Grant Agreement No.: 226479

SafeLand

Living with landslide risk in Europe: Assessment, effects of global change, and risk management strategies

7th Framework Programme
Cooperation Theme 6 Environment (including climate change)
Sub-Activity 6.1.3 Natural Hazards

Deliverable 5.2

Toolbox of landslide mitigation measures

Work Package 5.1 - Toolbox for landslide hazard and risk mitigation measures

Deliverable/Work Package Leader: ICG   Revision: 1 – Final

April 2011

Rev.	Deliverable Responsible	Controlled by	Date
0	ICG	SGI-MI	Dec. 2010
1	ICG	SGI-MI	April 2011
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SUMMARY

The report describes shortly the toolbox of landslide mitigation measures, and provides the ideas and options selected for its conception and contents. The purpose of toolbox is to assist decision-making and to guide the user in the choice of the most appropriate mitigation measures. The toolbox provides the ranking of the mitigation measures for potential landslides situations. The web-based toolbox includes the following features: data management (e.g. look up prepared examples, save data half-way in analysis, return to an earlier case, look at database of information on mitigation measures, …), user forum, help function, report generation function and the ranking of the mitigation measures considered in a case study. At this stage of the research, a weighted additive algorithm was developed for the ranking of the most appropriate mitigation measures. Default value and user-defined values for weighting and scoring of each of the mitigation measures are available.

Only a few mitigation measures are described in the present report. The complete compendium of the mitigation measures are found in the companion Deliverable D5.1 in the SafeLand project: “Compendium of tested and innovative structural, non-structural and risk-transfer mitigation measures for different landslide types”. The toolbox on the web provides a more illustrative and intuitive way to learn about the mitigation measures and on how to use the toolbox. Typical screen images from the toolbox and a few examples are also provided in this report.

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CONTENTS

1 INTRODUCTION

1.1 SCOPE

Work package 5.1 “Toolbox for landslide hazard and risk mitigation measures” aims at identifying cost-effective structural and non-structural landslide mitigation options and producing a web-based "toolbox" of innovative and technically appropriate prevention and mitigation measures.

The mitigation measures are based on technology, experience, recommended practice and expert judgment in Europe and abroad. The overview of mitigation measure includes structural, non-structural, including risk-transfer, measures applicable to countries in Europe. The toolbox includes technical specifications and policy prescriptions (how to), documents, with hindsight, the experience and effectiveness of the approach (do's and don'ts), and estimates the costs, benefits, hazards and vulnerability associated with each mitigation measure.

1.2 DELIVERABLE

Based on the compendium of mitigation measures produced in Deliverable D5.1 1 in the SafeLand project: “Compendium of tested and innovative structural, non-structural and risk-transfer mitigation measures for different landslide types”, a toolbox was developed for an easy, intuitive, operational and user-friendly digitised system to assist decision-making and to guide the user in the choice of the most appropriate mitigation measures.

The toolbox is to be one of the approaches for the risk assessment and management of Work package 5.2 on “Stakeholder process for choosing an appropriate set of mitigation and prevention measures”. The toolbox provides a roadmap within a methodical framework filled with details of tools available as well as their efficiency and acceptability and ability for landslide control (and tested examples). The toolbox will be part of a framework (risk management, urban planning, sustainable development) and decision-making model. The toolbox will be the focus point where models and frameworks will be assembled and a decision-making instrument.

This information focuses on rainfall-triggered slides and debris flows, rock falls, rockslides and clay slides. Examples and recommendations for "best practice" are provided. The toolbox presents both "tried and proven" practices and not-yet-tested innovative ideas. In the application of the ranking of the appropriate mitigation measures, the user should give appropriate attention in his weighting of the potential measures for implementation to how climate and other global-change phenomena can affect the efficacy and reliability of the mitigation measures (Work package 3).

2 DESCRIPTION OF TOOLBOX

2.1 PURPOSE OF TOOLBOX

The purpose of toolbox is to assist decision-making and to guide the user in the choice of the most appropriate mitigation measures. The toolbox provides the ranking of mitigation measures for a given landslide situation. The toolbox offers an extensive menu of different mitigation measures, and the user selects those that he wishes to consider in the study at hand.

2.2 GENERAL DESCRIPTION

The web-based toolbox documents measures applicable in Europe and document "do’s and don’ts" and include "how to". It will also estimate costs, benefits, hazards, effectiveness and vulnerability of each measure to mitigate hazard and/or risk. The measures consider the following types of ground movement: rainfall-triggered slides, debris flows, rock falls, rock-slides and clay slides. Non-structural measures are also listed.

The web-based toolbox has the following features:

- Algorithm to describe a case study, estimate the expected hazard and risk level and to rank, on an engineering judgment basis, the mitigation measures included in an analysis.
- Data management (e.g. save data half-way in analysis, return to an earlier case, look up prepared examples or look up in database for information on mitigation measures)
- Report generation function
- User forum
- Help function
- User management including password-protected user login

Figure 2.2.1 presents a simplified flowchart of the work flow in the toolbox. The toolbox will probably always be in evolution, even after the SafeLand project is completed, as it has ”dynamic” technical contents that need to be updated as experience grows and new information becomes available.

At all times, the user has access to the toolbox with options to Create a new case, Open a saves case, View a case study, Save a current case, Save as - - -, Delete a current case, Print ----, as illustrated in Figure 2.2.2.

Several modern technologies were implemented in developing the toolbox. One of them includes desktop toolbar that can automatically be enabled, disabled or hovered to improve user-interface. These toolbar icons of 64 x 64 pixels were designed using graphic software. More details are given in Appendix A.

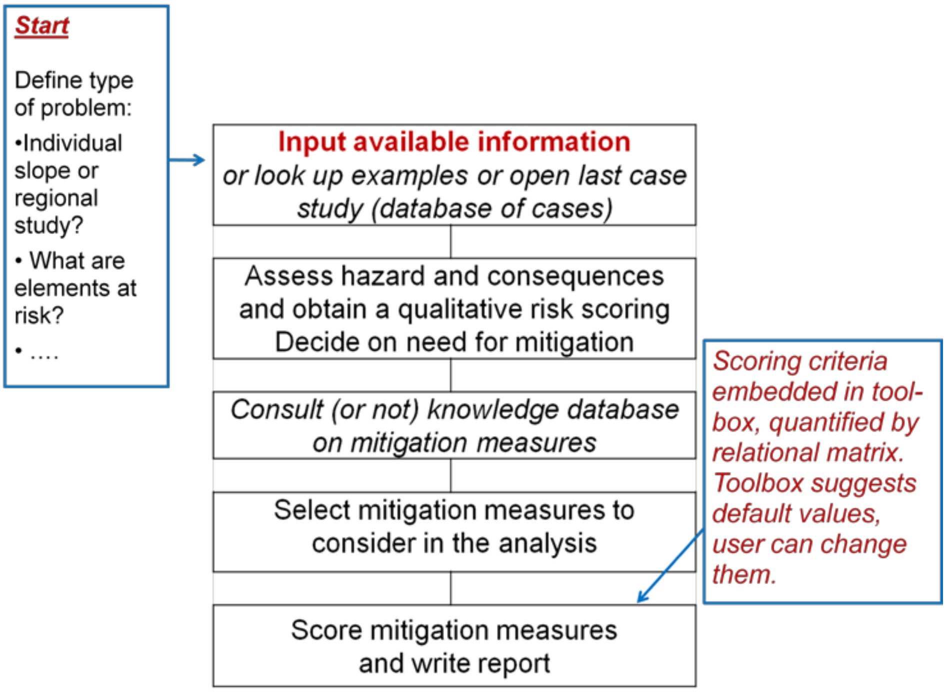

Figure 2.2.2 – Simplified flowchart of work flow in Toolbox of Mitigation Measures

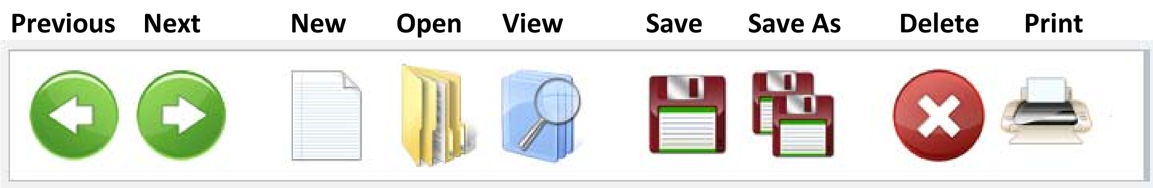

Figure 2.2.2 - Control toolbar in Toolbox of Mitigation Measures

2.3 DECISIONS IN TOOLBOX

2.3.1 Risk classes

The risk classes used in the toolbox are shown in Table 2.3.1 below. Depending on a combination of levels of consequence and hazard selected by the user, three risk classes can be assigned by the toolbox: Low, Medium and High. In this simplified model, "High risk" represents an unacceptable risk that requires new site investigations, stability calculations and mitigation measures, "Medium risk" is a risk level that requires considering doing new site investigations and analyses. For "Low risk" situation, further risk reducing measures are not necessary.

Table 2.3.1 - Risk classes in Toolbox of Mitigation measures

Hazard \ Consequence	Low	Medium	High
High	Medium Risk	High Risk	High Risk
Medium	Low Risk	Medium Risk	High Risk
Low	Low Risk	Low Risk	Medium Risk

2.3.2 Ranking of measures

The selection of the most appropriate mitigation measures to be adopted in specific situations take into account the following: (1) the factors that affect the hazard, in terms of the type, rate, depth and the probability of occurrence of the movement or landslide, such as, for example:

- the physical characteristics of the geo-system, including the stratigraphy and the mechanical characteristics of the materials, the hydrological (surface water) and the hydro-geological (groundwater) regime;
- the morphology of the area;
- the actual or potential causative processes affecting the geo-system, which can determine the occurrence of movement or landslides;

(2) the factors that affect the nature and the quantification of risk for a given hazard, such as the presence and vulnerability of elements at risk, both in the potentially unstable area and in the run-out area; and (3) the factors that affect the feasibility of specific mitigation measures, such as, for example:

- the phase and rate of movement at the time of implementation;
- the morphology of the area, accessibility and safety of workers and the public;
- environmental constraints, e.g. archeological, historical and visual values;
- pre-existing structures and infrastructure that may be affected directly or indirectly;
- capital and operating cost, including maintenance.

The user selects in the toolbox the mitigation measures to be considered. To rank the selected mitigation measures, a simple additive algorithm with weighted scoring factors for both default criteria and user-defined criteria in the toolbox was developed. The ranking (R_i) is therefore done on the basis of the summation of weighted(w_i) contributing factors (F_i) for each evaluation criterion:

$$R_i = \sum_{i=1}^{n} w_i F_i$$

where i = mitigation measures selected by the user for analysis, 1, 2, …, n
w = weighted factor proposed by the toolbox; the default value for all w_i at start is 1,0 and can be changed by the user

F = scoring factor proposed by the toolbox and which can be changed by the user

Values for F and w are proposed by the toolbox, based on a decision support matrix (see Chapter 3). The user can change the values of F and w according to his/her experience and/or engineering judgment. The user can also add additional factors F_i that will then be automatically included in the analysis.

The scoring factors (F_i) for each mitigation measure offered as default in the toolbox are for the user to consider, adopt or modify during his/her assessment of the problem at hand. The scoring for all ranking parameters is on a scale of 1 to 10, where 1 describes the least favourable attribute (worst, lowest, poorest, most expensive), and 10 the most favourable attribute (best, highest, strongest, least expensive or not expensive). The scoring of 0 is used when the mitigation measure is inapplicable or inappropriate.

Weighting factor (w_i) reflecting the relative importance of criteria or corresponding scoring factors is in the range of 0 (least) to 1 (most).

2.3.3 Priority setting

At the end of the ranking process, the toolbox lists the ranking of the selected mitigation measures in the order of most appropriate to least appropriate measures. The calculated value for R_i is also given as well as which factor(s) F_i has the most significance on the result. The user can compare the ranking order and can go back to the previous steps and change the weighting and scoring factors, especially those with high effect on the ranking R_i, if necessary.

3 COMPENDIUM OF MITIGATION MEASURES

3.1 CLASSIFICATION OF MITIGATION MEASURES

Deliverable D5.1, "Compendium of tested and innovative structural, non-structural and risk-transfer mitigation measures for different landslide types" (rev 1-Final dated 2011-03-31) prepared Partner Studio Geotechnico Italiano S.r.l. (SGI), was used a basis for the selection and evaluation of the different mitigation measures included in the toolbox for landslide hazard and risk mitigation measures. The toolbox uses the information from this deliverable.

Deliverable D5.1 discusses different classification of mitigation measures and opts for a classification in terms of the components of a risk assessment (hazard, vulnerability and elements at risk). Table 3.1.1 summarizes the classification used in the compendium. The classification system addresses three components of risk: hazard, vulnerability and elements at risk. Risk *R* can be expressed as:

$$R = H \cdot C = H \cdot V \cdot E$$

where H = hazard or the probability of occurrence of an adverse event (landslide)
C = Consequences
V = Vulnerability or the degree of loss of an element at risk for a given hazard
E = Elements at risk.

To reduce (or mitigate) the risk, one can reduce the hazard or reduce the consequences (reduce the vulnerability or reduce the exposure of the elements at risk).

