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Building damage classification and recording scheme for subsidence and landslip mapping

Urban Geoscience and Geological Hazards Programme

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Foreword

This internal report sets out the background information and thinking that lies behind the BGS building damage classification scheme. It details a scheme for recording building damage that has been caused by subsidence, landslip and heave. It is applicable to geological and hazard mapping in urban and rural areas. The information gathered in this manner can be used to map out unstable land, to quantify movement and help with hazard avoidance.

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Contents

FIGURES

Summary

Building damage due to subsidence and landslips within Great Britain is considerable. The degree of damage depends on the position of the building, the size of the unstable land area and the amount of movement. Recording building damage permits the delineation of areas of unstable land and the degree of damage gives an indication of the severity of the problem. This technical report reviews the schemes that have been used in numerous situations for recoding damage due to subsidence, landslips and earthquake damage. It compares the classifications and proposes a unified scheme that is the foundation of building damage recording in BGS. Seven categories are proposed ranging from 1, which is barely perceptible through 5, which is very severe with considerable damage to 7, which is total collapse.

1 Introduction

In Great Britain, building damage due to subsidence and landslides costs around many hundreds of million pounds a year. This damage is caused by various geological problems, which include natural subsidence, mining induced subsidence, shrink-swell clays, collapsible soils and landslips. In many cases, the severity of the subsidence damage can be directly related to either the nature of the geological failure or the distribution of the subsidence or landslip-prone deposit. Man-made structures, especially traditional buildings, are very prone to damage by such movements and as such form sensitive recording devices for quite small amounts of subsidence. By mapping out the degree of damage, it is possible to get a better understanding of the mechanisms and movements causing the subsidence. By repeating the monitoring after an interval of time, it is possible to see how the damage has progressed and assess the stability and rate of change of an area.

This report reviews and considers several similar building damage recording schemes. It presents an amalgamated and universal scheme that can be applied to various situations, it also indicates the type of damage that would occur on land adjacent to damaged buildings. The scheme is applied to the recording of building damage in BGS and the use of proforma field notebook sheets.

2 Comparison of damage classification schemes

The way in which building damage is assessed for mapping purposes on a town or village scale needs to be quick, easy to apply, and preferably performed from the street. It is also important that it can be universally applied to damage whatever the cause, and be carried out by staff that, most likely, will not be qualified structural engineers. Numerous workers have attempted the measurement and classification of building damage and many of the schemes have common features, but vary slightly in the parameters and categories.

The way in which damage has been assessed falls into four main types.

1. Schemes that define the amount of distortion applied to structures and assess the limits of that can occur before different types of damage result. These include, factors such as

curvature of bending, angle of rotation and differential movement amounts are applied for example by Bhattachraya and Singh (1985).

2. Detailed recording of crack patterns in buildings relating them to the type of cause for example, Audell, 1996.
3. Schemes such as those used to assess earthquake damage and intensity (Wood and Neumann, 1931).
4. Schemes that have been used to record building damage in various geological situations including mining, landslip, shrink-swell clays and general building damage. These are the most useful for damage recording on a mapping scale, but the other types of schemes also contribute useful information and are briefly reviewed below.

2.1 THE MEASURED DEFORMATION SCHEMES

Bhattachraya and Singh (1985) collated information from a large number of sources to define recommended values for subsidence effects in coal mining areas. Their values give parameters for engineers to design foundations and structures, but do not function as method of surveying and recording damage.

BuildingCategory (This is not a damage scale)	Damage level	Angular distortion (mm/m) range	Angular distortion (mm/m) recommen-ded value	Horizontal strain (mm/m) range	Horizontal strain (mm/m) recommen -ded value	Deflection Value (mm/m) range	Deflection Value (mm/m) recommen -ded value	Radius of curvature (km) range	Radius of curvature (km) recommen -ded value
1 Brick/masonry low -rise	Architectural	0.5-2.0	1.0	0.25-1.5	0.5	0.3-1.0	0.3	-	-
	Functional	2.0-6.0	2.5-3.0	1.0-4.0	1.5-2.0	0.14-0.6	0.5	3-20	20
	Structural	7.0-8.0	7.0	2.75-3.5	3.0	-	-	-	-
2 Steel reinforced concrete frame	Architectural	1.0-2.5	1.3	-	-	-	-	-	-
	Functional	2.5-5.5	3.3	-	-	-	-	-	-
	Structural	-	-	-	-	-	-	-	-
3 Timber frame structures	Architectural	2.0	1.5	1.0	1.0				-
	Functional	3.3-10	3.3-5.0	-	-				-
	Structural		-	-					-

Architectural: onset of architectural damage characterised by small-scale cracking of plaster and sticking doors and windows.

Functional: onset of functional damage characterised by instability of some structural elements, jammed doors and windows, broken window panes, building services restricted.

Structural: onset of structural damage characterised by impairment of primary structural members, possibility of collapse of members, complete or large-scale rebuilding necessary, may be unsafe for habitation.

