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ICUR2016
International Conference on Urban Risks



Environmental Hazards and Risk Assessment and Management
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Landslide deformation patterns in peri-urban areas

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Landslide deformation patterns in peri-urban areas
International Conference on Urban Risks - Lisbon (Portugal) - 30 June to 2 July



1. Framework

2. Landslide Events

3. Inventories

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Motivation

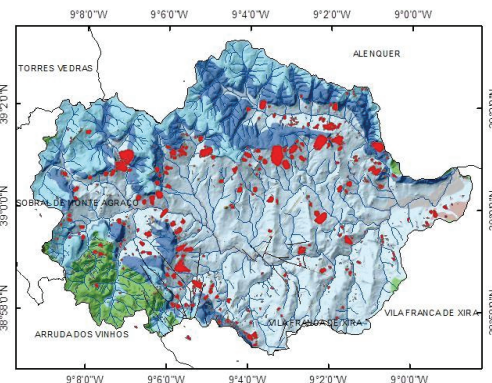
Region north of Lisbon - Rainfall trigger landslide events – Considerable damages (buildings and roads)

- Relevance: **growth potential of peri-urban areas**, the **proximity to the city of Lisbon** and the **less artificiality of the territory** in the proportion of urban / rural land.

Grande da Pipa River (GPR) basin - 110 km², > 1400 landslides

425 landslides – damages

Arruda dos Vinhos – 2nd municipality of West and Tagus Valley with a **higher percentage (about 16%) of territory classified as dispersed buildings** (Rego et al., 2008).



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Objectives

To establish the **cause-effect relationship between landslides and the pattern of damages** in to the exposed elements considering **two landslide events**:

- **18 November 1983** (short duration intense rainfall)
- **2009/2010** (long lasting rainfall period).

For this purpose were considered directly or indirectly:

- (I) the **critical rainfall conditions** that generate regional instability;
- (ii) the **landslides spatial pattern**, typology, **magnitude**, landslide activity and **how the landslide mass affects the exposed element**;
- (iii) the **estimated structural strength of the affected element**.

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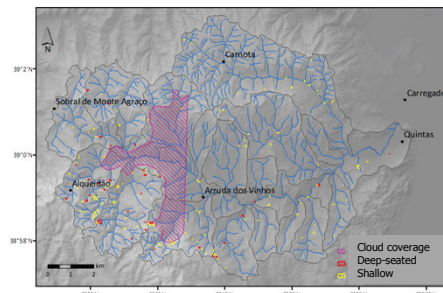
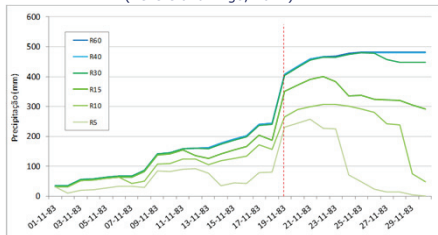
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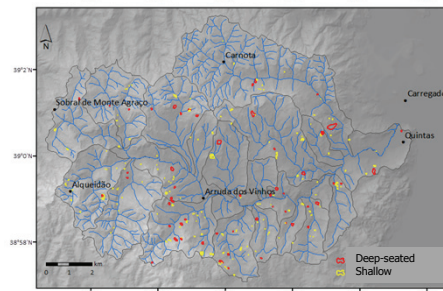
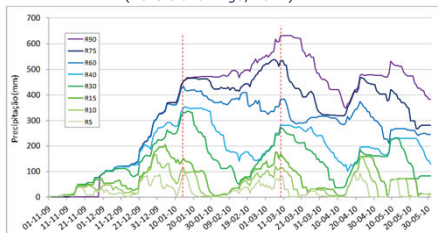
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1983 – 164 mm/1 day RP = 194 years
(Zêzere and Trigo, 2011)



2010 – 632 mm /90 days RP = 8 years
(Zêzere and Trigo, 2011)



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1983

- 220 landslides - 161,413 m² (0,14%)
- Rotational slides
- 37 deep rotational slides (> 1.5 m)

2010

- 254 landslides – 511,820 m² (0.45 %)
- Rotational slides (178 cases)
- 55 deep rotational slides (331988 m²)

• TOTAL : 474 landslides - **17 % (82 cases, mainly rotational slides) – damages to buildings and roads**

- 2010 – **56 cases** (68,3 %), 27 cases (deep rotational slides)
- 1983 – **26 cases** (31,7%), shallow translational and rotational slides on cut/fill slopes (14 cases).

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Main considerations/assumptions:

- Vulnerability - "degree of loss" of an element or set of elements at risk, considering a landslide of a certain magnitude. Is expressed on a scale from 0 (no damage) to 1 (total loss of the element);
- The damage level (structural/non-structural) is largely dependent on the resistance of the affected element;
- The position of the affected element within the landslide mass affects the potential vulnerability;
- The level of damage can be referenced in a qualitative way to measure deformation patterns.