Table 3.1.1 - Classification of mitigation measures used in compendium (D5.1)

Classification		Component of risk addressed	Brief description	Notes and other terms used
STRUCTURAL	Stabilization	Hazard (H)	Engineering works to reduce the landslide probability of occurrence	Preventive, remedial, hard, soft, active stabilization.
STRUCTURAL	Control	Vulnerability (V) (consequence)	Engineering works to protect, reinforce, isolate the elements at risk from the landslide zone of influence	Preventive, hard, soft, passive stabilization.
NON STRUCTURAL	Avoidance	Elements (E) (consequence)	Temporary and/or permanent reduction of exposure through: warning systems, emergency evacuation, safe sheltering, land-use planning and/or relocation of existing facilities	Reduction of the exposure of the elements at risk. Monitoring, early warning systems and civil protection procedures, often described as reducing vulnerability, are essentially temporary, selective avoidance measures.
NON STRUCTURAL	Tolerance	Elements (E) (consequence)	Awareness, acceptance and/or sharing of risk	Indirect reduction of the exposure of the elements at risk.

Within the general domain of the structural mitigation measures classified above as "stabilization", i.e. reduction of hazard, it is possible to consider a further subdivision in relation to the triggering factors and mechanisms that each measure addresses.

The toolbox includes 56 structural mitigation measures and six non-structural mitigation measures. The 56 structural measures are divided into categories and belong to the class of measures under reducing hazard. The structural mitigation measures included are:

<u>Structural measures reducing hazard</u>

1 Surface protection and control of surface erosion

- 1.1 Hydroseeding, turfing and trees/bushes
- 1.2 Fascines/brush
- 1.3 Geosynthetics
- 1.4 Substitution - drainage blanket
- 1.5 Beach replenishment, rip rap
- 1.6 Dentition

2 Modifying the slope geometry and/or mass distribution

- 2.1 Removal of (actual or potentially) unstable soil/rock mass
- 2.2 Removal of loose or potentially unstable blocks/boulders (scaling)
- 2.3 Removal of material from driving area
- 2.4 Substitution of material in driving area with lightweight fill
- 2.5 Addition of material to the area maintaining stability

3 Modifying surface water regime - surface drainage

- 3.1 Surface drainage works (ditches, channels, pipeworks)
- 3.2 Local regrading to facilitate run-off
- 3.3 Sealing tension cracks
- 3.4 Impermeabilization (geo-membranes, impervious facing)
- 3.5 Vegetation - hydrological effect
- 3.6 Hydraulic control works (channel lining and check dams)
- 3.7 Diversion channels

4 Modifying groundwater regime - deep drainage

- 4.1 Shallow trenches filled with free-draining material
- 4.2 Deep trenches filled with free-draining material
- 4.3 Sub-horizontal drains (conventional drilling)
- 4.4 Sub-horizontal drains (directional drilling)
- 4.5 Wells
  - 4.5.1 Small and medium diameter vertical wells (<800 mm)
    - 4.5.1.1 Relief of artesian pressure
    - 4.5.1.2 Under-drainage of perched aquifer
    - 4.5.1.3 Pumps
    - 4.5.1.4 Siphons
  - 4.5.2 Medium diameter vertical wells (1200-1500 mm) - gravity drainage through base conductor

4.5.3 Large diameter vertical wells (>2000 mm) - gravity drainage through base conductor
4.5.4 Caissons (>5-6 m) - with gravity drainage (and secondary sub-horizontal drains)
4.6 Drainage tunnels, adits, galleries, with secondary drains or as outlet for wells

5 Modifying the mechanical characteristics of unstable mass
5.1 Vegetation - mechanical effects
5.2 Substitution
5.3 Compaction from surface
5.4 Deep compaction (vibro-compaction, vibro-replacement, vibro-displacement)
5.5 Mechanical deep mixing with lime and/or cement
5.6 Low pressure grouting with cementitious or chemical binder
5.7 Jet grouting
5.8 Modification of ground water chemistry (e.g. lime piles)

6 Transfer of loads to more competent strata
6.1 Counterfort drains (trench drains intersecting basal shear plane)
6.2 Piles
6.3 Barrettes (diaphragm walls)
6.4 Caissons - mechanical effects
6.5 Soil nailing
6.6 Dowels and harnessing
6.7 Rock bolting
6.8 Strand anchors

7 Retaining structures (to modify slope geometry and/or to transfer stress to competent layer)
7.1 Reinforced soil structure
7.2 Gabion walls
7.3 Crib walls
7.4 Drystack masonry walls
7.5 Mass concrete or masonry walls
7.6 Reinforced concrete stem walls

The following non-structural mitigation measures, reducing either the hazard or the consequences (or vulnerability and exposure of elements at risk), are included in the toolbox:

a Early warning systems
b Restricting construction activities
c Discouraging construction activities
d Increasing resistance or coping capacity of elements at risk
e Relocation of elements at risk
f Sharing of risk through insurance

3.2 RANKING CRITERIA IN TOOLBOX

The following criteria to rank the appropriateness of each mitigation measure were used in the toolbox:

Table 3.2.1 Ranking criteria used for each mitigation measure

Ranking criterion	**Descriptor**
Type of movement	Falls Topples Slides Spreads Flows
Material type	Earth Debris Rock
Depth of movement	Superficial (< 0.5 m) Shallow (0.5 to 3 m) Medium (3 to 8 m) Deep (8 to 15 m) Very deep (> 15 m)
Rate of movement	Moderate to fast Slow Very slow Extremely slow

Ranking criterion	**Descriptor**
Groundwater	Artesian High Low Absent
Surface water	Rain Snowmelt Localized Stream Torrent River
Maturity of technology	
Reliability of performance	
Reliability in terms of uncertainty in design	
Reliability in terms of uncertainty in implementation	
Safety during construction	
Service life required (durability)	
Aesthetics	
Typical cost	

3.3 DOCUMENTATION ON MITIGATION MEASURES IN TOOLBOX

The toolbox contains extensive information for each of the mitigation measures available for ranking. An example of the documentation for one mitigation measure is presented in this report: Section 3.3.1 reproduces the information that the user can find when using the toolbox. The illustration is for one of the several measures reducing the landslide hazard by transferring the loads to more competent strata (see categories of mitigation measures above).

In the toolbox, the user can obtain information for each of the mitigation measures on the basic principles and physical process of the approach, and a description of the procedures, including design and illustrative figures, and a list of references on each of the methods. The user can also refer an explanation for the default scoring assigned in the toolbox, and can modify these. Except for some of the performance and reliability ranking criteria (reliability in terms of uncertainty in design, reliability in terms of uncertainty in implementation, safety during construction, service life required (durability) and aesthetics), the text below is taken verbatim from Deliverable D5.1 "Compendium of tested and innovative structural, non-structural and risk-transfer mitigation measures for different landslide types" (rev 1-Final dated 2011-03-31).

3.3.1 Transferring the load to more competent strata

Basic principles and physical process

Mitigation measures in this category operate as a surrogate increase in the resistance of the actual or potential sliding mass either by partially replacing the shear surface with more competent materials (e.g. shear keys, piles, etc. in Fig. 3.3.1) or by mechanically increasing the effective normal stress on the actual or potential failure surface, thus increasing the shear resistance of the soil or rock (e.g. pre-tensioned strand anchors in Fig. 3.3.2). Some systems operate on both principles simultaneously (e.g. passive anchors, soil/rock nailing in Fig. 3.3.3). In both cases, these measures operate by transferring part of the driving forces to the more competent, stable strata underlying the (actual or potential) sliding mass. These systems progressively lose their effectiveness as the sliding mass becomes a flowing mass, either through internal processes (e.g. loss of microstructure, especially in saturated materials), or through mixing with addition of water from surface runoff or groundwater).

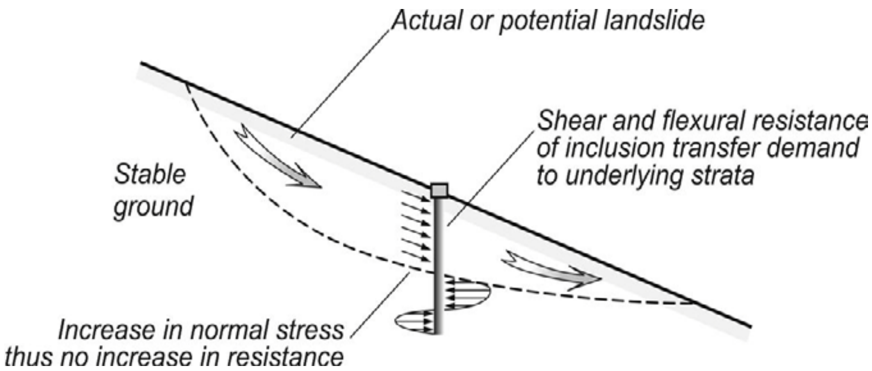

Figure 3.3.1 Example of shear keys or piles

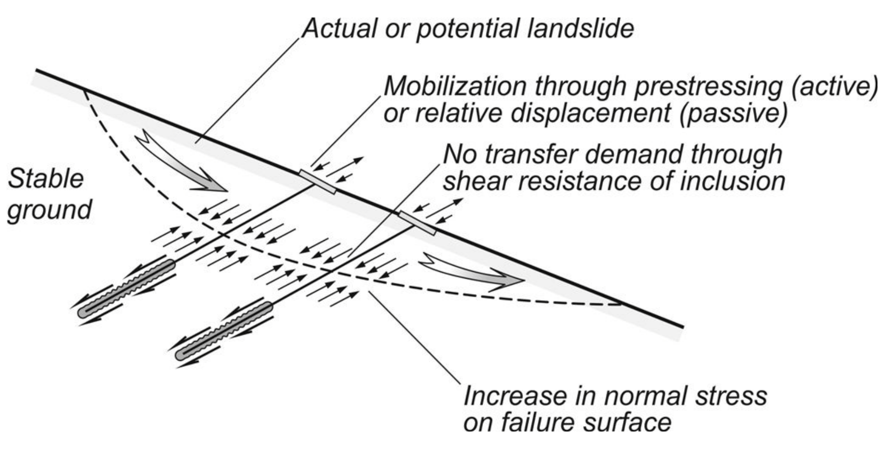

Figure 3.3.2 Example of pre-tensioned strand anchors

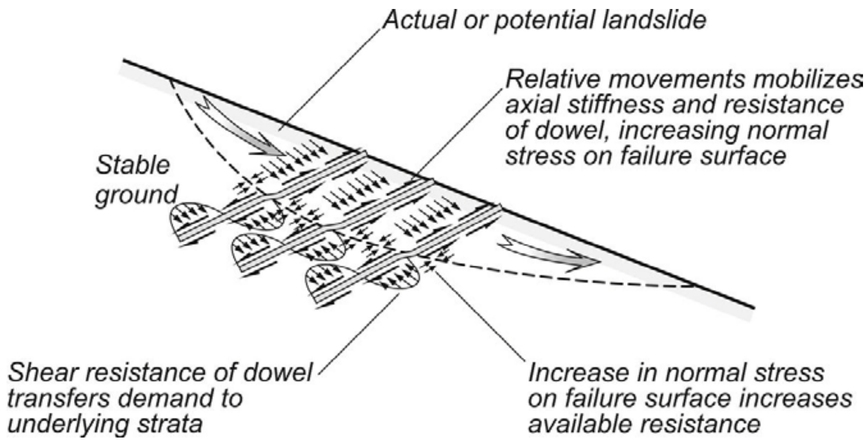

Figure 3.3.3 Example of soil nails

3.3.2 Piles

3.3.2.1 Description of mitigation measure

General description of measure

Piles (measure 6.2 in list above) can be placed in earth and debris slopes, either at regular 2D spacing over the whole slide or portion thereof, to act as isolated dowels, or, more commonly, at close spacing along one or more specific alignments to form piled walls across the direction of movement (Ito *et al.*, 1982; Hassiotis and Chameau, 1984; Soric and Kleiner, 1986; Popescu, 1991; Reese *et al.*, 1992; Polysou *et al.* (1998); Poulos, 1999). Figures 3.3.4 to 3.3.8 illustrate schematically and with field pictures the method with large diameter piles to strengthen the resistance of a slope along a roadway.