Figure 1. The building damage recording scheme of Bhattacharya and Singh (1985)

The blanks in the table represent insufficient data, which the authors hoped to be able to complete in due course. Their scheme was based on a major review of the literature with the aim of producing a universally workable scheme that could be applied by people other than qualified specialists.

2.2 DETAILED CRACK RECORDING SCHEMES

Audell (1996) presented a comprehensive scheme of crack classification. This thorough, but fairly complicated scheme requires a full internal survey of the property and would be best carried out by a structural engineer. The work is a useful insight into the way that different movements affect a structure and how lateral movements can cause very different crack patterns to vertical subsidence movements and bending. The scheme is useful for detailed inspection of properties to determine the sort of stresses endured to cause the damage, but it is not the basis of a field recording technique.

2.3 EARTHQUAKE RECORDING SCHEMES

Severe damage is caused to buildings by earthquakes and there are several schemes that have been applied to earthquake damage. The modified Mercalli scale of Wood and Neumann (1931) includes some details of building damage. A similar, but more detailed scheme by Medvedev et al. (1965) included a sub-table of building damage characteristics, and that table is comparable to some of the recording schemes applied to damage by other causes. The more recent European Macroseismic Scale (Grunthal, 1998) presents damage classification information relevant to different construction types and links that to the intensity scale.

2.3.1 The modified Mercalli scale of earthquake damage

Degrees	Description	Acceleration mm s^2
I	Not felt. Only detected on seismographs.	<2.5
II	Feeble. Felt by persons at rest, on upper floors, or favourably placed.	2.5-5.0
III	Slightly felt indoors. Hanging object swing. Vibration like passing of light trucks. Duration estimated. May not be recognised as an earthquake.	5.0-10
IV	Slightly felt indoors. Hanging object swing. Vibration like passing of light trucks, or sensation of jolt like a heavy ball striking the walls. Standing motor cars rock Windows, dishes and doors rattle. Glasses clink. Crockery clashes. In the upper range of IV wooden walls and frames creak.	10-25
V	Rather strong. Felt outdoors. Sleepers wakened. Liquids disturbed, some spilled. Small unstable objects displaced or upset. Doors swing, close, open. Shutters and pictures move. Pendulum clocks stop, start, change rate.	25-50
VI	Strong. Felt by all. Many frightened and run outdoors. Persons walk unsteadily. Windows, dishes, glassware broken. Ornaments, books, etc., fall off shelves. Pictures fall off walls. Furniture moved or overturned. Weak plaster or masonry cracked. Small bells ring (church, school). Trees shaken visibly or heard to rustle.	50-100
VII	Very strong. Difficult to stand. Noticed by drivers of motor cars. Hanging objects quiver. Furniture broken. Damage to masonry D, including cracks. Weak chimneys broken at roof line. Fall of plaster, loose bricks, stones, tiles, cornices also unbraced parapets and architectural ornaments. Some cracks in masonry C. Waves on ponds, water turbid with mud. Small slides and caving-in along sand or gravel banks. Large bell rings. Concrete irrigation ditches damaged.	100-250
VIII	Destructive. Steering of motor cars affected. Damage to masonry C, partial collapse. Some damage to masonry B, not to masonry A. Fall of stucco and some masonry walls. Twisting, fall of chimneys factory stacks, monuments, towers, elevated tanks. Frame houses moved on foundations if not bolted down, loose panel walls thrown out. Decayed piling broken off. Branches broken from trees. Changes in flow or temperature of springs and wells. Cracks in wet ground and on steep slopes.	250-500
IX	Ruinous. General panic. Masonry D destroyed, masonry C heavily damaged, sometimes with complete collapse, masonry B seriously damaged. General damage to foundations. Frame structures, if not bolted down, shifted on foundations. Frames cracked serious damage to reservoirs. Underground pipes broken. Conspicuous cracks in ground. In alluviated areas sand and mud ejected, earthquake fountains and sand craters.	500-1000
X	Disastrous. Most masonry and frame structures destroyed with their foundations. Some well-built wooden structures and bridges destroyed., serious damage to dams, dykes, embankments. Large landslides. Water thrown on banks of canals, rivers, lakes, etc. Sand and mud shifted horizontally on beaches and flat land. Rail tracks bent slightly.	1000-2500
XI	Very disastrous. Rail tracks bent greatly. Underground pipelines completely out of service.	2500-5000
XII	Catastrophic. Damage nearly total. Large rock masses displaced. lines of sight and level distorted. Objects thrown in the air.	>5000

Figure 2. The modified Mercalli scale of earthquake damage by Wood and Neumann, 1931 as applied to earthquake severity and damage.

2.3.2 The Medvedev-Sponheuer-Karnik building damage classification scheme

This scheme is similar in many respects to the modified Mercalli scale, but has sub-tables defining 1. Types of structures; 2. Definition of quality; 3. Classification of building damage; 4 Arrangement of the scale. The classification of the building damage is the scale that is the most important for comparison with the other damage scales.