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graph LR
  A[Elements Typology] --> B[Position of the affected element within the landslide mass]
  B --> C[Degree of Loss]
  
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Elements Typology
 ↓
 Structural resistance



ID	Buildings Typology	ID	Roads Typology
E4	Edifícios com elementos resistentes de betão	V4	Highway
E3	Edifícios com paredes de alvenaria argamassada	V3	National road (asphalted)
E2	Edifícios com pedra de adobe ou taipa	V2	Municipal road or similar (asphalted)
E1	Edifícios com outros elementos resistentes (madeira, metal)	V1	Rural road (compacted earth or other less resistant materials)

(Adapted from Garcia, 2012)

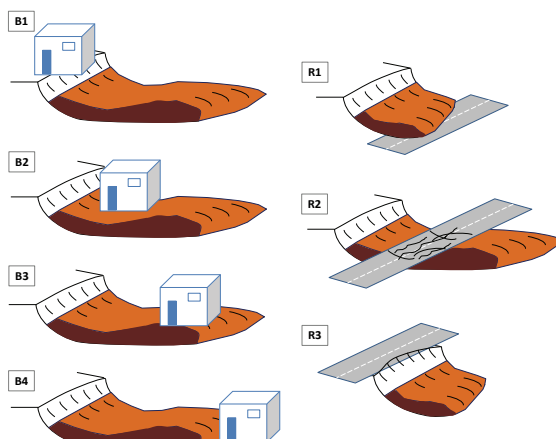
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Position of the affected element within the landslide mass



- Buildings and roads location type on different internal sectors of the landslides mass: scarp (B1, R3), depletion area (B2), accumulation area (B3, R1), landslide main body (R2) and landslide front (B4).

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Degree of Loss 5 qualitative classes (0,2; 0,4; 0,6; 0,8; 1).

Nível de danos --- Grau de perda	Tipologia de danos			
	Edifícios		Estradas	
	Situação de rotura ou deformação	Situação de soterramento	Situações de rotura ou deformação	Situação de soterramento
D1 - Negligenciável Danos estéticos [0, 0,2]	Deformação superficial de cobertura (reboco), fissuras sem abertura ou desnível lateral	Acumulação de material até 0,5m de altura	Pequena deformação do pavimento; fendas de tração sem deslocamento vertical. Não afeta a estrutura	Acumulação de material <0,5m. Praticamente não interrompe a circulação.
D2 - Ligeiro Danos menores [0,2; 0,4]	Queda de estuque, fissuras pequenas ou com desnível lateral, danos em portas e janelas.	Acumulação de material entre 0,5m e 2m de altura.	Pequenas fraturas com desnível, deformação da via. Danos que afetam a estrutura mas não impedem a circulação.	Acumulação de material entre 0,5m e 2m. Interrupção da circulação de média duração.
D3 - Significativo Danos importantes / estruturais [0,4; 0,6]	Deslocamento ou colapso parcial de paredes ou painéis. Não compromete a integridade estrutural, fissuras muito desenvolvidas. Reparação complexa.	Acumulação de material com altura superior a 2m.	Fraturas ou deformações que danificam a estrutura da via. Restabelecimento da circulação relativamente expedito. Roturas a afetar apenas a berm da estrada.	Acumulação de material > 2m. Interrupção da circulação de longa duração.
D4 - Severo Danos estruturais [0,6; 0,8]	Deslocamento ou colapso de alvenarias, queda parcial de pisos, fissuração grave ou colapso de secções da estrutura devido a assentamentos. Pode afetar a estabilidade do edifício.		Danos que <u>afetam gravemente parte da via</u> (fraturas, abatimentos, deformação do piso). O restabelecimento total da circulação só é possível mediante intervenção complexa e demorada. Pode originar o abandono da via ou circulação alternada.	
D5 - Muito severo Danos estruturais [0,8; 1]	Danos que comprometem gravemente a integridade estrutural: colapso parcial ou total do edifício. Inclinação do edifício impeditiva da sua funcionalidade		Danos que <u>afetam gravemente a totalidade da via</u> (fraturas, abatimentos, deformação do piso). O restabelecimento da circulação só é possível mediante intervenção complexa e demorada. Pode originar o abandono da via.	