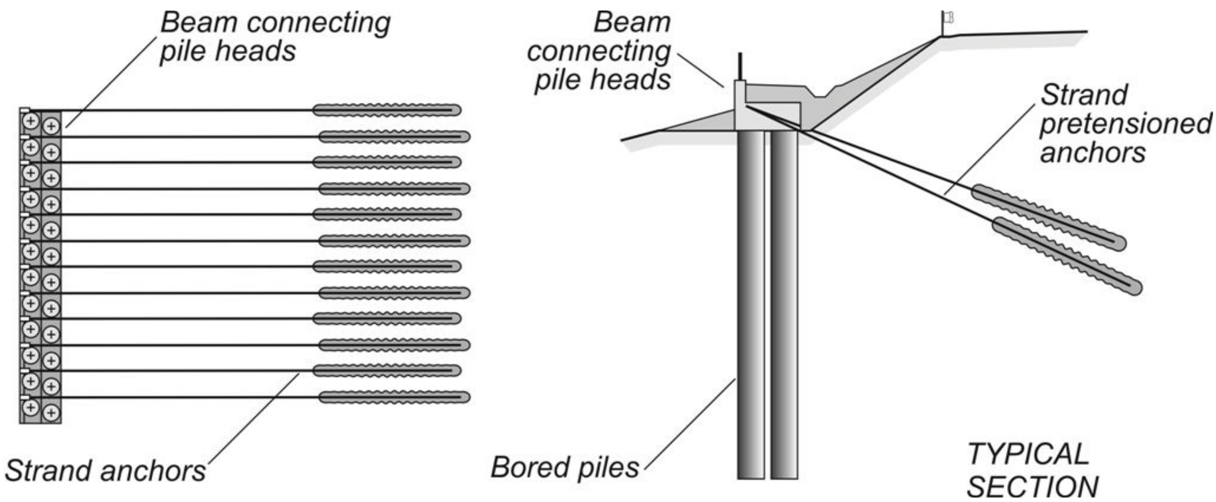

Figure 3.3.4 - Schematic of stabilization with piles

Figure 3.3.5 - Double row of large diameter piles

Figure 3.3.6 - Dapping beam connecting pile and anchor heads

Figure 3.3.7 - Rows of micropiles reinforced by steel pipes

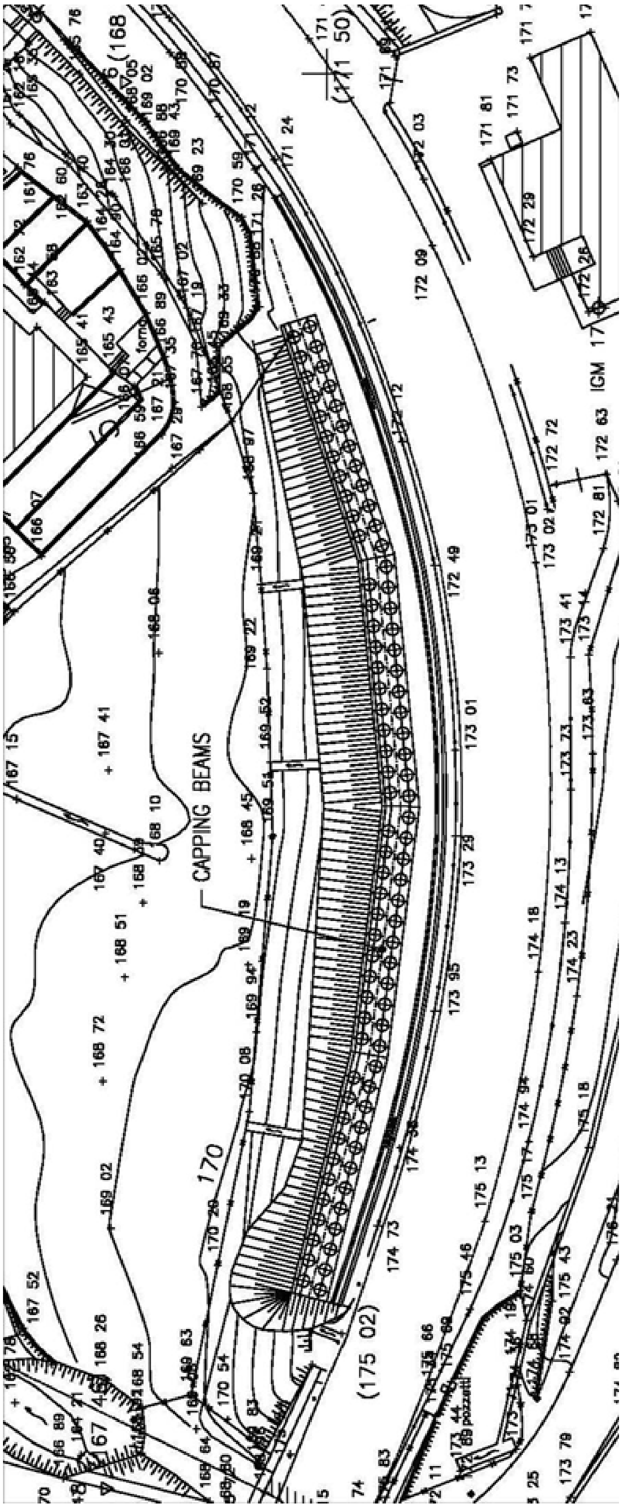

Figure 3.3.8 - Typical layout

Typically, large diameter bored cast-in-situ piles are used, with diameter 800 to 2000 (most used is 1200) mm and spacing 1.2-2 times the pile diameter. Where access is difficult and/or the depth of sliding is modest, micropiles (200 to 300 mm diameter) are also used, normally reinforced by steel pipes to maximize bending and shear resistance of the micropiles.

The advantages of this method are its applicable in a variety of topographical conditions, subject to access constraints; the casings limit hole instability during construction and the risk of damage to green concrete when piles are formed in moving slides; and conventional equipment may overcome thin layers of rock. Pile heads are usually completed by a capping beam to allow redistribution of horizontal loads between piles, the installation of anchors, where required to improve the resistance of the wall, and the installation of sub-horizontal drains, where required to reduce the thrust on the wall.

Design of mitigation measure

The design load on the pile wall may be determined in 2D limit equilibrium analyses by calculating the reaction on the vertical section corresponding to the piled wall which is necessary to guarantee, with the appropriate factor of safety, the stability of the portion of the slide located upslope of the wall in the absence of the downslope portion. In all cases, the load on the wall cannot exceed passive soil pressure.

The contribution of the downslope portion can be considered only if this portion remains stable with an appropriate factor of safety once the driving force from the upper portion is removed. Even in this case, it may be prudent to consider this mass only as confinement for the stable soil below, since even very small deformation such as shrinkage in a dry season may be sufficient to reduce or completely remove downslope support to the wall.

The design loads and the stability of the downslope portion in seismic conditions are normally determined from pseudo-static limit equilibrium analyses, taking into account the excess pore pressures that may develop in the slope, where applicable.

Once the net actions imposed by the landslide on the pile wall are known, a suitable soil-structure interaction analysis is carried out by an appropriate method to determine both the reactions in the stable soil into which the piles are anchored and the effects of actions on the piles.

The spacing between the piles must be determined by balancing cost-effectiveness and the need to avoid interference among adjacent piles during construction and/or interference with natural drainage, and the need to ensure that soil arching develops between adjacent piles and that the soil does not "flow" between the piles.

The check whether soil arching develops between adjacent piles and whether the soil does not "flow" through the piles should be done by means of analytical (simplified) tools (see for example Ito and Matsui, 1975) or 3D numerical analysis. Provided soil arching occurs, plain strain 2D soil-structure interaction analysis can be representative of actual conditions, with the effects of actions on each pile being those derived from the 2D analyses, multiplied by the pile centre to centre spacing. The same analysis may be used to determine the optimal length of the piles and the benefit of additional anchors, if used.

The calculation of the pile capacity in relation to the soil/structure interaction may be carried out according to several approaches and simplified methods (De Beer, 1977; Viggiani, 1981; Hassiotis and Chameau, 1984; Cantoni et al, 1989; Pearlman and Withiam, 1992). Finite element methods may also be used to provide a simultaneous and consistent estimate of the soil-structure interaction both with the sliding mass and with the underlying stable soil. Finite element analyses in the time domain can also be used to refine the evaluation of the performance of the structure under seismic conditions.

The mechanical characteristics of the piles must be adequate to sustain the actions and the effects of actions on the piles. The structural checks must satisfy all applicable codes and standards on the subject.

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3.3.2.2 Reasons for the scores assigned as default values

An explanation for the scoring for the mitigation measure "transferring the load to more competent strata with piles" is given as an example. The same explanation can be found in the toolbox. Table 3.3.1 presents the reasoning for the scoring factors in the toolbox. These are based on the values provided in the compendium.

Table 3.3.1 - Scoring factors (default value) for piles as mitigation measure

Ranking criterion	Descriptor	Scoring factor	Notes
Type of movement	Falls	0	Measure is best suited for slides and the slide-like portion of complex landslides. Measure may be applicable to prevent the triggering of slides with the potential to turn into spreads or flows, the measure is essentially ineffective once fluidization has occurred. One of the better measures for complex soil conditions.
	Topples	0	
	Slides	8	
	Spreads	4	
	Flows	4	
Material type	Earth	8	Measure is difficult, very expensive and typically inappropriate in rock. Tools and temporary hole support to be selected taking into account ground conditions. Special care must be exercised where the ground contains large boulders. Pile driving should be preferably achieved without causing excessive vibration.
	Debris	8	
	Rock	0	
Depth of movement	Superficial (< 0.5 m)	0	Typically, the measure is: best suited where the movement is medium deep (3 to 8 m), inappropriate in shallower movements because excessively expensive, difficult (large diameter, multiple rows) in case of deep movements, not applicable for very deep movements.
	Shallow (0.5 to 3 m)	4	
	Medium (3 to 8 m)	8	
	Deep (8 to 15 m)	4	
	Very deep (> 15 m)	0	
Rate of movement	Moderately to fast	0	Workers' safety and end result require construction to take place when movement is extremely slow or very slow (maximum 1.5 m/year, corresponding to approximately 5 mm/day). Under special conditions and while taking due precautions (permanent casing; drilling non-stop to avoid blockage and broken piles, the measure may be selected movement is "slow" (up to 1.5 m/month, corresponding to 5 cm/day) .
	Slow	4	
	Very slow	8	
	Extremely slow	8	
Groundwater	Artesian	2	High groundwater levels can be dealt with by standard pile construction procedures, but artesian groundwater conditions pose special problems during construction, possibly making piles not feasible in extreme cases.
	High	6	
	Low	8	
	Absent	8	
Surface water	Rain	8	Water courses need to be temporarily diverted or kept reasonable dry during construction. Potential pollution of watercourses by piling operations (for example by drilling fluid and/or by grout) may impose restriction on construction procedure. No problems once the works are completed, except possibly when piles provide an undesired "hard bank" to watercourses.
	Snowmelt	8	
	Localized	8	
	Stream	2	
	Torrent	2	
	River	2	

Ranking criterion	Descriptor	Scoring factor	Notes
Maturity of technology		10	Technique and design processes are well established and widely used in suitable conditions.
Reliability of performance		8	Experience with good and reliable performance in well characterized landslides. For first time slides, performance depends on estimate of porewater pressure regime and shear strength parameters of soil.
Reliability Uncertainty in design-		5	Uncertainties in soil parameters for pile design and empiricism in calculation methods for pile capacity may be large.
Reliability Uncertainty in implemen-tation		6	Requires specialist equipment and techniques; implementation may need temporary roads and working platform for safe operation.
Safety during construction		5	Normal. Problems may occur during construction, for example if unforeseen boulders are encountered.
Service life required (durability)		8	When well built, can last a very long time
Æsthetics		--	Depends on user and situation at hand
Typical Cost		4	Mitigation measure is relatively expensive.

Footnote
Ratings are given on a scale of 1 to 10; the higher the grade, the most suitable is the specific method under consideration to use in landslides of the given characteristics, evaluated individually. Overall suitability to specific case under consideration may be obtained by a weighted average of these ratings, with user defined weights. Zero rating means "not applicable".

3.4 DECISION SUPPORT MATRIX IN TOOLBOX

3.4.1 Structural mitigation measures

The decision scoring matrix implemented in the toolbox for the structural measures listed in Section 3 is described in Tables 3.4.1 and 3.4.2. The values in these two tables are the default values provided by the toolbox, and these can be changed by the user. Some changes have been made to the scoring matrix provided in the compendium.

The scoring factors necessary for ranking of the “surface protection and control of surface erosion” mitigation measures (measures 1.1 to 1.6 in Section 3.1) were not quantified in the compendium, but were treated in a qualitative manner. In the toolbox, the scoring factors shown in Table 3.4.1 and 3.4.2 are provided as default values, but may need to be changed by the user. Values between 1 and 10 were used, depending on suitability (see footnote to Table 3.2.1), in order to make the scoring for these measures comparable to that for the mitigation measures where the scoring factors have been quantified.

For the criteria on reliability, aesthetics and costs (maturity of technology, reliability of performance, reliability in terms of uncertainty in design, reliability in terms of uncertainty in implementation, safety during construction, service life required (durability), aesthetics and typical cost), relative scoring factors between 1 and 10 were also established and entered in the toolbox as default values, as per listed in Table 3.4.2. As these scoring factors are based on local and personal experience, the user should consider changing these. The aesthetics criterion should be changed in all cases, since it depends on the local setting,

3.4.2 Non-Structural mitigation measures

For the non-structural mitigation measures, the compendium discusses briefly the approaches, but no quantitative scoring was done. Table 3.4.3 lists the scoring factors suggested for the six non-structural mitigation measures. The toolbox provides scores based on earlier experience at ICG and NGI, and the user can change these values (both score and weight) where necessary. Relative scoring factors between 1 and 10 were established and entered in the toolbox as default values. These should be carefully considered by the user. In the toolbox, the scoring and ranking are treated separately from the structural measures, because the sum of the weighted factor ends up being different from that for the structural measures.

The user should add into the analysis (in areas provided for this purpose in the toolbox, new scoring criteria such as social acceptance, stakeholder participation and consequence of measure for locality/society, as a function of the geography, location, culture and politics in the area of analysis.

3.4.3 Scale of scoring

The scores are given on a scale of 1 to 10; the higher the grade, the most suitable is the specific method under consideration for the landslides with the given characteristics. Overall suitability for the specific case under study is obtained by a weighted average of these ratings, with toolbox default or user-defined weights. Zero rating means "not applicable".

