coefficient of pore pressure (interstitial pressure coefficient), which determines the rain infiltration factor on the slopes. As it is well known, the water that infiltrates the soil may produce a *modification of the pore pressure, affecting its resistant capacity. This factor may vary from 0 (dry conditions) to 0.5 (saturated conditions). In the article of Spencer (Spencer, 1967), assuming a homogeneous pore-pressure distribution as proposed by Bishop and Morgenstern (1960), the mean pore-pressure on the base of the slice can be written like the equation 7."*

(1)There is the need to explain and show in a map where this test has been carried out. Is this a private company? (Lines 181-183).

(2) The following sentence is deleted: *"According to the in situ test carried out by the Geoner SL laboratory, the soil is a silty clay from Gibraltar Flish"*

The Flysch of Gibraltar is not the soil analyzed later in the case study in Viñuela, it is only used in this section of the document to see how the proposed program works. It is replaced by:

(3)"*Geotechnical data of a cohesive soil of the Flysch type of Gibraltar, (Vallejo et al., 2002)*".

(1) If possible, show it in figure 2. (Line 194-195). The user? (line 201). Is this the same point of line 194? (line 207)

(2) The point (xc, yc) is entered in the output graph of the program; but for a better understanding of the code, we introduce a new figure in the manuscript, only with the initial curve.

The function that is minimized with the proposed code is the safety factor Fs calculated with the Spencer method and subject to restrictions on the lower cut point with the slope (0, yt) as well as on the position of the center of the turn of the critical curve (xc, yc). Given an initial curve (yellow curve) characterized by the point x = (xc, yc, yt), the fmincon function of Matlab is used in our code to obtain the critical point (xc *, yc *, yt *) so the code draws the critical curve (green curve), where the safety factor is minimal. The following paragraph and figure are entered in line 183.

There is a typo, it is (xc, yc) and not (x0, y0) in the line 207.

The following sentence is deleted: *"According to the in situ test carried out by the Geolen SL laboratory, the soil is a silty clay from Gibraltar Flish"*

The Flysch of Gibraltar is not the soil analyzed later in the case study in Viñuela, it is only used in this section of the document to see how the proposed program works. It is replaced by:

(3) *"Figure 2 shows the results of applying the Terrain Stability model to an irregular slope, including the initial and final points of the first failure circle (shown in yellow). This circle corresponds with the initial value introduced by the user into the FSOLVE function. The points of the slope (topographic) are extracted from a DEM model in ArcGIS 10 (Glennon et al., 2008). The slope height is equal to 15 m, and the soil is uniform with the following nominal properties: γ = 19500 N/m^3, ϕ = 22º, c = 15000 N/m^2, u = 0 N/m^2. "*

