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Methodology for Landslide Damage Assessment

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Abstract

This article focuses on an original methodology for landslide damage assessment of either masonry or reinforced concrete ordinary buildings at the urban scale. In the first step of the methodology, an analysis of the crack patterns is quickly performed for all the buildings by means of the Load Path Method [1]. The second step consists in the filling in of new survey damage forms and it ends with the creation of a landslide damage geotechnical chart of the region under study. This chart includes geomorphological data together with both the damage grade of the buildings and the direction of the possible settlements.

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Keywords: landslide; vulnerability; load path method;

1. Introduction

The assessment of landslide vulnerability [2] is a research topic of increasing interest all over the world, given the widening of urbanization and transport infrastructures that interact with unstable slopes.

This article contributes to the knowledge in this field by introducing an original methodology for landslide damage assessment of ordinary buildings within landslide areas. This methodology has been developed as part of the Multiscalar Method for Landslide Mitigation, MMLM [3,4,5], applying to urban scale (i.e. from detailed to large scale according to [6]) and validated in the Daunia region in the South of Italy [3].

To assess structural vulnerability at the urban scale, both the complexity of the investigations and the variety of the vulnerable elements make it necessary a 'multilevel approach' that implements in the analysis different levels of detail, depending on the size of the area, the number of elements, the time and the economic constraints [7]. The aim is to

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sort out the vulnerability level of buildings in order to budget the different intervention options and support the definition of mid-term and long-term mitigation strategies. In this scenario, this article proposes a new methodology for the damage assessment of ordinary buildings at urban scale.

2. The methodology for landslide damage assessment of ordinary buildings at the urban scale

The proposed multi-level approach entails two levels of analysis. The first one (Level 1) covers all the buildings across the region under study and it is based on the acquisition of general building data and on rapid visual inspections. This level should end with the assignment of both a damage and a vulnerability grade to each building in order to identify those that need either rapid interventions or a more accurate investigation. Level 2, instead, involves only buildings that at the end of the Level 1 are classified as 'at high vulnerability'. It is a complete structural vulnerability assessment, that includes detailed inspections, standard and non-standard tests, numerical analyses, and strategies for remedial actions.

Figure 1 shows the methodology proposed by [8] for the Level 1 landslide vulnerability assessment. In the first step, simple models [9] are used to interpret the behaviour of buildings subjected to foundation settlements due to landsliding and to back-analyse their crack patterns. The second step of the methodology deals with the rapid survey of the damage for ordinary buildings. The main aims are to provide: a) rapid and objective information that, together with geomorphologic and geotechnical ones, are fundamental for the diagnosis of the distribution of the landslide damage across the territory; b) the basis for the vulnerability assessment that represents the third step of the 1st level method. The third step of Figure 1 benefits from the data acquired in the previous ones and deals with the first level assessment of the structural landslide vulnerability.

In step 1 (Fig. 1) the Load Path Method (LPM hereafter; [1,9]) has been used to define the most recurrent typologies of crack patterns that affect ordinary buildings subjected to foundation settlements. In Figure 2 some examples of the most widespread crack patterns that have been recorded during the MMLM research project are represented; for more complex cases and other LPM applications see [9]. Moreover, the presence of visible landslide features about the structure allows to assess that the structural damage being examined is due to landsliding. However, it has to be noted that the back analysis of the crack patterns through LPM makes it possible also to derive the settlement direction. This information, when collected for several buildings in urban areas, can be of use to recognise the morphology of a landslide body, even when landslide features have been cancelled out by urbanisation.

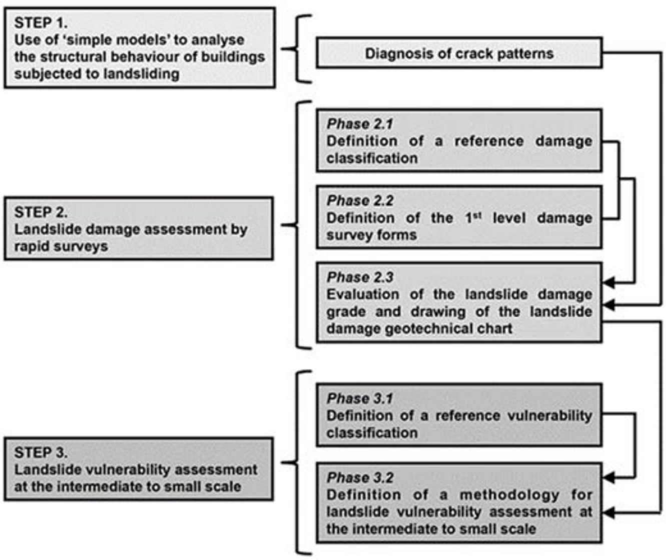

Fig. 1. The approach proposed for the 1st level landslide vulnerability assessment for structures [8].