Table 3.4.1 - Decision support matrix for structural mitigation measures – technological criteria

Category	No.	Structural mitigation measure	Type of movement					Material			Depth of movement					Rate of movement at time of works				Groundwater				Surface water					
			Falls	**Topples**	**Slides**	**Spreads**	**Flows**	**Earth**	**Debris**	**Rock**	**Superficial (< 0.5m)**	**Shallow (0.5 - 3 m)**	**Medium (3 - 8 m)**	**Deep (8 - 15 m)**	**Very deep (>15m)**	**Moderate to fast**	**Slow**	**Very slow**	**Extremely slow**	**Artesian**	**High**	**Low**	**Absent**	**Rain**	**Snowmelt**	**Localized**	**Stream**	**Torrent**	**River**
1		**Surface protection and control of surface erosion**																											
	1.1	Hydroseeding, turfing, trees,..	0	0	8	0	6	8	7	2	8	4	0	0	0	2	5	8	10	8	8	5	5	7	5	3	0	0	4
	1.2	Fascines/brush	0	0	8	0	6	8	8	0	10	4	0	0	0	2	6	8	10	8	8	6	4	8	7	6	6	0	6
	135	Geosynthetics	0	0	7	0	0	8	6	0	8	4	0	0	0	4	6	8	10	8	8	8	8	8	8	6	6	2	6
	1.4	Substitution/drainage blanket	0	0	7	0	6	8	4	0	10	4	0	0	0	6	8	10	10	8	8	4	2	8	8	4	0	0	0
	1.5	Beach replenishment, rip rap	0	0	7	0	0	8	8	4	10	4	0	0	0	6	8	10	10	8	8	4	2	6	6	6	7	8	7
	1.6	Dentition	8	6	0	0	0	0	0	8	8	0	0	0	0	8	8	8	8	7	8	8	8	6	6	8	4	2	0
2		**Modifying the slope geometry and/or the mass distribution**																											
	2.1	Removal of (actual or potential) unstable soil/rock mass	4	4	6	0	2	8	8	4	10	6	4	2	0	2	6	8	8	2	4	8	6	6	0	0	0	0	0
	2.2	Removal of loose/potentially unstable blocks/boulders	8	6	0	0	0	2	0	8	8	2	0	0	0	0	0	8	8	0	2	8	10	6	8	4	0	0	0
	2.3	Removal of material from driving area	0	2	8	0	0	8	8	4	8	8	8	6	6	2	8	8	8	4	6	8	8	6	6	4	2	0	0
	2.4	Substitution of material in driving area with lightweight fill	0	0	6	0	0	8	6	2	6	6	6	4	0	0	2	6	8	6	6	8	8	6	6	6	2	0	0
	2.5	Addition of material to the area maintaining stability	0	2	8	0	0	8	6	4	6	8	8	6	4	2	8	8	8	8	8	8	8	6	6	4	2	0	0
3		**Modifying surface water regime - surface drainage**																											
	3.1	Surface drainage works (ditches, channels, pipeworks)	0	0	8	4	6	8	6	2	8	8	6	4	0	0	6	8	8	6	6	6	6	8	8	8	4	0	0

			Type of movement					**Material**			**Depth of movement**					**Rate of movement at time of works**				**Groundwater**				**Surface water**					
Cat.egory	**No.**	**Structural mitigation measure**	**Falls**	**Topples**	**Slides**	**Spreads**	**Flows**	**Earth**	**Debris**	**Rock**	**Superficial (< 0.5m)**	**Shallow (0.5 - 3 m)**	**Medium (3 - 8 m)**	**Deep (8 - 15 m)**	**Very deep (>15m)**	**Moderate to fast**	**Slow**	**Very slow**	**Extremely slow**	**Artesian**	**High**	**Low**	**Absent**	**Rain**	**Snowmelt**	**Localized**	**Stream**	**Torrent**	**River**
	3.2	Local regrading to facilitate run-off	0	0	8	4	6	8	6	2	8	8	6	4	0	2	6	8	8	6	6	8	8	8	8	8	4	0	0
	3.3	Sealing tension cracks	0	0	8	4	0	8	6	2	8	8	6	4	0	2	6	8	8	6	6	8	8	8	8	8	4	0	0
	3.4	Impermeabilization (geomem--branes, impervious facing)	0	0	8	4	0	8	6	2	8	8	6	4	0	2	6	8	8	6	6	8	8	8	8	8	4	0	0
	3.5	Vegetation-hydrological effect	0	0	8	0	6	8	6	0	8	8	6	2	0	2	6	8	8	8	8	6	6	8	8	6	4	0	0
	3.6	Hydraulic control works	0	0	8	0	8	8	8	0	8	8	8	6	4	0	0	6	8	6	6	8	8	6	6	8	8	10	8
	3.7	Diversion channels	6	6	8	6	6	8	8	8	0	0	4	6	10	8	8	8	8	8	8	8	8	6	6	6	8	8	8
4		**Modifying groundwater regime - deep drainage**																											
	4.1	Shallow trenches filled with free-draining material	0	0	6	0	4	8	6	0	8	8	4	0	0	0	8	8	8	2	6	2	0	8	8	0	0	0	0
	4.2	Deep trenches filled with free-draining material	0	0	8	2	6	8	6	4	8	8	8	4	0	6	8	8	8	4	8	4	0	6	6	0	0	0	0
	4.3	Sub-horizontal drains (conventional drilling)	2	2	6	2	4	4	8	4	0	2	6	6	4	2	6	8	8	4	6	8	0	4	4	0	0	0	0
	4.4	Sub-horizontal drains (directional drilling)	2	2	6	4	4	4	8	4	0	0	6	8	8	2	6	8	8	4	6	8	0	4	4	0	0	0	0
	4.5	<u>Wells</u>																											
	4.5.1	<u>Small and medium diameter vertical wells (<800 mm)</u>																											
	4.5.1.1	Relief of artesian pressure	0	0	4	2	4	8	4	4	0	6	8	8	6	0	4	8	8	20	0	0	0	2	2	0	0	0	0
	4.5.1.2	Underdrainage, perched aq'fer	2	2	6	0	0	6	8	4	0	4	6	4	4	0	4	8	8	0	8	0	0	2	2	0	0	0	0
	4.5.1.3	Pumps	0	0	5	3	0	5	6	4	0	0	5	8	8	0	2	8	8	6	8	6	0	2	2	0	0	0	0
	4.5.1.4	Siphons	0	0	6	2	0	6	6	4	0	4	6	8	4	0	2	8	8	6	8	6	0	2	2	0	0	0	0

Category	No.	Structural mitigation measure	Type of movement					Material			Depth of movement					Rate of movement at time of works				Groundwater				Surface water					
			Falls	Topples	Slides	Spreads	Flows	Earth	Debris	Rock	Superficial (< 0.5m)	Shallow (0.5 - 3 m)	Medium (3 - 8 m)	Deep (8 - 15 m)	Very deep (>15m)	Moderate to fast	Slow	Very slow	Extremely slow	Artesian	High	Low	Absent	Rain	Snowmelt	Localized	Stream	Torrent	River
	4.5.2	Medium diameter vertical well (1200-1500 mm), gravity drainage through base conductor	0	0	6	4	2	8	6	2	0	0	2	8	4	0	2	8	8	4	8	6	0	2	2	0	0	0	0
	4.5.3	Large diameter vertical wells (>2000 mm) - gravity drainage through base conductor	0	0	6	4	2	8	6	2	0	0	2	8	4	0	2	8	8	4	8	6	90	2	2	0	0	0	0
	4.5.4	Caisson (>5-6 m), with gravity drainage (and secondary sub-horizontal drains)	0	0	6	6	4	8	6	2	0	0	0	6	8	0	2	8	8	4	8	6	0	2	2	0	0	0	0
	4.6	Drainage tunnels, adits, galleries, with secondary drains or as outlet for wells	2	4	6	6	6	6	6	6	0	0	2	6	8	4	8	8	8	6	8	8	0	0	0	0	0	0	0
5		**Modifying the mechanical characteristics of unstable mass**																											
	5.1	Vegetation-mechanical effects	0	0	4	0	0	8	4	2	8	4	0	0	0	2	6	8	8	8	8	4	2	8	8	6	4	0	4
	5.2	Substitution	0	0	8	0	0	8	6	8	8	6	8	4	0	0	2	6	10	2	4	8	10	8	8	8	2	0	0
	5.3	Compaction from surface	0	0	4	0	0	6	4	0	6	2	0	0	0	0	0	2	8	0	2	8	8	6	6	2	0	0	0
	5.4	Deep compaction (vibro-compaction, vibro-displacement, vibro-replacement)	0	0	6	4	4	8	4	0	0	0	8	8	6	0	0	2	8	0	8	6	6	8	8	8	2	0	0
	5.5	Mechanical deep mixing with lime and/or cement	0	0	6	4	4	8	4	0	0	4	8	8	6	0	2	6	8	6	8	8	8	8	8	8	2	2	2
	5.6	Low pressure grouting with cementitious or chemical binder	6	4	6	6	4	6	8	6	0	4	6	8	8	0	0	2	8	0	6	8	8	8	8	6	0	0	0
	5.7	Jet grouting	0	0	6	4	4	6	8	0	0	0	6	8	8	0	2	6	8	6	8	8	8	8	8	8	2	2	2
	5.8	Modification of ground water	0	0	6	4	4	6	0	0	0	4	8	8	8	0	0	6	8	0	8	4	0	6	6	0	0	0	0

Category	No.	Structural mitigation measure	Type of movement					Material			Depth of movement					Rate of movement at time of works				Groundwater				Surface water					
			Falls	Topples	Slides	Spreads	Flows	Earth	Debris	Rock	Superficial (< 0.5m)	Shallow (0.5 - 3 m)	Medium (3 - 8 m)	Deep (8 - 15 m)	Very deep (>15m)	Moderate to fast	Slow	Very slow	Extremely slow	Artesian	High	Low	Absent	Rain	Snowmelt	Localized	Stream	Torrent	River
		chemistry (e.g. lime piles)																											
6		**Transfer of loads to more competent strata**																											
	6.1	Counterfort drains (trench drains intersecting shear plane)	0	0	8	0	0	8	4	0	8	8	4	0	0	0	4	8	8	4	8	6	2	6	6	4	2	0	0
	6.2	Piles	0	0	8	4	4	8	8	0	0	4	8	4	0	0	4	8	8	2	6	8	8	8	8	8	8	2	2
	6.3	Barrettes (diaphragm walls)	0	0	8	4	4	8	8	0	0	0	6	8	4	0	2	6	8	2	6	8	8	8	8	8	2	2	2
	6.4	Caissons - mechanical effect	0	0	8	4	4	8	8	0	0	0	4	6	8	0	2	6	8	2	6	8	8	8	8	6	2	0	0
	6.5	Soil nailing	6	6	8	0	0	8	6	0	8	8	6	0	0	0	2	8	10	0	2	4	10	8	8	4	2	0	0
	6.6	Dowels and harnessing	8	2	0	0	0	0	0	8	8	2	0	0	0	0	0	0	8	0	6	6	6	8	8	6	0	0	0
	6.7	Rock bolting	8	8	0	0	0	0	0	8	6	8	6	0	0	0	0	0	8	0	6	8	8	8	8	6	0	0	0
	6.8	Strand anchors	6	8	8	0	0	8	6	8	0	2	6	8	8	0	0	4	8	2	6	8	8	8	8	8	2	0	0
7		**Retaining structures (to modify slope geometry and/or to transfer stress to competent layer)**																											
	7.1	Reinforced soil structure	0	2	8	0	0	8	6	4	0	4	8	6	2	0	4	8	8	8	8	8	8	6	6	6	4	0	2
	7.2	Gabion walls	0	2	8	0	0	8	6	4	4	8	8	2	0	0	4	8	8	8	8	8	8	6	6	6	6	0	6
	7.3	Crib walls	0	2	8	0	0	8	6	4	0	8	8	2	0	0	4	8	8	8	8	8	8	6	6	6	0	0	0
	7.4	Drystack masonry walls	0	0	4	0	0	8	6	4	8	8	2	0	0	0	0	6	8	8	8	8	8	6	6	6	0	0	0
	7.5	Mass concrete/masonry walls	0	0	6	0	0	8	6	4	0	8	6	0	0	0	0	6	8	8	8	8	8	6	6	6	6	4	6
	7.6	Reinforced concrete stem walls	0	0	6	0	0	8	6	4	0	8	6	0	0	0	0	6	8	8	8	8	8	6	6	6	6	4	6

Table 3.4.2 - Decision support matrix for structural mitigation measures – performance and reliability criteria

Category	No.	Structural mitigation measure	Maturity of technology	Reliability of performance	Reliability - design	Reliability – implementation	Safety during construction	Service life required (durability)	Aesthetics	Typical Cost
1		**Surface protection and control of surface erosion**								
	1.1	Hydroseeding, turfing, trees,..	10	8	8	6	10	7	1	8
	1.2	Fascines/brush	10	8	8	6	10	7	1	8
	135	Geosynthetics	10	8	8	8	10	8	1	6
	1.4	Substitution/drainage blanket	10	8	8	8	10	8	1	6
	1.5	Beach replenishment, rip rap	10	8	8	8	10	8	1	6
	1.6	Dentition	10	8	8	8	10	8	1	5
2		**Modifying the slope geometry and/or the mass distribution**								
	2.1	Removal of (actual or potential) unstable soil/rock mass	10	8	10	8	5	8	1	6
	2.2	Removal of loose/potentially unstable blocks/boulders	8	8	10	4	5	8	1	8
	2.3	Removal of material from driving area	8	6	10	8	6	8	1	8
	2.4	Substitution of material in driving area with lightweight fill	6	6	10	6	8	8	1	6
	2.5	Addition of material to the area maintaining stability	10	10	8	8	8	8	1	8
3		**Modifying surface water regime - surface drainage**								
	3.1	Surface drainage works (ditches, channels, pipeworks)	10	8	8	10	8	6	1	10
	3.2	Local regrading to facilitate run-off	10	8	8	10	8	6	1	10
	3.3	Sealing tension cracks	10	8	6	10	8	6	1	10
	3.4	Impermeabilization (geomembranes, impervious facing)	10	8	8	10	8	6	1	10
	3.5	Vegetation-hydrological effect	6	6	6	8	8	6	1	10
	3.6	Hydraulic control works	8	8	4	6	8	6	1	5
	3.7	Diversion channels	6	6	6	6	8	6	1	2

