Landslide Damage to Buildings

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ABSTRACT / Landslides are a significant and expensive hazard in urban areas, however, a universal methodology for classifying the damage to buildings has not been adopted This article proposes an intensity scale for structural damage caused by subsidence, compression, or extension of the ground during landslides and offers a checklist of site observations that could be made by planners, engineers, architects, surveyors, geologists, or gemorphologists.

Introduction

Ground failure by landsliding is recognized as one of the most significant geological hazards affecting urban areas. In 1976 the annual cost of landslide damage to buildings and their sites in the USA was variously estimated as $400 million (Krohn and Slosson 1976) and $500 million (Schuster 1978), while the cost of damage to private property alone represented 30–50% of total damage costs attributable to mass movement (U.S. Geological Survey 1982).

Urban areas are occasionally zones of particular vulnerability to landslide damage: mass movements in the largely built-up areas of Allegheny County (Pennsylvania), Hamilton County (Ohio), and the San Francisco Bay region (California) cost, respectively, $4 million, $5.2 million, and $5.9 million each year from 1969 to 1978 (Fleming and Taylor 1980). In Orange County, California, 40 major bedrock landslides caused more than $40 million of damage to urban property (Gray 1984). Similar examples in other countries have been documented by Záruba and Mencl (1982), while in the Marche Region of Italy, where the intensity scale described below was developed, 122 of 246 urban centers have been damaged by mass movements, including the regional capital city, Ancona, which suffered a $740 million landslide in December 1982 (Alexander 1983a).

The frequency and significance of urban landslides indicate that it would be helpful to have a standard for recording and classifying the damage, which could be used by scientific researchers and by engineers and surveyors acting for municipal authorities. In major urban landslides, damage is not necessarily localized or restricted to a few buildings; therefore it would also be useful to have a scale for comparison between levels of damage in different local areas. The author proposes the following scale and damage survey checklist not to produce a definitive classification scheme but to stimulate further improvements in methodology, such as those applied to earthquake intensity scales since their inception in the late 1700s.

Scope and Limitations

Among natural hazards earthquakes were the first to have their effects classified by a descriptive gradation of intensity. The foundations of modern scales were laid by De Rossi in 1879, Forel in 1883, and Mercalli in 1902 (Bolt and others 1977). Similar scales have recently been determined to classify the effects of tornadoes (Fujita 1973), hurricanes (Weatherwise 1974), and tsunamis (Soloviev 1978), although flood and volcanic eruption damages cannot be classified simply. Taxonomy has, however, been applied to the morphology, dimensions, and substance of landslides (Skempton and Hutchinson 1969, Crozier 1978, Varnes 1978), and methods have been devised for making standardized inventories of widely distributed slides (Carrara and Merenda 1976). The damaging effects of mass movement do not appear to have been classified in any formal way (cf. Sieberg 1932). In fact, attention has been directed towards planning to avoid urban landslide disasters rather than assessing their impact (Leighton 1976).

A landslide damage intensity scale is probably not feasible with respect to rural areas, where the signs of damage may be sparse, and where the classification depends too much on slope form, lithology, and the nature of the vegetation cover, which are controlling variables rather than effects. The scale proposed here refers to landslide damage by subsidence, translational or rotational movements, or slow thrusts, rather than by the impact of avalanching debris, which is also an occasional hazard to urban areas (Alexander 1983b).

It should be noted that, although the scale and checklist refer to the possibility of repairing damaged buildings, reconstruction will depend first on being able to halt, drain, and stabilize the landslide, and secondly on using an appropriate level of technology and expenditure on the repairs.

Intensity Scale

The following scale has been developed from fieldwork at the site of the 1982 Ancona landslide,

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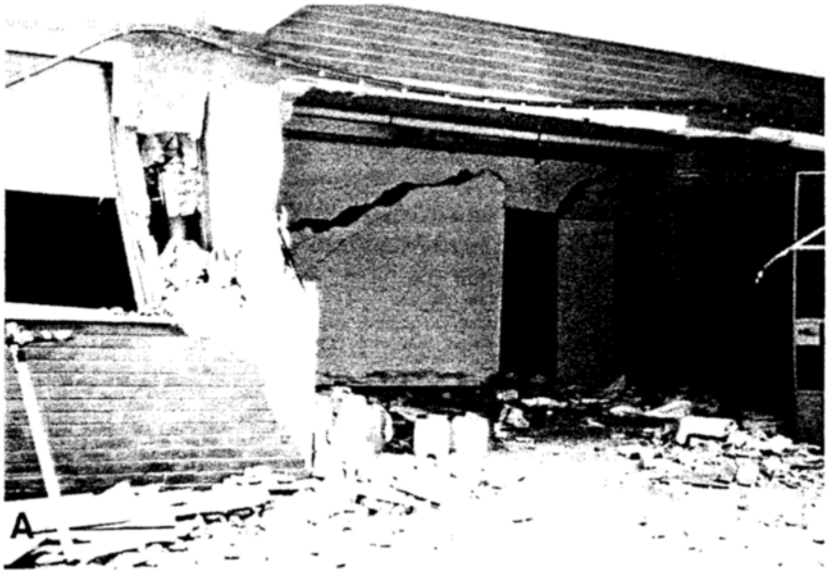

Figure 1. Landslide damage of grades 5, 6, and 7 in Italy: **A.** Hospital in reinforced concrete, Ancona (grade 5). **B.** Houses in rubble masonry, Tricarico, Matera (grade 6). **C.** Total destruction of the urban environment, Craco, Matera (grade 7).

central Italy, which involved 3.41 km^2 of land and about 475 buildings (Alexander 1984), and by adapting post-earthquake building inspection forms used in Italy (Lagorio and Mader 1981, GNDT 1984). Figure 1 shows three examples of landslide damage, which can be related to the severer parts of the scale.