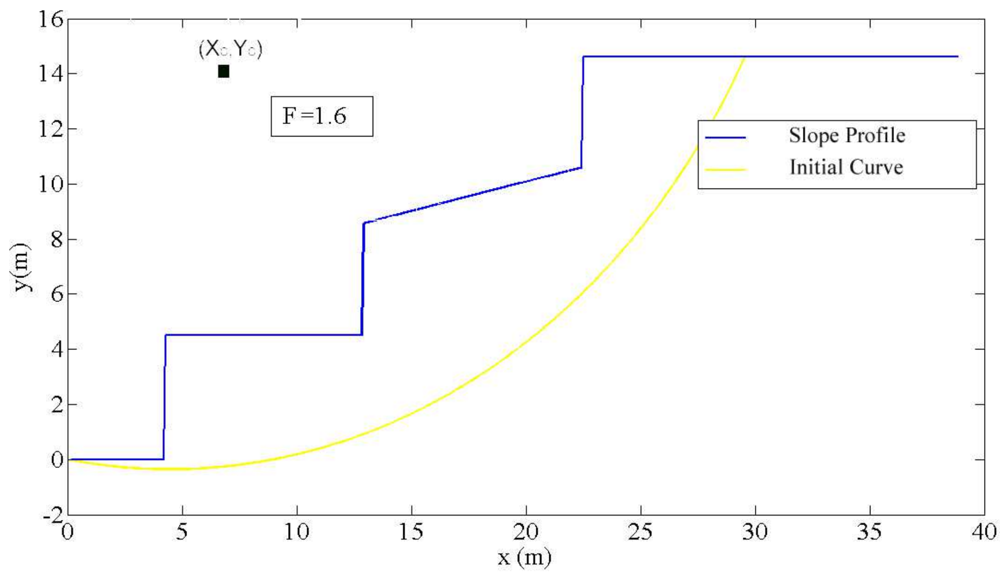


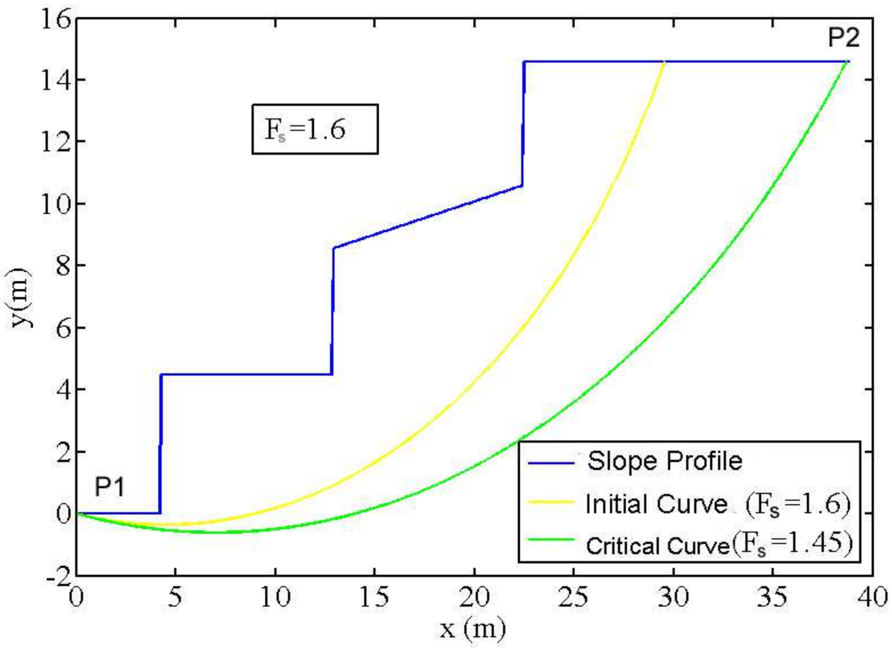
***Figure 2**. In this example, the center coordinates are equal to xc = 7 m; yc = 14 m, and the lower cut with the slope coordinates (P1 point) equal to xt = 0 m, and t = 0 m, data that the user introduces.*

The code works as follows: the initial circular failure curve is plotted using the FPLOT tool, as shown in Figure 2 (yellow line). In this example, the centre coordinates are equal to xc = 7 m; yc = 14 m and the lower cut with the slope coordinates (P1 point) equal to xt = 0 m, yt = 0 m. The Fs obtained was 1.6, which is, in principle, a stable slope. It must be taken into account that the mass susceptible *to slipping must be divided into N pieces equal to the number of slices; in this example, the mass was divided into N = 500 slices, the value of N is entered into the user code, plus divisions of the sliding mass, more accuracy but greater need for computer capacity.*

(1) This rectangular box should be shown in Figure 2. Too many coordinates. Also, if possible, show it in figure 2. (lines 213-215) (line 220)

(2) In figure 2, we could not draw the center of critical coordinates, since it indicates the calculation un y_c= 28,1091 m. and the scale of Y(m) would in this case reach 16 m., but if necessary, it could be drawn by changing the scale of the drawing. In any case, as indicated by the initial point in Figure 2, the possibility is shown.