Category	No.	Structural mitigation measure	Maturity of technology	Reliability of performance	Reliability - design	Reliability – implementation	Safety during construction	Service life required (durability)	Aesthetics	Typical Cost
4		**Modifying groundwater regime - deep drainage**								
	4.1	Shallow trenches filled with free-draining material	8	7	10	7	8	8	1	7
	4.2	Deep trenches filled with free-draining material	8	7	8	6	6	8	1	6
	4.3	Sub-horizontal drains (conventional drilling)	7	6	8	6	8	8	1	7
	4.4	Sub-horizontal drains (directional drilling)	6	6	6	7	8	8	1	6
	4.5	Wells								
	4.5.1	Small and medium diameter vertical wells (<800 mm)								
	4.5.1.1	Relief of artesian pressure	8	7	7	7	8	4	1	6
	4.5.1.2	Under-drainage, perched aquifer	6	6	7	7	8	4	1	6
	4.5.1.3	Pumps	7	6	6	7	8	4	1	5
	4.5.1.4	Siphons	5	6	4	7	8	4	1	5
	4.5.2	Medium diameter vertical well (1200-1500 mm), gravity drainage through base conductor	8	7	6	6	8	6	1	4
	4.5.3	Large diameter vertical wells (>2000 mm) - gravity drainage through base conductor	8	7	6	6	8	6	1	4
	4.5.4	Caisson (>5-6 m), with gravity drainage (and secondary sub-horizontal drains)	7	7	6	7	4	8	1	2
	4.6	Drainage tunnels, adits, galleries, with secondary drains or as outlet for wells	7	7	6	6	6	8	1	1
5		**Modifying the mechanical characteristics of unstable mass**								
	5.1	Vegetation-mechanical effects	8	8	8	8	10	8	1	8
	5.2	Substitution	8	8	10	8	10	8	1	8
	5.3	Compaction from surface	6	4	8	8	10	7	1	8
	5.4	Deep compaction (vibro-compaction, vibro-displacement, vibro-replacement)	6	8	6	6	9	6	1	4
	5.5	Mechanical deep mixing with lime and/or cement	6	8	6	6	8	8	1	4
	5.6	Low pressure grouting with cementitious or chemical binder	6	6	6	6	6	6	1	6
	5.7	Jet grouting	6	6	5	5	6	8	1	4

Category	No.	Structural mitigation measure	Maturity of technology	Reliability of performance	Reliability - design	Reliability – implementation	Safety during construction	Service life required (durability)	Aesthetics	Typical Cost
	5.8	Modification of ground water chemistry (e.g. lime piles)	4	4	4	8	7	6	1	6
6		**Transfer of loads to more competent strata**								
	6.1	Counterfort drains (trench drains intersecting shear plane)	8	8	6	6	8	6	1	8
	6.2	Piles	10	8	5	6	6	8	1	4
	6.3	Barrettes (diaphragm walls)	10	8	6	6	6	8	1	4
	6.4	Caissons - mechanical effect	8	8	6	6	4	8	1	2
	6.5	Soil nailing	6	6	6	6	6	8	1	6
	6.6	Dowels and harnessing	8	8	6	6	6	6	1	6
	6.7	Rock bolting	8	8	8	6	8	8	1	6
	6.8	Strand anchors	6	6	6	6	6	6	1	6
7		**Retaining structures (to modify slope geometry and/or to transfer stress to competent layer)**								
	7.1	Reinforced soil structure	8	8	6	8	8	8	1	6
	7.2	Gabion walls	8	8	8	8	8	8	1	8
	7.3	Crib walls	8	8	8	8	8	6	1	6
	7.4	Drystack masonry walls	6	4	6	8	8	6	1	8
	7.5	Mass concrete/masonry walls	8	6	6	8	8	6	1	8
	7.6	Reinforced concrete stem walls	8	6	8	8	8	8	1	6

Table 3.4.3 - Decision support matrix for non-structural measures

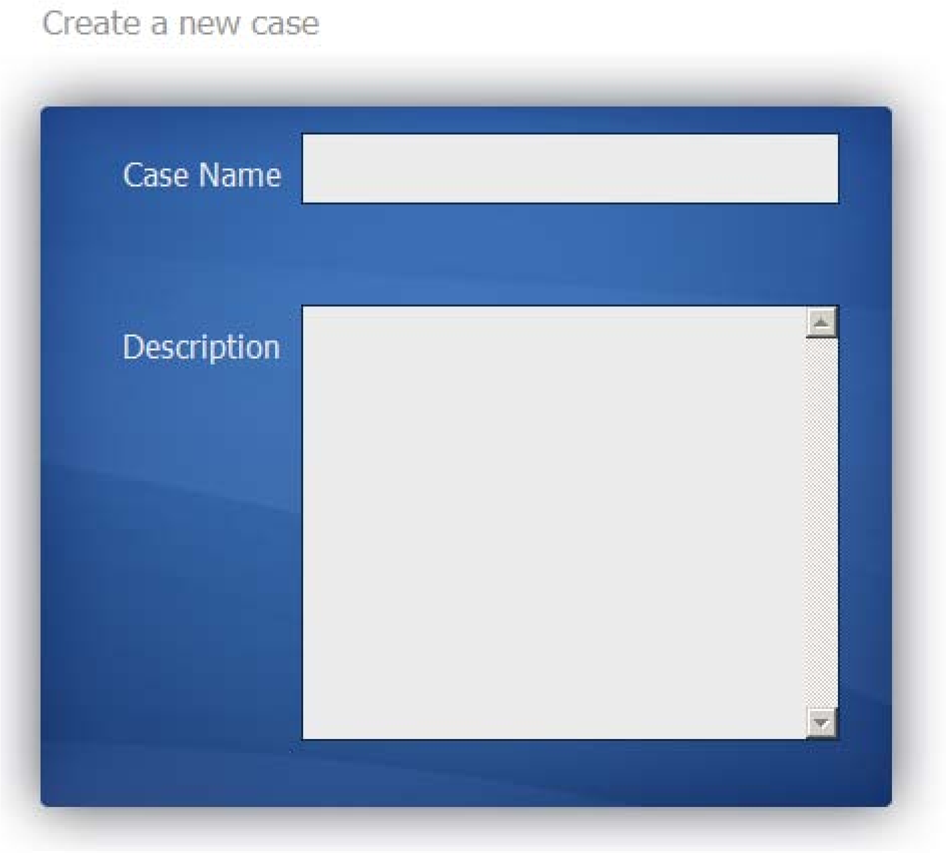
No.	Non-structural mitigation measure	Maturity of technology	Reliability of performance	Reliability - design	Reliability - implementation	Safety during construction	Service life required (durability)	Aesthetics	Typical Cost
a	Early warning systems	8	6	7	5	0	8	6	6
b	Restricting construction activities	8	8	8	8	0	6	8	10
c	Discouraging construction activities	8	8	8	8	0	6	8	10
d	Increasing resistance or coping capacity of elements at risk	5	5	6	10	0	10	10	4
e	Relocation of elements at risk	4	10	10	10	0	10	10	2
f	Sharing of risk through insurance	4	6	8	6	0	10	10	5

4 DETAILED DESCRIPTION OF TOOLBOX

4.1 DESCRIPTION OF ANALYSIS TO BE DONE IN TOOLBOX

4.1.1 Creating a new case and initial information

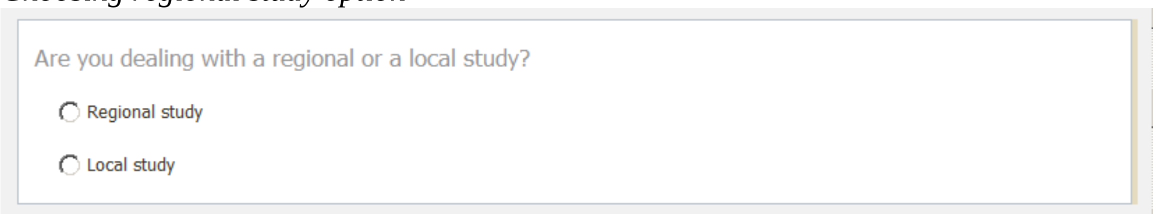
At any time in the analysis, the user is able to create a new case, retrieve an case analysed earlier or view an example already provided in the toolbox. A first page on the web enables the user to create a new analysis case.



4.1.2 Regional Study

Five steps give information on a regional vs local study and guide the user toward a local study, where mitigation measured are to prioritized.

Choosing regional study option



Identifying the region

Please identify the region?

Requesting information

For this region, do you have information on the slope hazard?

- Yes
- No

Do you have information on the following:

- Regional plans for land use
- GIS maps, including indentification of hotspots
- Early warning systems

Study this information and identify the most critical slopes and treat as an individual slope

Option: Returning to local study

Get the information avalaible for the region.

If no information is available, you will have to select the most critical slopes in the region and do a study of those as individual slopes.

- Go back to choice of local or regional study
- Terminate program

4.1.3 Local study

Identifying the case study

Please identify the local slope to analyse.

Country

Location

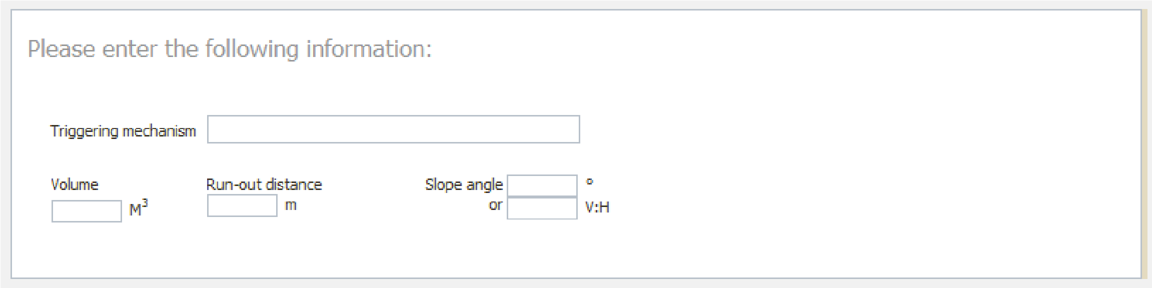
Slope identification

Description of analysis

4.2 HAZARD AND CONSEQUENCE ASSESSMENT

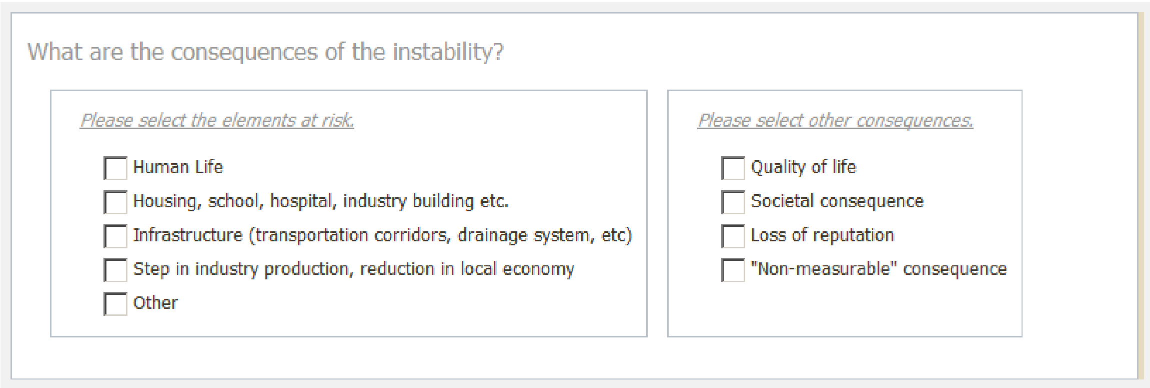
4.2.1 Defining hazard and consequence

Defining triggering mechanism and extent of landslide

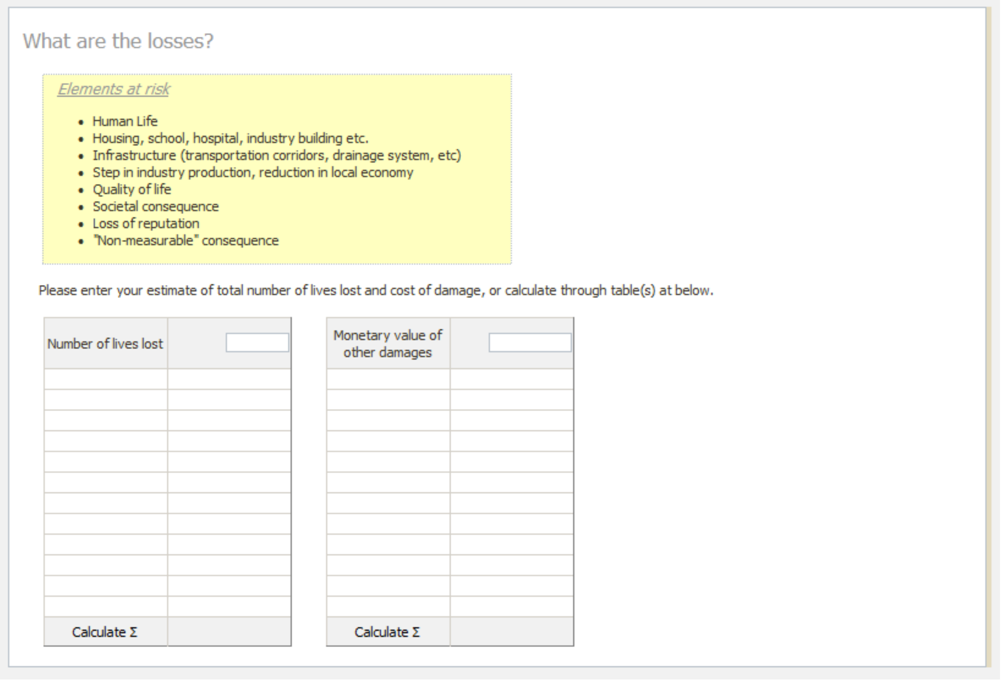


4.2.2 Defining the consequences

The evaluation of the consequences includes the evaluation of vulnerability and the exposure of the elements at risk.



