A web-based tool for ranking landslide mitigation measures

Un outil internet pour classer les techniques visant à diminuer le risque de glissements de terrain

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ABSTRACT: As part of the European project SafeLand, a compendium of structural and non-structural mitigation measures for different landslide types in Europe was prepared, and the measures were assembled into a web-based "toolbox". The purpose of web-based toolbox is to assist decision-making and to guide the user in the choice of the most appropriate mitigation measures. The paper presents an overview of the toolbox features, mitigation measures considered and an example of the report for one application of the toolbox.

RÉSUMÉ : Parti intégrante du projet européen « SafeLand », un recueil des mesures d'atténuation structurelles et non structurelles pour les différents types de glissements de terrain en Europe a été établi. Les mesures d'atténuation ont été assemblées dans une "boîte à outils" utilisable via internet. Le but de la boîte à outils est d'aider la prise de décision et de guider l'utilisateur dans le choix des mesures de diminution des risques les plus appropriées. Le document présente un aperçu des fonctionnalités de la boîte à outils, des mesures de diminution des risques envisagées et un exemple de rapport pour une utilisation spécifique de la boîte à outils.

KEYWORDS: Landslide, Quantitative vulnerability evaluation, Intensity, Susceptibility

1 INTRODUCTION

As part of the research done in the European project SafeLand "Living with landslide risk in Europe: assessment, effects of global change, and risk management strategies", a compendium of structural and non-structural mitigation measures for different landslide types in Europe was prepared, and the measures were assembled into a web-based "toolbox". Emphasis was placed on providing a rational and flexible framework applicable to existing and future mitigation measures.

The purpose of web-based toolbox is to assist decision-making and to guide the user in the choice of the most appropriate mitigation measures.

The mitigation measures were classified into three categories, describing whether the mitigation measures addressed the landslide hazard, the vulnerability or the elements at risk themselves. The measures considered include structural measures reducing hazard and non-structural mitigation measures, reducing either the hazard, the vulnerability or the exposure of the elements at risk. The structural measures include surface protection and control of surface erosion; measures modifying the slope geometry and/or mass distribution; measures modifying surface water regime - surface drainage; measures modifying groundwater regime - deep drainage; measured modifying the mechanical characteristics of unstable mass; transfer of loads to more competent strata; retaining structures (to modify slope geometry and/or to transfer stress to competent layer); deviating the path of landslide debris; dissipating the energy of debris flows; and arresting and containing landslide debris or rock fall.

The non-structural mitigation measures, reducing either the hazard or the consequences: early warning systems; restricting or discouraging construction activities; increasing resistance or coping capacity of elements at risk; relocation of elements at risk; sharing of risk through insurance. The measures are described in the toolbox with fact sheets providing a brief description, guidance on design, schematic details, practical examples and references for each mitigation measure. Each of the measures was given a score on its ability and applicability for different types of landslides and boundary conditions, and a decision support matrix was established.

The web-based toolbox organizes the information in the compendium and provides an algorithm to rank the measures on the basis of the decision support matrix, and on the basis of the risk level estimated at the site. The toolbox includes a description of the case under study and offers a simplified option for estimating the hazard and risk levels of the slide at hand. The user selects the mitigation measures to be included in the assessment. The toolbox then ranks, with built-in assessment factors and weights and/or with user-defined ranking values and criteria, the mitigation measures included in the analysis. The toolbox includes data management, e.g. saving data half-way in an analysis, returning to an earlier case, looking up prepared examples or looking up information on mitigation measures. The toolbox also generates a report and has user-forum and help features.

The paper presents an overview of the toolbox features, mitigation measures considered and an example of the report for one application of the toolbox. The reports in the reference list can be found on the SafeLand project website, www.safeland-fp7.eu. Much more details and the descriptions of each mitigation measure along with references for each can be found in the reports in the list of reference.

2 TOOLBOX FEATURES

The toolbox is organized to guide the user in ranking different mitigation measures and to assist in the decision-making about the most appropriate mitigation measures to select for a site. The toolbox suggests 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.

The toolbox documents "do's and don'ts" and "how to". It estimates relative costs, benefits, hazards, effectiveness and vulnerability of each measure to mitigate hazard and/or risk.

The toolbox offers a simplified option for estimating the hazard and risk levels of the slide at hand. The user selects the mitigation measures to be included in the assessment. The toolbox then ranks, with built-in assessment factors and weights and/or with user-defined ranking values and criteria, the mitigation measures included in the analysis.

The web-based toolbox does data management, generates a report and provides help to the user, as well as a user forum. 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, with password-protected user login.

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 , and Print.

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.

3 DECISIONS IN TOOLBOX

3.1 *Risk classes and need for mitigation*

The risk classes used in the toolbox are shown in Figure 1. 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.

Consequence / Hazard	Low	Medium	High
High	Medium Risk	High Risk	High Risk
Medium	Low Risk	Medium Risk	High Risk
Low	Low Risk	Low Risk	Medium Risk

Figure 1. Risk classes in Toolbox of Mitigation measures.

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:

$$R_i = \sum w_i \cdot F_i \quad (1)$$

Where i are the mitigation measures selected by the user for analysis, from 1 to *n*; *w* is the weighting factor proposed by the toolbox; the default value for all w_i at start is 1.0 and can be changed by the user; and *F* is the 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. 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.