Grade	Damage Level	Explanation
0	None	Building is intact.
1.	Negligible	Hairline cracks in wall or structural members; no distortion of structure or de-

		tachment of external architectural details.
2.	Light	Building continues to be habitable; repair not urgent. Settlement of foundations, distortion of structure and inclination of walls are not sufficient to compromise overall stability.
3.	Moderate	Walls out of perpendicular by 1 to 2 degrees, or substantial cracking has occurred to structural members, or foundations have settled during differential subsidence of at least 15 cm; building requires evacuation and rapid attention to ensure its continued life.
4.	Serious	Walls out of perpendicular by several degrees; open cracks in walls; fracture of structural members; fragmentation of masonry; differential settlement of at least 25 cm compromises foundations; floors inclined by up to 1 to 2 degrees, or ruined by soil heave; internal partition walls will need to be replaced; door and window frames too distorted to use; occupants must be evacuated and major repairs carried out.
5.	Very Serious	Walls out of plumb by 5–6 degrees; structure grossly distorted and differential settlement will have seriously cracked floors and walls or caused major rotation or slewing of the building (wooden buildings may have detached completely from their foundations). Partition walls and brick infill walls will have at least partly collapsed; occupants will need to be rehoused on a long-term basis, and rehabilitation of the building will probably not be feasible.
6.	Partial Collapse	Requires immediate evacuation of the occupants and cordoning of the site to prevent accidents with falling masonry.
7.	Total Collapse	Requires clearance of the site.

Checklist

The possible motives for surveying landslide damage are administrative (to issue post-disaster evacuation orders), planning (to estimate the need for reconstruction and repair), scientific (to assess the extent of the phenomenon), and engineering (as groundwork for reconstruction plans). Items from the following checklist would need to be used selectively in order to derive information suited to any one of these specific purposes.

A. The Building—Administrative

1. Address; ownership and occupier details; temporary evacuation details (if known).
2. Number of stories; number of wings (if appropriate); number of rooms; approximate ground floor size (m^2; number of residences or business units (as appropriate).
3. Use: residential, commercial, industrial, office, public service (hospital, church, police station, etc.), brief description.
4. Approximate age: pre-1900, 1900–1944, 1945–1964, 1965 and after.

B The Building—Construction

5. Materials used in vertical construction: rubble masonry, ashlar masonry, pisé (cobb, adobe, etc.), tuff or tufa block (or compressed fibre/aggregate block), wood frame, steel frame, reinforced concrete (wall, cylindrical, or rectangular column, prestressed member), mixed construction.
6. Materials used in horizontal construction:
   a. Stone or brick vault, wooden beams, steel joists, mixed construction.
   b. Reinforced concrete—flat plate, beam and girder (two-way slab), flat slab with drop-panel and capital.
   c. Type of roofing: mansard, pantile, reinforced concrete, thatch, metal, etc.
7. Foundation (if visible or known from records): none, continuous rock, earth or sediment,

rubble, short pile, long pile, reinforced concrete (raft and columns, cantilever, wall or pedestal footing).

8. Type of architectural details: garage, cornices, steps, patio, porch, terraces, balconies, retaining walls, etc.
9. Common façade or frontage with other buildings?
10. Presence or absence of cellar, detached or linked garage, barn or stall.
11. Regularity of plan-form: rectangular, square, circular, irregular, etc.
12. Orientation of building (°N), direction of hillslope (°N)

C. The Landslide

13. Landslide event:
    a. Previous event: stabilized/potentially active (date?).
    b. Current event: potential/active.
    c. Unknown.
14. Dominant type of ground movement: subsidence or heave, extension or compression, translation or rotation; scarp, scarpette, bowl-shaped scar, mudflow, other.
15. Position of building with respect to landslide (Varnes 1978):

a. Above crown b. Headscarp (crown scarp) c. Intermediate step or scarp	zone of depletion
d. Neck	
e. Flank	
f. Foot, toe, or basal fan g. Compression ridges	zone of accumulation
h. Other.	

16. Has the landslide been mapped by geologists or planners? Have mass movement processes been monitored at or near the site? Do base maps, aerial photographs, or remote sensing images of the site exist?

D The Damage

17. Maximum vertical movement (cm), maximum horizontal movement (cm), and their directions (°N).
18. Maximum inclination of (a) walls, (b) basal raft or foundations (in degrees); direction of rotation: upslope, downslope, parallel to the contour, diagonal (°N).
19. Direction of slew (if any): clockwise, anticlockwise (degrees).
20. Dominant type of cracking:
    a. Horizontal, diagonal, vertical, network, X.
    b. Compression, dilation, relative slip (for each elevation—front, rear, left, right).
21. Damage to window and door apertures: compression, distortion, cracking of sill, lintel or jamb, shattering of glass and splintering of wood, etc.
22. Grade of damage (0–7): none, negligible, light, moderate, serious, very serious, partial collapse, total collapse (see scale).

Acknowledgments

This research was supported by the Graduate School of the University of Massachusetts. Valuable help was given by the Amministrazione Regionale delle Marche and Comune di Ancona (Italy) and by Dr. Leonardo Polonara.

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