4.2.3 Quantifying the losses



What are the losses?

Elements at risk

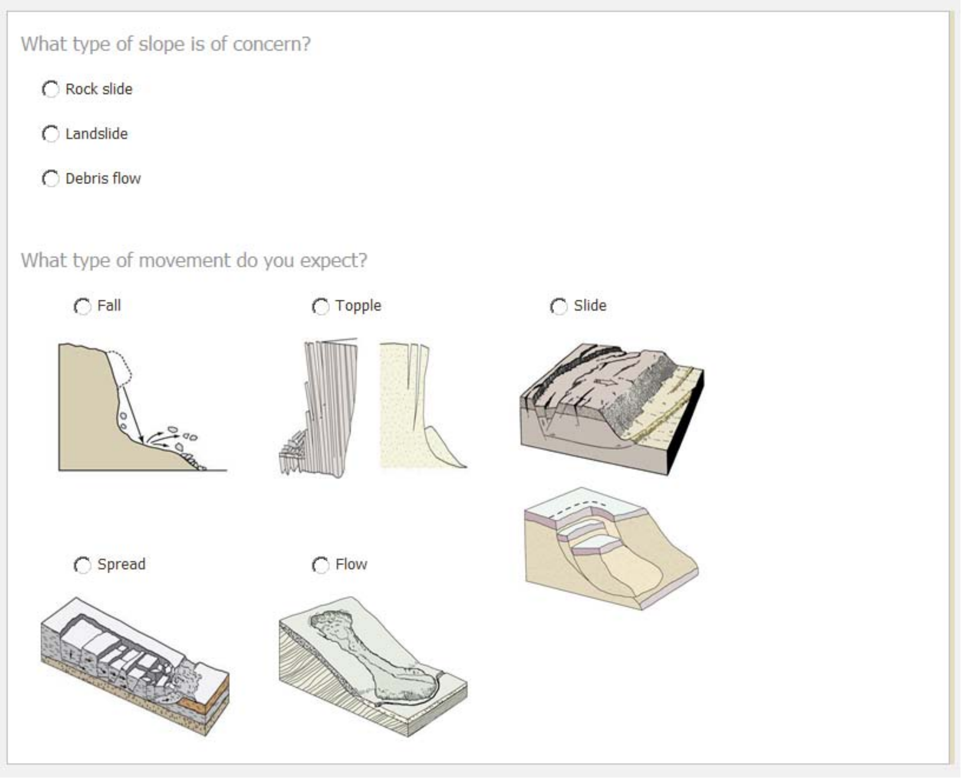
- Human Life
- Housing, school, hospital, industry building etc.
- Infrastructure (transportation corridors, drainage system, etc)
- Step in industry production, reduction in local economy
- Quality of life
- Societal consequence
- Loss of reputation
- "Non-measurable" consequence

Please enter your estimate of total number of lives lost and cost of damage, or calculate through table(s) at below.

Number of lives lost	
Calculate Σ	

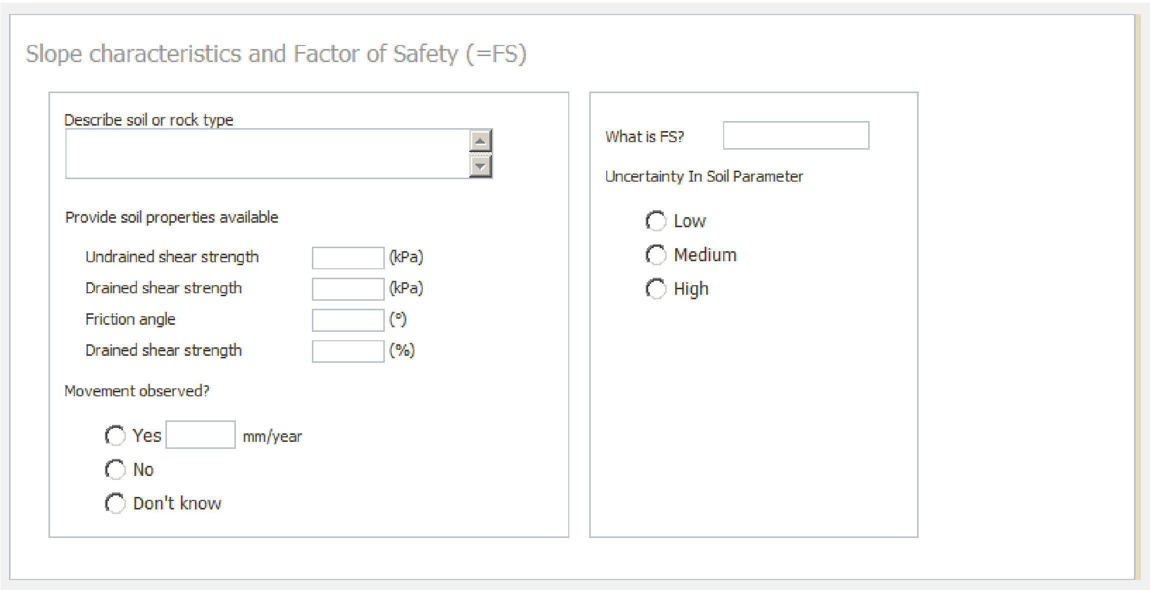
Monetary value of other damages	
Calculate Σ	

4.2.4 Assessing the type of movement

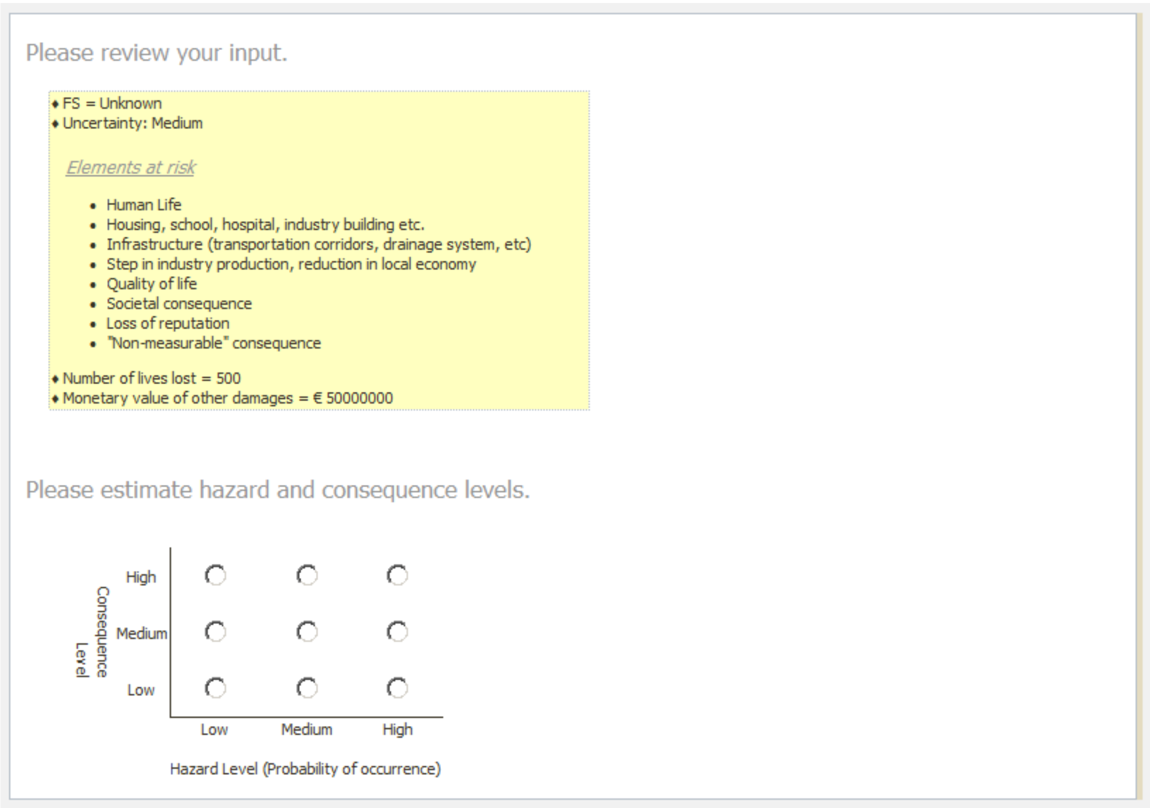


4.3 RISK ASSESSMENT

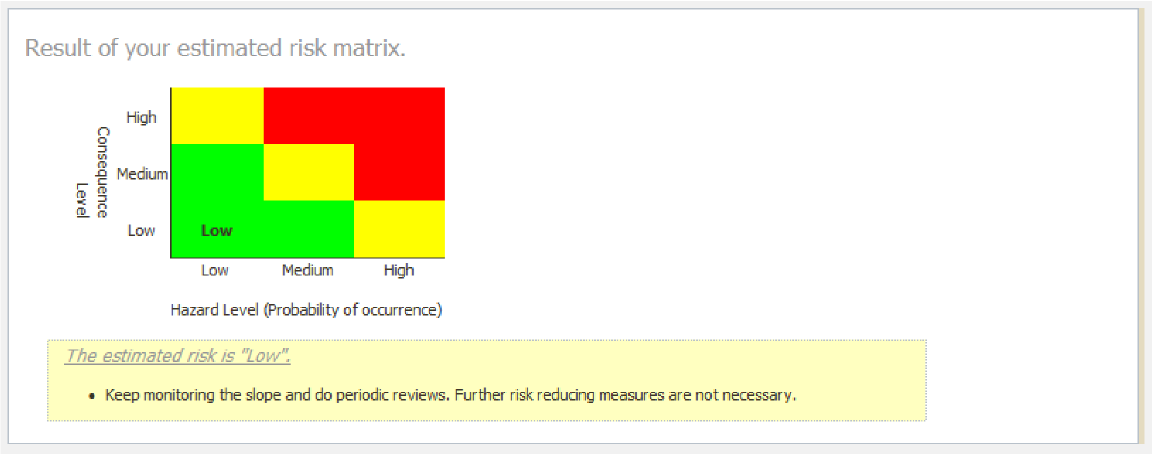
4.3.1 Assessment of factor of safety (or indicator thereof)



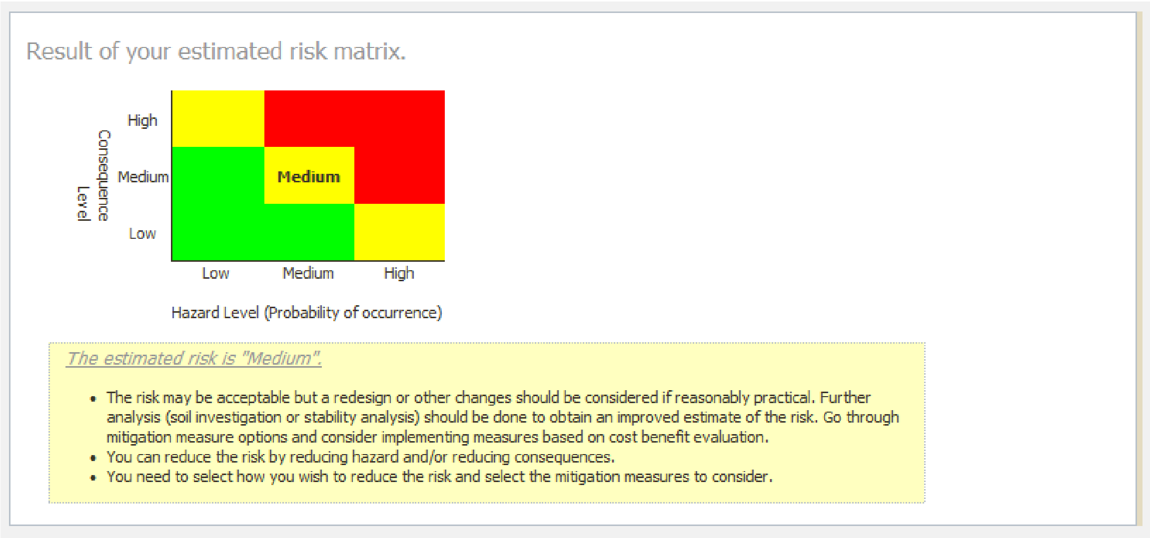
4.3.2 Assesment of risk level (low, medium, high)