The weighting factor (w_i) reflecting the relative importance of criteria or corresponding scoring factors is in the range of 0 (least) to 1 (most). The default value is set to zero, and the toolbox assigns a values of unity (1) as a function of the input provided by the user in the following technological criteria categories: type of movement, type of sliding material, depth of movement, rate of movement, groundwater, and surface water.

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.

4 CLASSIFICATION OF MITIGATION MEASURES

The Safeland partner Studio Geotechnico Italiano S.r.l. (SGI) prepared a "Compendium of tested and innovative structural, non-structural and risk-transfer mitigation measures for different landslide types" (SafeLand 1). This review 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 classification of the mitigation measures was done in terms of the components of a risk assessment (hazard, vulnerability and elements at risk). Table 1 presents this classification. The classification system addresses three components of risk: hazard, vulnerability and elements at risk, where risk R can be expressed as:

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

where H is the hazard or the probability of occurrence of an adverse event (landslide); C is the consequence(s); V is the vulnerability or the degree of loss of an element at risk for a given hazard; and E are the 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 2. Classification of mitigation measures (structural measures on top, non-structural measures on bottom)

Class	Component of risk addressed	Brief description	Notes and other terms used
Stabilization	Hazard (H)	Eng'g works to reduce the landslide probability of occurrence	Preventive, remedial, hard, soft, active stabilization.
Control	Vulnerability(V) (consequence)	Eng'g works to protect, reinforce, isolate the elements at risk from the landslide area	Preventive, hard, soft, passive stabilization.
Avoidance	Elements (E) (consequence)	Temporary or permanent reduction of exposure w/ warning systems, evacuation/-relocation, sheltering, land-use planning.	Reduction of the exposure of the elements at risk. Monitoring, early warning systems and civil protection procedures, often temporary, selective avoidance measures.
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.

5 MITIGATION MEASURES CONSIDERED

The toolbox includes near 70 structural mitigation measures and six non-structural mitigation measures. The structural measures are divided into ten categories and belong to the class of measures either reducing hazard or reducing consequences. The structural mitigation measures included are:

A Structural measures reducing hazard
1 Surface protection and control of surface erosion
1.1 Hydro-seeding, 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
2.3 Removal of material from driving area
2.4 Substitution 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, pipe works)
3.2 Local re-grading 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 dia. 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)
4.5.3 Large diameter vertical wells (>2000 mm)
4.5.4 Caissons (>5-6 m) with gravity drainage
4.6 Drainage tunnels, adits, galleries, with secondary drains
5 Modifying mechanical characteristics of unstable mass
5.1 Vegetation - mechanical effects
5.2 Substitution
5.3 Compaction from surface
5.4 Deep compaction (e.g. vibro-compaction)
5.5 Mechanical deep mixing with lime and/or cement
5.6 Low pressure grouting with chemical binder
5.7 Jet grouting
5.8 Modification of ground water chemistry
6 Transfer of loads to more competent strata
6.1 Counterfort drains (trench drains)
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 Dry stack masonry walls
7.5 Mass concrete or masonry walls
7.6 Reinforced concrete stem walls

B Structural measures reducing consequences
8 Deviating the path of landslide debris
8.1 Deflection structure
8.2 Debris flow/rockfall shed
9 Dissipating the energy of debris flows
9.1 Drop structure
9.2 Debris-restraining structure
9.3 Debris flow impediments

10 Arresting and containing landslide debris or rockfall
10.1 Debris-resisting barrier
10.2 Rock fall barrier
10.3 Rock fall net
10.4 Debris retention basin

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

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

6 RANKING CRITERIA

Six criteria categories were implemented to rank the appropriateness of each mitigation measure: type of movement, type of sliding material, depth of movement, rate of movement, groundwater, and surface water. Table 3 lists the criteria used in the toolbox.

Table 3. 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
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	

7 EXAMPLE RESULT

Table 4 presents a typical result of the ranking algorithm for a potential instability in a soft clay slope.

Table 4. Typical report from toolbox.

Rank	Category	Measure	Score	Most significant parameters *
1	Surface protection	Vegetated cover	66	Material/debris Type of movement/-flow
2	Surface protection	Surface drainage	65	Depth of movement Surface water/-stream
3	Surface protection	Infilling of cracks	62	Surface water/stream Rate of movement/-slow
4	Reducing consequence	Early warning system	36	Depth of movement/-superficial Material/rock

* With respect to measure appropriateness

8 SUMMARY

The paper provides only a glimpse in the toolbox. One has to use it to actually see how it functions. The toolbox will be available at the Safeland web site in 2013.

The purpose of web-based toolbox is to assist decision-making and to guide the user in the choice of the most appropriate mitigation measures. The mitigation measures are classified into three categories, describing whether the mitigation measures addressed the landslide hazard, the vulnerability or the elements at risk themselves. The measures are described in the toolbox with fact sheets providing a brief description, guidance on design, schematic details, practical examples and references for each mitigation measure. Each of the measures was given a score on its ability and applicability for different types of landslides and boundary conditions, and a decision support matrix was established.

The web-based toolbox organizes the and provides an algorithm to rank the measures on the basis of a decision support matrix, and on the basis of the risk level estimated at the site.

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10 REFERENCES

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