(3) *"Figure 2, would be renamed figure 3.*



(1) How this parameter have been calculated? (line 236) How this parameter have been calculated? (line 398).

(2) The pore pressure will be hydrostatic, defined by: $u = \gamma_w(\mathrm{h} - \mathrm{h}_w)$, γ_w is the saturated density of soil, h and h_w is the difference between saturated and dry height.

$$r_u = \frac{u}{\gamma h}$$

In this expression, u is the pore pressure (permanent interstitial pressure) at the base of the slice, γ is the density of soil, h is the mean height of slice (if the height is not constant) and the weight of it affects the W evaluation.

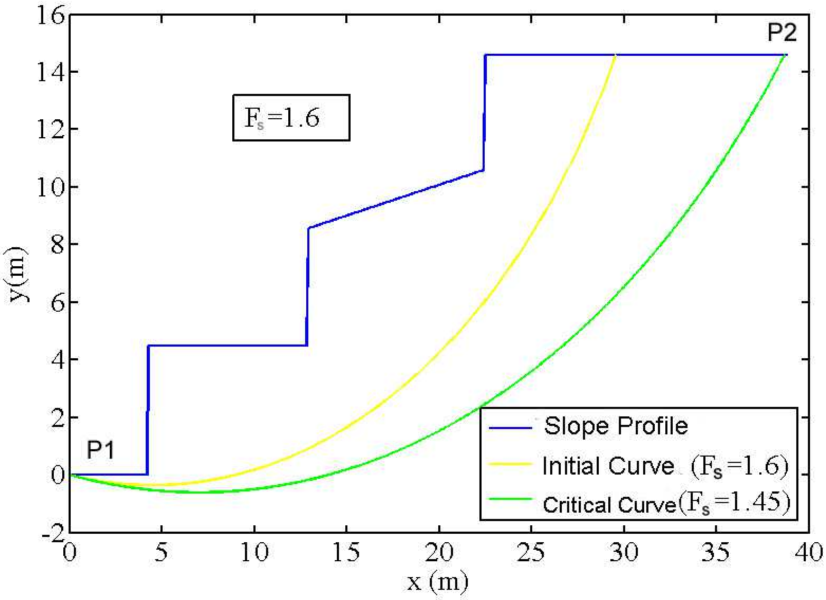
(3) *"The pore pressure will be hydrostatic, defined by:* $u = \gamma_w(h - h_w)$, *γ_w is the saturated density of soil, h and h_w is the difference between saturated and dry height. The calculation of the infiltration factor is calculated with the following equation:*