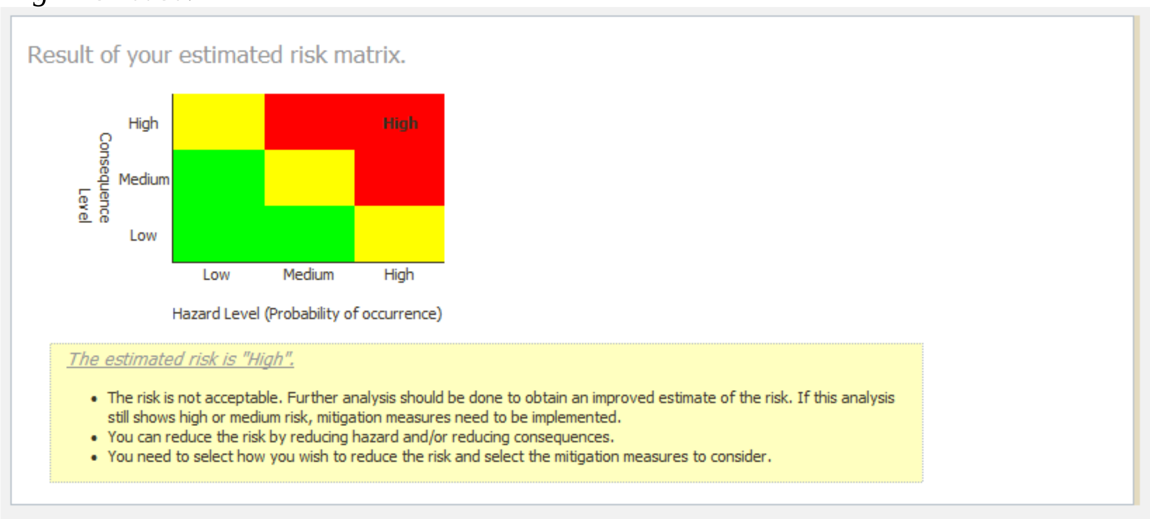
Low risk case:



Medium risk case:



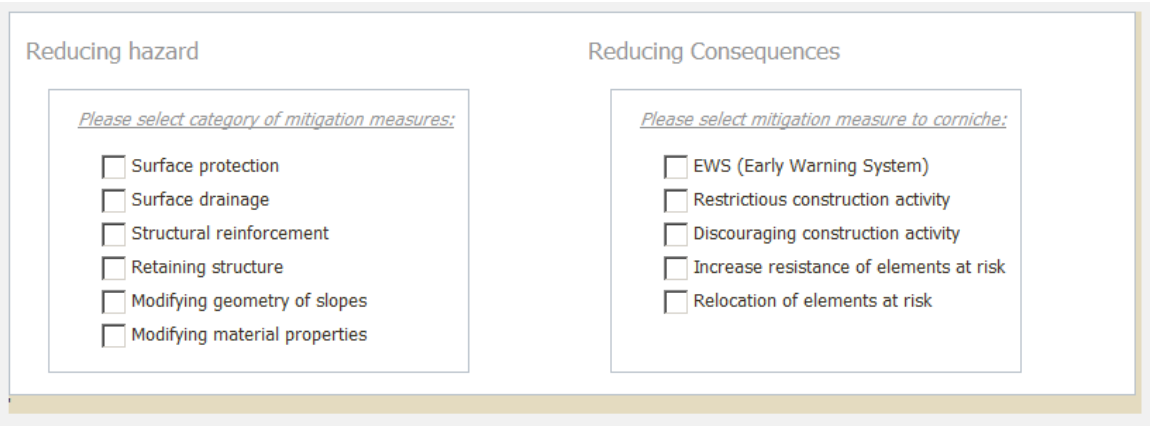
High risk case:

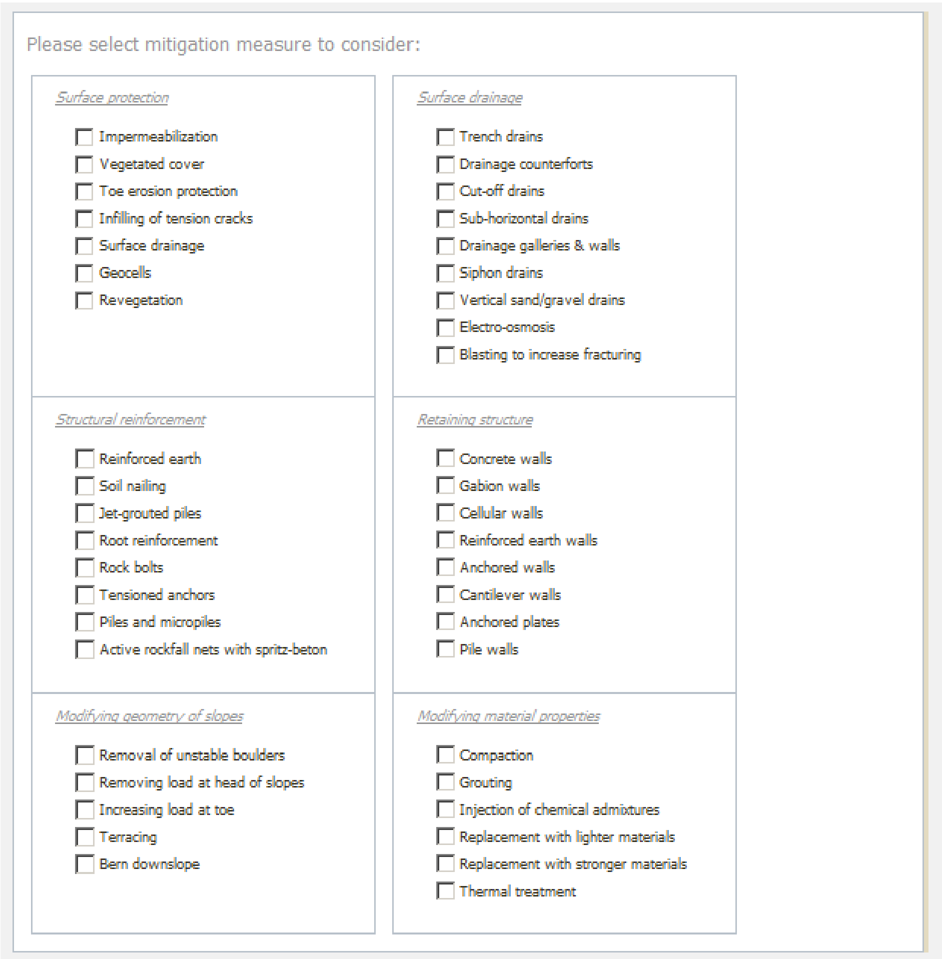


4.4 SELECTION OF MITIGATION MEASURES

4.4.1 Selecting mitigation measures to consider in analysis

The measures were categorized with respect to reducing hazard or reducing consequences, and divided into the categories indicated in Section 3





4.4.2 Qualitative example result of selected measures

4.5 RANKING OF MEASURES

4.5.1 User input of scoring and weighting factors

The decision support matrix (section 3.1.3) are the default scoring values in the toolbox. All weighting factors start at 1.0. Each scoring and weighting factor can be overwritten by the user.

Please enter weighting factors to make a rank.

Mitigation Measures	Weighting / Factor	Type of movement						Material			Depth of movement					Rate of movement at time of works				Groundwater				Surface water						ΣwiFi	Category
		Falls	Topples	Slides	Spreads	Flows	Complex	Earth	Debris	Rock	Superficial (< 0.5m)	Shallow (0.5 - 3 m)	Medium (3 - 8 m)	Deep (8 - 15 m)	Very deep (>15m)	Fast	Slow	Very slow	Negligible - creep	Artesian	High	Low	Absent	Rain	Snowmelt	Localized	Stream	Torrent	River	Update	
Vegetated cover	W	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	Update 36	Surface protection
	F	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		
Infilling of tension cracks	W	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	Update 36	
	F	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		
Surface drainage	W	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	Update 36	
	F	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		
Soil nailing	W	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	Update 36	Structural reinforcement
	F	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		
Jet-grouted piles	W	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	Update 36	
	F	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		
Root reinforcement	W	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	Update 36	
	F	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		
EWS (Early Warning System)	W	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	Update 36	Reducing Consequences
	F	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		
Restrictious construction activity	W	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	Update 36	
	F	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		

4.5.2 Ranking the mitigation measures and presentation of results

Please review mitigation method(s) by priority

Rank	Category	Mitigation Measures	ΣwiFi	Most weighting factor
1	Surface protection	Vegetated cover	66	Material / Debris Type of movement / Flows
2	Surface protection	Surface drainage	65	Depth of movement / Shallow (0.5 - 3 m) Depth of movement / Superficial (< 0.5m)
3	Surface protection	Infilling of tension cracks	62	Rate of movement at time of works / Slow Rate of movement at time of works / Fast
4	Reducing Consequences	EWS (Early Warning System)	36	Depth of movement / Superficial (< 0.5m) Material / Rock
4	Reducing Consequences	Restrictious construction activity	36	Depth of movement / Superficial (< 0.5m) Material / Rock
6	Structural reinforcement	Jet-grouted piles	31	Type of movement / Flows Type of movement / Spreads
7	Structural reinforcement	Soil nailing	24	Type of movement / Flows Type of movement / Falls
8	Structural reinforcement	Root reinforcement	21	Groundwater / Artesian Groundwater / High

5 EXAMPLE OF RANKING OF MITIGATION MEASURES WITH TOOLBOX

Slope in clay, flow slide

Risk class: high (in populated area)

Mitigation measures selected: all measures within Category 3 (Modifying surface water regime)

Depth of movement: 3-15 m
Rate of movement: slow

Groundwater: high
Surface water: snowmelt and stream

$$R_i = \sum_{i=1}^{n} w_i F_i$$

where i goes through following measures (see descriptions in compendium or toolbox)

1) diversion channels
2) hydraulic control works
3) ditches
4) sealing tension cracks
5) vegetation - hydrological effect
6) geomembranes

$$R_1 = \sum_{i=1} (1 \cdot 6) + (0.5 \cdot 8 + 0.5 \cdot 4) + (1 \cdot 4) \cdot (1 \cdot 8)(\tfrac{1}{4} \cdot 0 + \tfrac{3}{4} \cdot 6) = 28.5$$

Result for all measures considered:

Mitigation Measure	R_i
1) diversion channels	28.5
2) hydraulic control works	29.5
3) ditches	21.5
4) sealing tension cracks	25
5) vegetation - hydrological effect	17.5
6) geomembranes	4.5

Summary: for this example, hydraulic control work and diversion channels are the most appropriate with sealing tension cracks as good third choice. Geomembranes are inappropriate.

APPENDIX A SPECIFICATION OF WEB-BASED TOOLBOX

A1 DEVELOPMENT ENVIRONMENT SETUP

A1.1 REGISTRATION OF DOMAIN NAME

The toolbox is currently registered at the two places:
(1) ns27.domaincontrol.com (Dedicated IP: 216.69.185.14) for the primary domain name system (DNS) and
(2) ns28.domaincontrol.com (Dedicate IP: 208.109.255.14) for the secondary DNS.

A1.2 WEB HOSTING SERVICE

The toolbox is currently enrolled in a web hosting service company, Godaddy.com. Extensive study on system requirements has been performed to find the appropriate hosting company. The company is one of the leading companies in web hosting business, where more than 43 million domains are being enrolled. It has an excellent reputation and reliable services. The toolbox is currently being hosted in the U.S regional data center of Godaddy.com at Dedicated IP: 97.74.215.127 and it can be accessed with http protocol at http://thesafeland.com or http://thesafeland.com. Note that at the end of the project, the hosting service company may be transferred to another hosting company in Europe.

A1.3 CONFIGURATION OF WEB HOSTING SERVICE

The SafeLand Web site runs on Windows Platforms with Microsoft Windows 2003 server. The operation environment has changed from IIS 6.0/ASP.NET2.0 to IIS7.0/ASP.NET 3.x. because of some technical problems after flexibility and compatibility testing during the first few months.

A1.4 DATABASE MANAGEMENT SYSTEM (DBMS)

Microsoft SQL Server 2005 for managing data has been adopted. The database can be accessed via database name inquiry service at shavykim.db.5429297.hostdresource.com during the developing phase. At the end of the project, it can be regenerated under other company’s SQL servers.

A1.5 PROGRAMMING SOFTWARE

The toolbox is currently being programmed with Microsoft Visual Studio 2008 Professional and connected to the web hosting service company via FrontPage extension. However the connection to the hosting service will be made via FTP instead of FrontPage extension in the near future due to security reasons. In addition, for making and converting images and icons, Adobe Photoshop CS edition is currently being used.

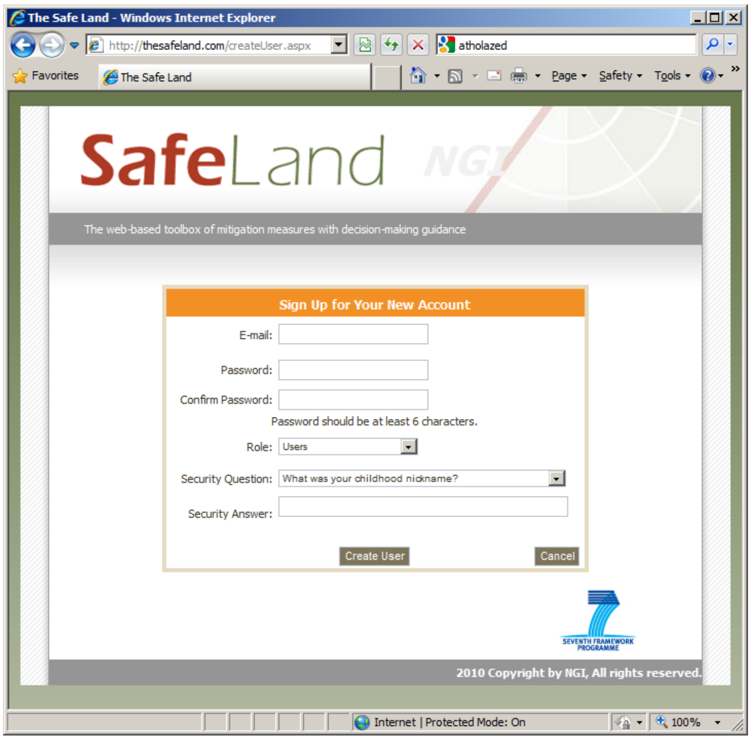
A2 USER LOGIN SYSTEM

A2.1 LOGIN PAGE

As shown in the figure below, for the security reason, the user is asked to login with a registered user's email address and password. The email address is used as a unique ID. An anonymous user access is not allowed. The login information is saved to the SQL server database in a unique format and the password is transformed to an encrypted code.