The landslide damage assessment for ordinary buildings starts from filling in on-purpose designed forms (Phase 2.2 in Fig. 1). The forms are useful to assign a damage grade to each building and to select those that are damaged by foundation settlement. Moreover, the application of the LPM to the crack patterns makes it possible to select, among all the damaged buildings, those that are most likely to have been damaged by foundation settlements in order to create a landslide damage geotechnical chart of the urban area under study (i.e. Phase 2.3 in Fig. 1).

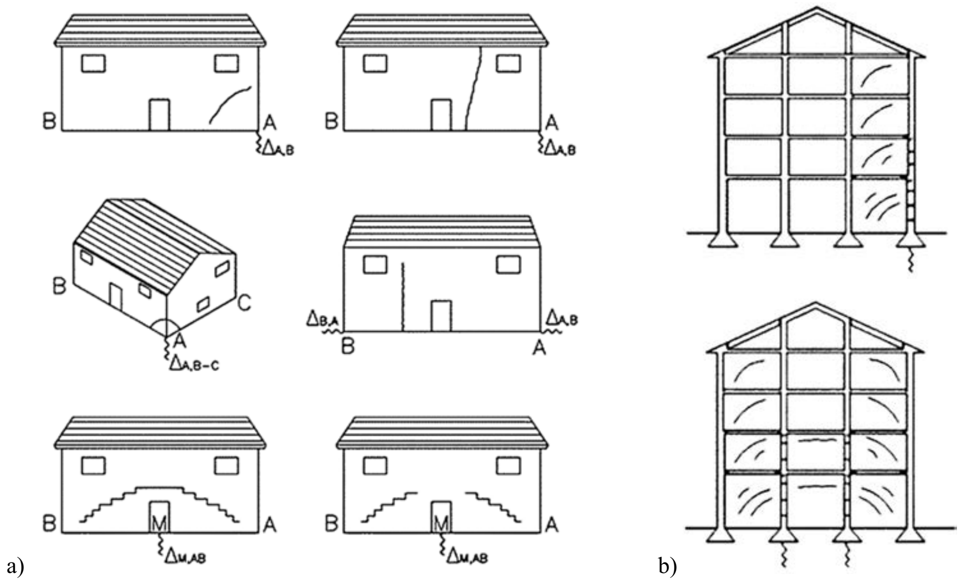

Fig. 2. Typical crack patterns of (a) masonry buildings and of (b) R.C. buildings subjected to foundation settlements.

3. The 1st level damage survey forms

The 1st level damage survey forms aim to detect both typological and damage characteristics of ordinary masonry and reinforced concrete buildings. Therefore, they are not applicable to 'non-ordinary' buildings, such as theatres, churches, sports facilities, industrial buildings, architectural heritage buildings. It is worth noting that, even though the proposed methodology has been studied for slow-moving landslides, the 1st level damage forms are also useful in the immediate aftermath of a rapid landslide. They have been designed in order to be easily filled in by surveyors after direct and 'rapid' surveys in the area affected by landsliding. The damage survey forms for ordinary buildings are composed of eight sections. After the first three sections concerning respectively the building identification, description and typology, Sections 4 and 5 are dedicated to damages to structural and non-structural elements. In Section 6 possible external danger and existing emergency measures are reported, whereas additional notes can be introduced in Section 7. The last part of the forms, Section 8, is used to assign a damage grade to the building under analysis. In particular, four levels of damage intensity and three levels of damage extension have been distinguished, in order to facilitate the compilation and to make it possible the correlation with the damage classification, as discussed later. Moreover, if the analysis of the crack patterns has been performed (first step of the method in Fig. 1), the surveyor is usually capable to identify if the damage is caused by foundation settlement [10]. In this case, a sketch of the building plan with the direction of the settlement has to be added. For a more detailed presentation of the forms see [11].

4. Landslide damage assessment for ordinary buildings

The careful analysis of the completed damage forms allows for a synthetic evaluation of the damage condition of the buildings and for the first selection of those buildings that require either rapid interventions or a more accurate investigation. Moreover, it is necessary to correlate the collected structural data with those deriving from geological and geomorphological studies. In particular, while outside urban areas the geomorphologic analysis can be conducted by using classical tools (e.g. multiple-year topographic maps, on site surveys, aerial photos, together with topographic, interferometer, inclinometer monitoring data), the experience gathered in urban areas has shown that the detection of structural damages gives evidence of landslide activity otherwise difficult to be detected. For this purpose, the proposed procedure for landslide damage assessment at urban scale is completed by associating to each building a level of damage, according to an original damage classification (Fig. 3) that draws inspiration from those by the European Macroseismic Scale 1998 (EMS-98 hereafter; [12]) and [13].