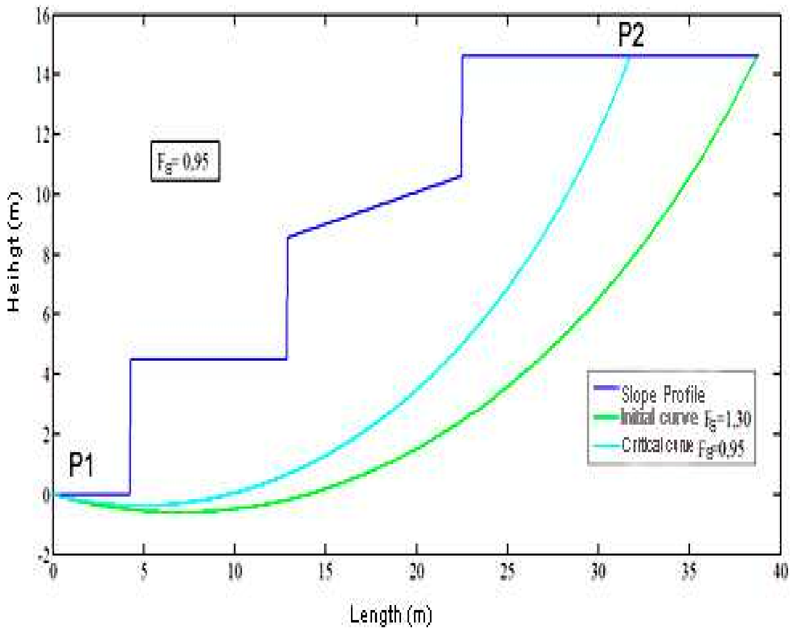
$$r_u = \frac{u}{\gamma h}$$

The factor r_u is a coefficient of pore pressure (interstitial pressure coefficient), which determines the rain infiltration factor on the slopes. As it is well known, the water that infiltrates the soil may produce a modification of the pore pressure, affecting its resistant capacity. This factor may vary from 0 (dry conditions) to 0.5 (saturated conditions). In the article of Spencer (Spencer, 1967), assuming a homogeneous pore pressure distribution as proposed by Bishop and Morgenstern (1960), the mean pore-pressure on the base of the slice can be written like the equation 7."

(1)Please, resize the Figure 2 and 3 in order to be comparable.
(2) Scales are equalized.

(3)



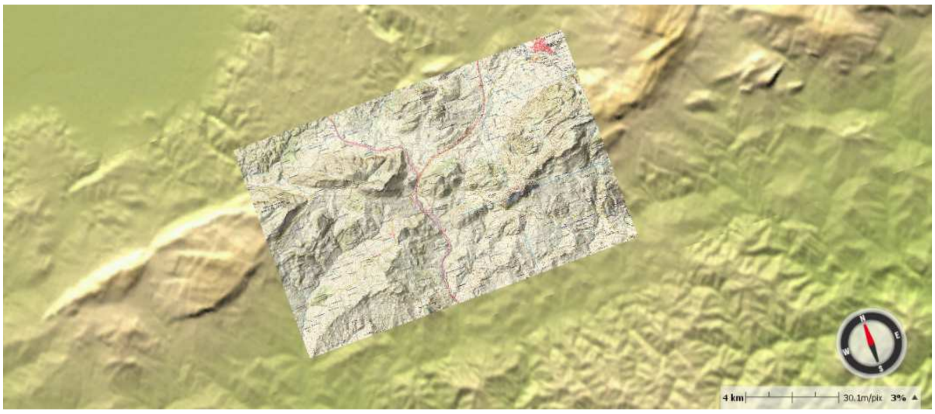


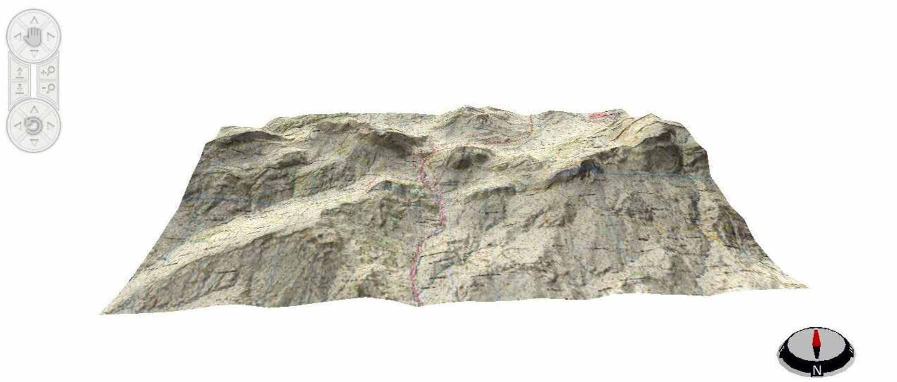
(1)It would be good to put all these information in a GIS map