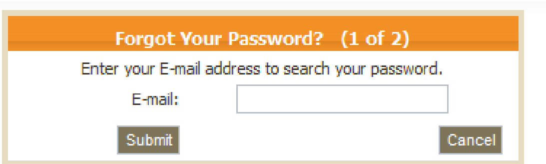
A2.2 CREATING USER

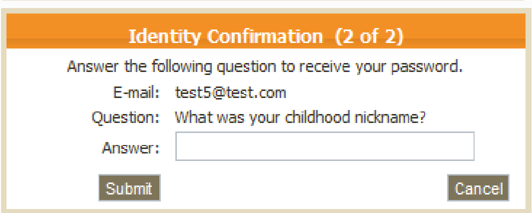
A new user should create a new username and password via the hyper-link of "Create User" at this stage of the project. This link will be removed after the toolbox has officially launched. After removal, this page will be controlled only by administrator users who would assign privileges to the new user. A new user will be asked for a security question & corresponding answer for password recovery system in case of forgetting the login information.



A2.3 FORGOT PASSWORD PAGE

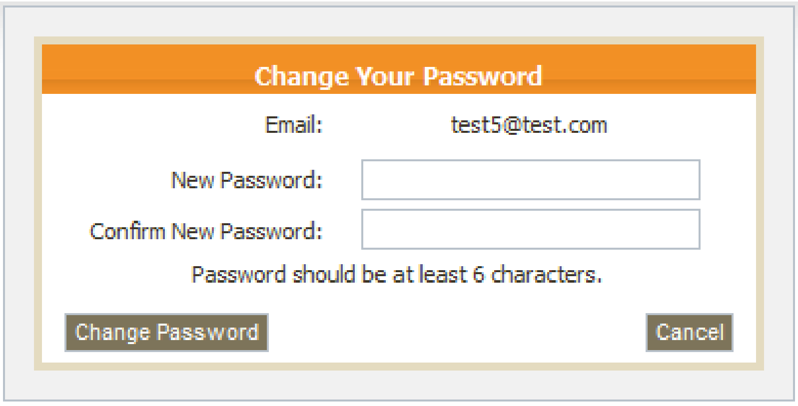
If a user forgot his/her password, the user can automatically be logged in the website by correctly answering the question. The password will then be mailed to the user's email address.





A2.4 CHANGE PASSWORD

A user can change his/her password at this time. This feature will be inactivated for users at the end of the project. However, administrators can access this page.



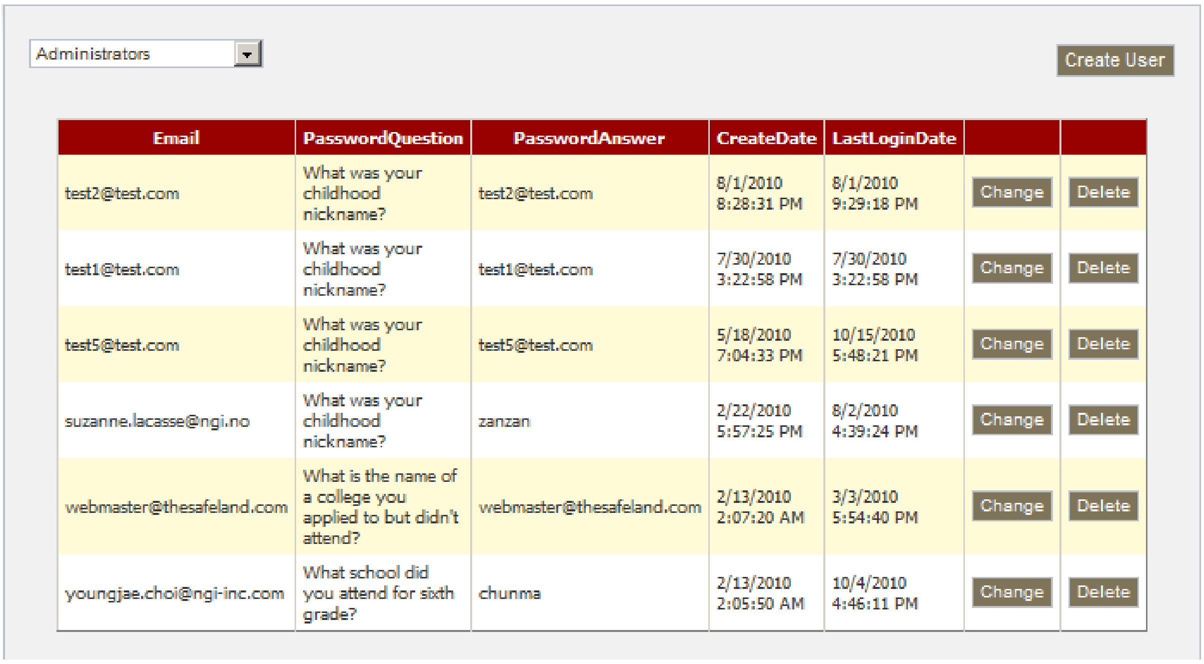
A3 USER MANAGEMENT SYSTEM

A3.1 MODIFY USERS PAGE

Modify Users page is carefully designed and implemented in the toolbox. Administrator users can access to the "Modify Users" page where it includes several important information (such as his/her role, data grid view, time zone, user's saved cases).

A3.2 ROLE SYSTEM

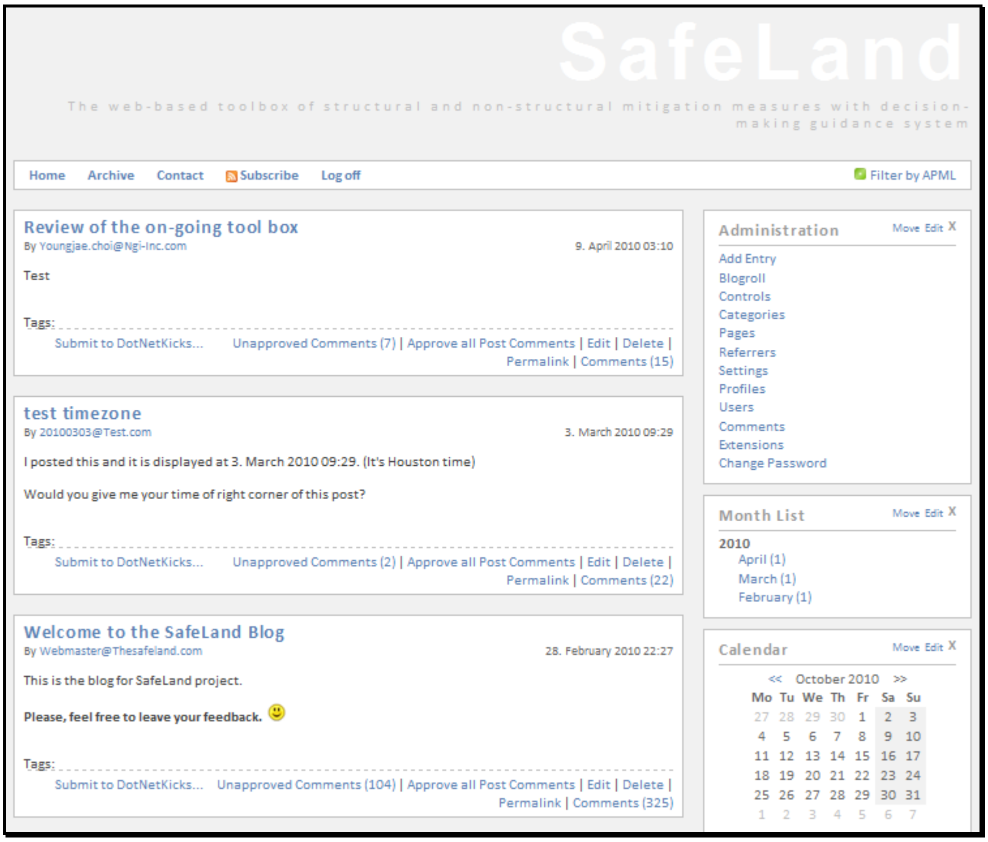
For the time being, there are two roles: administrators and users. Administrators have full control over the toolbox including stored data and managing users while users can change his/her own data only. This system was carefully programmed to make sure each role operates correctly.



Email	PasswordQuestion	PasswordAnswer	CreateDate	LastLoginDate		
test2@test.com	What was your childhood nickname?	test2@test.com	8/1/2010 8:28:31 PM	8/1/2010 9:29:18 PM	Change	Delete
test1@test.com	What was your childhood nickname?	test1@test.com	7/30/2010 3:22:58 PM	7/30/2010 3:22:58 PM	Change	Delete
test5@test.com	What was your childhood nickname?	test5@test.com	5/18/2010 7:04:33 PM	10/15/2010 5:48:21 PM	Change	Delete
suzanne.lacasse@ngi.no	What was your childhood nickname?	zanzan	2/22/2010 5:57:25 PM	8/2/2010 4:39:24 PM	Change	Delete
webmaster@thesafeland.com	What is the name of a college you applied to but didn't attend?	webmaster@thesafeland.com	2/13/2010 2:07:20 AM	3/3/2010 5:54:40 PM	Change	Delete
youngjae.choi@ngi-inc.com	What school did you attend for sixth grade?	chunma	2/13/2010 2:05:50 AM	10/4/2010 4:46:11 PM	Change	Delete

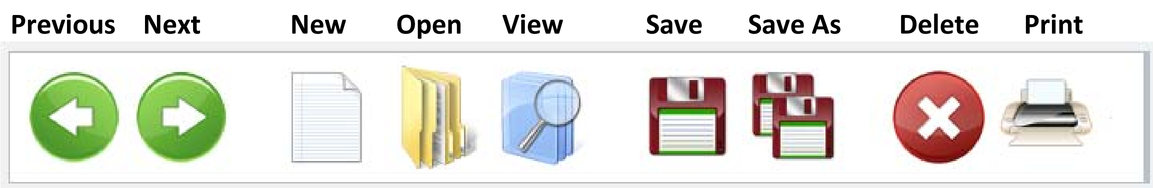
A3.3 USER FORUM

During the programming phase of the toolbox, User Forum was developed using blogEngine.net 1.6 to make communication with the programmer easier. The forum is not embedded in the toolbox but hyper-linked for the time being. This user forum can be accessed at http://thesafeland.com/blogs/.



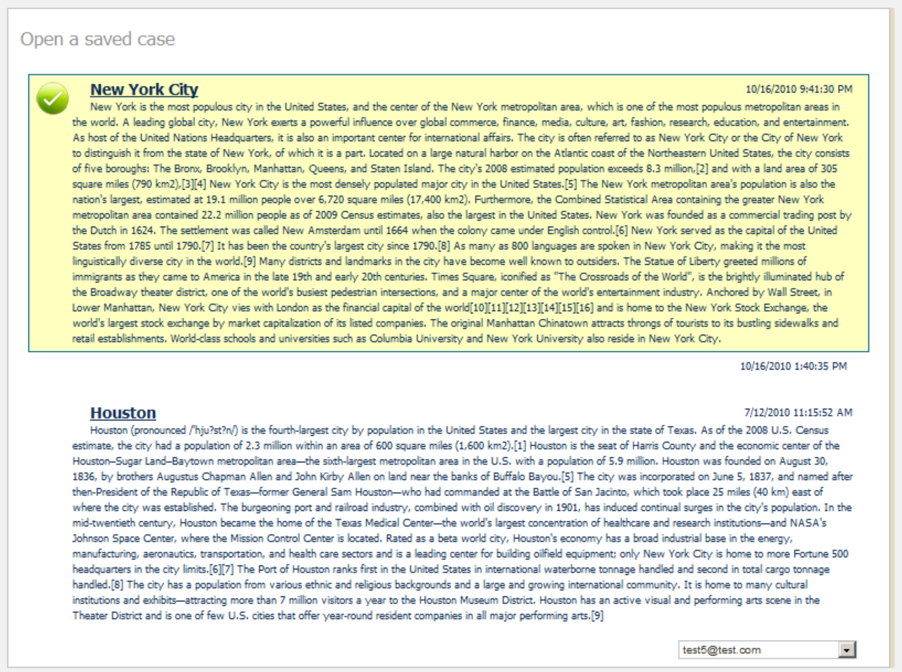
A4 IMPROVING PERFORMANCE

In order to improve user interface, desktop toolbars in the main page of the toolbox are carefully designed using Adobe Photoshop. The toolbar provides easy access to frequently used operations. Note that some of the toolbars also have toolbars within their windows.



When reloading or moving pages, AJAX is used to improve performance in the transition by partially loading specific regions and overlapping images.

The toolbox has features with regard to saving current cases and retrieving previously saved cases. In the next stage, user interface is to be improved for performance and stability issues.



In addition, client side SQL was converted to stored procedures. It reduces responding time and improves reliability for the toolbox