The proposed classification defines six grades of damage, i.e. from 0 to 3c as the severity of the damage increases. Grades 0 and 1 relate to serviceability limit state, grade 2 to serviceability/ultimate limit state, grade 3a to ultimate limit state, grade 3b to ultimate limit state/collapse and grade 3c to collapse.

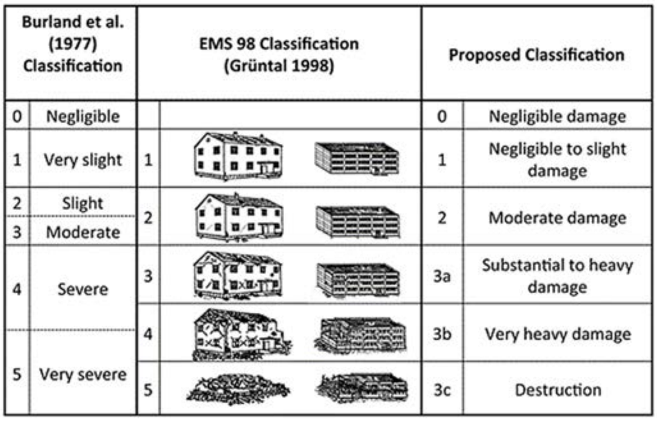

Fig. 3. Comparison of the proposed classification with those from [12] and [13].

The last phase of this step of the methodology (Phase 2.3 in Fig. 1) is to draw the so-called landslide damage geotechnical chart. This chart includes the geomorphological map of the town under study, the damage grade of all the buildings to which a sure or possible dependence of the damage on foundation settlement has been assessed and the direction of the possible settlement (according to section 8 of the damage forms). The correlation of the structural damages to the geomorphologic map and analysis of the damage distribution all over the region under study, makes it possible to add new information about the morphology of the landslide body. Moreover, it is worth noting that the systematic updating of the forms could be a strategic tool for monitoring the landslide activity within the urban area.

As an example, Fig. 4 shows the landslide damage geotechnical chart resulted from the surveys carried out between 2008 to 2013 in the town of Bovino, that is located within the Daunia region in the South of Italy. It is representative of many other that are located in chain areas all along the Apennine chain in Italy and whose urban development is strongly affected by the presence of diffuse active landsliding. The arrows in the chart represent the displacement direction of the buildings. The chart shows that the majority of the damaged buildings is located either on the crown or near the crown of landslides. This observation seems to highlight that buildings located on within landslide body are mainly subjected to 'rigid-body' displacements, that do not induce damages. This observation can lead, for example, useful conclusion for planning the urban development of this town.

5. Conclusions

Within a multi-level approach to the landslide structural vulnerability assessment, the 1st level of analysis involves the urban scale. The aim of the analysis at this scale is to identify those buildings that are at high level of damage or vulnerability and, hence, need either rapid interventions or a more accurate investigation.

In this article, the first two steps of the method proposed for the Level 1 landslide structural vulnerability assessment have been presented: the analysis of the crack patterns and the landslide damage assessment. The proposed procedure allows for the creation of landslide damage geotechnical charts for the territorial cells under study. The charts include the geomorphological map, the damage grade of the buildings and the settlement directions.

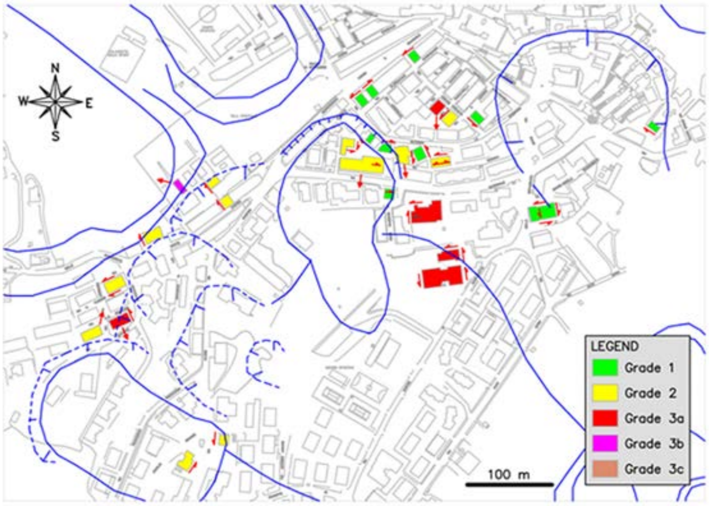

Fig. 4. Landslide damage geotechnical chart of Bovino.

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