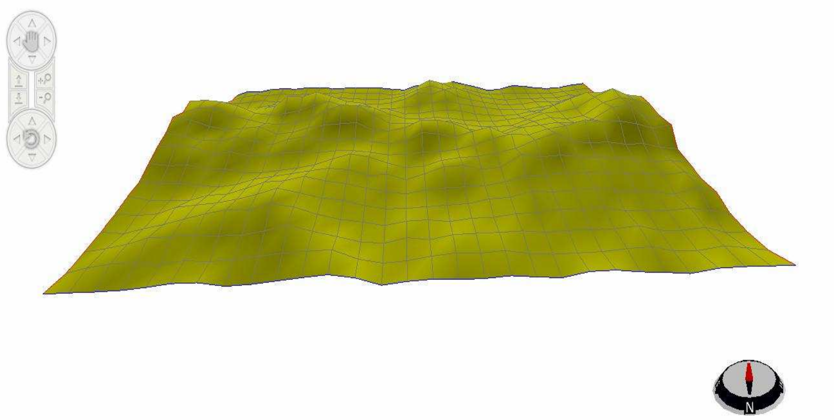
(2)We introduce map GIS:

(3)*"In this case we have looked for the map in the IGN, National GeographicInstitute:websitehttp://centrodedescargas.cnig.es/Centro Descargas/index.jsp, We have downloaded the raster map MTN25, which is a 1: 25.000 topographic map, with ETRS 89 coordinates, UTM projection. It is a File generated by means of a digital rasterization (vector to raster conversion) georeferenced, specifically* *we have downloaded sheet number 1039, which is the one corresponding to the landslide zone.*

Once we have downloaded the ecw file, we open it with any GIS software, be it the ArcGis, the Land basic Map, among others. With this map we can have the topographic map and make the necessary profiles for the study and analysis of the landslide, normally the most unfavourable profile of the topography is studied in this case."







(1)Add reference. (lines 259-261)

(2)The references are introduced as follows

(3)*"This type of mechanism is characteristic of homogeneous cohesive soils, as was the one analysed here (Cornforth, 2005; Rahardjo et al., 2007; Lu and Godt, 2008)."*

(1)You did not mentioned the date of the failure, therefore the rainfall series does not make sense here.(line 319-320). Highlight the date of the landslide in this figure. Label the axes and show the months in the x-axis. How far is from the site? Where you can find the data?

(2)The landslide analyzed began in February 2010, ending in March of that same year, hence we have indicated those specific months in the histogram. Hence, we believe that the rain histogram supplied by the Meteorological Agency of Spain in that area is necessary, through the Viñuela Weather Station.

(3)*"The landslide analyzed began in February 2010, ending in March of that same year.*

Figure 7. Rainfall histogram at La Viñuela from August 2009 to April 2010. The data to make the rain histogram, has been supplied by the Meteorological Agency of Spain, through the Meteorological Station of Viñuela."

(1)The units of measurements should be consistent with the figure. Line 332.
(2)A syntax error is detected.

(3)"*It can be observed that large amounts of precipitation fell during the months of December, January, February and March of 2010, with peaks of most 60 l/m2 in a single day (January and February). In total, 890 l/m2 fell in the 2009-2010 hydro cycle, which ended at the end of April 2010."*

(1)Please, clarify this sentence
(2)A syntax error is detected

(3)*"We applied the TS model using topographic data obtained from the ArcGIS 10 software program. We did so to obtain the degree of* *stability of the sliding land based on the angle of internal friction, the cohesion, the density and the angle of the slope we analyzed. Figure 9 shows the analytical results from the real slope, by studying and analyzing the most unfavorable profile of the landslide studied. In addition we compared the results given by the developed TS model and the results given by STB 2010 model, using free surfaces in both cases. In our model the worst curve (shown in green) was calculated automatically from the initial curve (show in blue), resulting in F_S = 2.300, in the dry state."*

(1)See comments in the introduction. (Line 415)

(2)Clarify the sentence

(3)*"our original algorithm TS model appears to be more efficient and accurate."*

(1) This list is disjuncted from the rest of the text and probably belongs to the chapter 2 (description of the model). (Lines 415-444).

(2) The change to the description of the model in section 2 has been done and can be checked in previous comments.