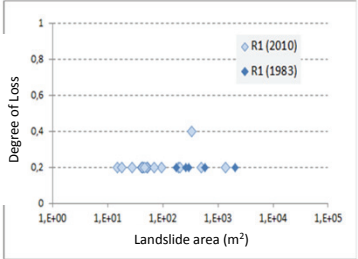
(In Portuguese. Adapted from: García, 2012; Guillard-Gonçalves et al., 2015 Nat. Hazards earth Syst. Sci., 16, 311-331)

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Asphalted roads (V2, V3)

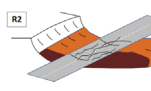
- Independently of the road typology (rural or asphalted) / landslide event – **Damage level D1 (degree of loss of 0.2) is dominant.** Loss of functionality - full or partial interruption (material accumulation does not exceed 0.5 m thickness).
- 3 cases – material accumulation on road up to more than 2 m thickness. Cachoeiras complex slide (roto-translational slide) - road partially or completely interrupted discontinuously between February 2010 to April 2013. No structural damage.

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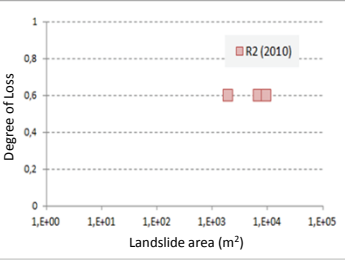
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R2



Asphalted roads (V2, V3)



Landslide area (m ²)	Degree of Loss
~1,000	~0.6
~1,500	~0.6
~2,000	~0.6
~3,000	~0.6
~4,000	~0.6
~5,000	~0.6
~6,000	~0.6
~7,000	~0.6
~8,000	~0.6
~9,000	~0.6
~10,000	~0.6

Rural roads - Damage 0.4 to 0.6. Fractures and pavement deformation, horizontal/vertical displacement, could allow vehicles circulation or road traffic restoration in short time. Landslides > 100 m²

Asphalted roads – Damage 0.6 (3 cases). Deformation and fractures affecting the road structure, restoration of vehicles circulation, even on a temporary road pavement , after seven days.

Landslides - 1000 and 10,000 m².

Possible related: Road width; Event intensity - Rural roads (1983 event) Asphalted roads (2010 event),_{11/16}

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R3

Rural roads (V1)



Asphalted roads (V2, V3)



Records mainly associated with the 2010 landslide event. Exception: 2 cases.

Diversified deformation pattern (even considering the landslides size and roads typology) – Small deformations of the road pavement to severe vertical displacements (landslide scarps) which seriously affect vehicles circulation and demands complex and time-consuming structural intervention.

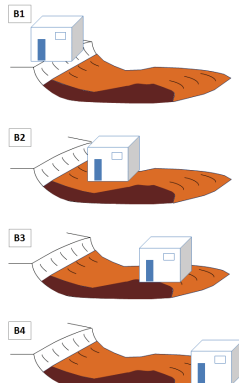
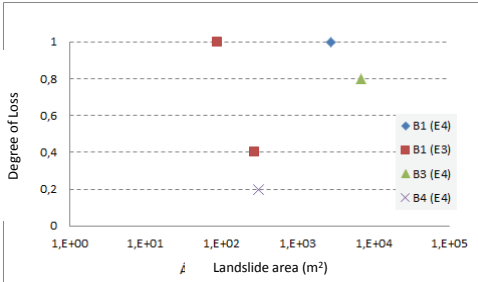

Degree of loss - dependent of height of landslide scarp.

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Reduced number of cases (5) - Is not possible to accurately determine a deformation pattern. 4 cases (2010 event). 1 case (1983 event) (B1 (E3) degree of loss = 0.4).

Considering the relationship B1 and B3, and the types of buildings E3 and E4, the **higher degree of damage (above 0.8)** was only registered on slides with an area greater than 2500 m².

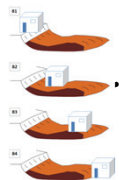
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- The occurrence of landslides triggered by long lasting rainfall or high intensity short duration episodes in GPR basin allowed an standard exploratory assessment of damage patterns in buildings and roads, based on the resistance of the exposed element, the landslide magnitude and the spatial relationship between the affected element and the different sectors of a landslide.



- For buildings, the lack of data did not allow to establish consistent conclusions with respect to deformation patterns.
- In the case of roads, three different deformation patterns can be inferred:
 - R1, Negligible damages - degree of loss (0.2) – mainly due to the loss of functionality by partial or total vehicles circulation interruption, caused by the accumulation of material on road, but without the need of any structural repair.

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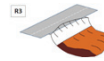
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- R1 – Registered damages are consistently higher than in R2 (degree of loss between 0.4 and 0.6).



- R2 - the degree of loss is sorted from 0.2 to 1, regardless the landslide magnitude or road typology. Dependent of the height of landslide scarp and can lead to severe to very severe damages .

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This work was financed by national funds through FCT – Portuguese Foundation for Science and Technology, I.P., under the framework of the project FORLAND – Hydro-geomorphologic risk in Portugal: driving forces and application for land use planning (PTDC/ATPGE0/1660/2014). S. C. Oliveira has a postdoctoral grant (SFRH/BPD/85827/2012) funded by the Portuguese Foundation for Science and Technology (FCT).