Grade	Damage
1 Slight damage	Fine cracks in plaster, fall of small pieces of plaster
2 Moderate damage	Small cracks in walls, fall of fairly large pieces of plaster; pantiles slip off; cracks in chimney; parts of chimney fall down.
3 Heavy damage	Large and deep cracks in walls; fall of chimneys.
4 Destruction	Gaps in walls; parts or buildings may collapse; separate parts of the buildings lose their cohesion; inner walls and filled in walls fo the fram collapse.
5 Total damage	Total collapse of buildings.

Figure 3. Medvedev-Sponheuer-Karnik building damage classification to complement their seismic intensity scale.

2.3.3 European Macroseismic Intensity Scale

Grade	Damage to masonry structures	Damage to reinforced concrete buildings
1 Negligible to slight damage (no structural damage to slight non-structural damage)	Hairline cracks in a few walls, Fall of small pieces of plaster only. Fall of loose stoned from upper parts of buildings in very few cases.	Fine cracks in plaster over frame members or in walls at the base. Fine cracks in partitions and infills.
2 Moderate damage (slight structural damage, moderate non-structural damage	Cracks in many walls. Fall of fairly large pieces of plaster. Partial collapse of chimneys.	Cracks in columns and beams of frames and in structural walls. Cracks in partition and infill walls; fall of brittle cladding and plaster. Falling mortar from the joint of wall panels.
3 Substantial to heavy damage (moderate structural damage, heavy non-structural damage)	Large and extensive cracks in most walls. Roof tiles detach. Chimneys fracture at the roof line; failure of individual non-structural elements (partitions, gable walls)	Cracks in columns and beam column joints of frames at the base and at joints of coupled walls. Spalling of concrete cover, buckling of reinforced rods.
4 Very heavy damage (Heavy structural damage, very heavy structural damage)	Serious failure of walls; partial structural failure of roofs and floors.	Large cracks in structural elements with compression failure of concrete and fracture of rebars; bond failure of beam reinforced bars; tilting of columns. Collapse of a few columns or of a single upper floor.
5 Destruction (Very heavy structural damage)	Total or near total collapse.	Collapse of ground floor or parts (e.g. wings) of buildings

Figure 4. European Macroseismic Intensity Scale (Grunthal, 1998)

2.4 BUILDING DAMAGE RECORDING SCHEMES

Some schemes are subdivided depending on the type of building or structure that are affected. This is logical since a brick building with very slight foundations will be much more severely affected than a concrete and steel structure on a concrete raft foundation. However, from a practical point of view of recording damage, it is unlikely that details of foundations and construction methods will be available. Consequently schemes that look at the actual damage, rather than the causes and underlying physical distortion parameters, are more practical for field recording. When detailed studies of individual buildings are considered, the schemes that consider the measured parameters are applicable. They are also useful for planning to cope with geologically induced building damage where they allow design parameters to be specified.

2.4.1 The NCB (1975) Scheme

The scheme is based on the National Coal Board methodology detailed in the Subsidence Engineers Handbook (1975). The scheme is based on the change in the length of the structure related to the length of the actual structure. As such, it required the use of another table (to be scanned and inserted here?) to relate the actual strain to the length of the building. This table could be interpreted to give an indication of the amount of extension and cracking a building of any category could include.

Change in length of structure	Class of damage	Description of typical damage
Up to 0.03m	**1** **Very slight or negligible**	Hairline cracks in plaster, perhaps isolated slight fracture in the building, not visible from the outside.
0.03- 0.06m	**2** **Slight**	Several slight fractures showing inside the building. Doors and windows may stick slightly. Repairs to decoration probably necessary.
0.06- 0.12	**3** **Appreciable**	Slight fractures showing on outside of building (or one main fracture). Doors and windows sticking. Service pipes may fracture.
0.12 -0.18m	**4** **Severe**	Service pipes disrupted. Open fractures requiring rebonding and allowing weather into the structure. Window and door frames distorted; floors sloping noticeably; walls leaning or bulging noticeably. Some loss of bearing in beams. If compressive damage, overlapping of roof joints and lifting of brickwork with open horizontal fractures.
More than 0.18m	**5** **Very severe**	As above, but worse and requiring partial or complete rebuilding. Roof and floor beams loose bearing and need shoring up. Windows broken with distortion. Severe slopes on floors. If compressive damage, severe buckling and bulging of the roof and walls.

Figure 5. The building damage classification scheme established by the NCB (British National Coal Board)

2.4.2 The scheme used by Howard Humphreys & Partners 1993 for the Department of the Environment Norwich study

In the Norwich area, much of the town is undermined with uncharted chalk and flint mines. These sporadically collapse and cause structural damage. In addition, there may be subsidence due to natural dissolution of the Chalk and the settlement or piping of fill in dolines. The subsidence damage classification proposed by Howard Humphreys and Partners (1993) was used to rank historic records of subsidence in the town. It is based on the NCB scheme with the addition of two extra fields to allow the incorporation of historically based details.

Category	Typical damage to buildings	Effect on open ground and highways
0 Negligible	Hairline cracks in walls and between floor and skirtings	Not noticeable
1 Very slight	Perhaps isolated slight cracking in walls, but not visible in external brickwork. Cracks below skirting.	Not noticeable
2 Slight	Hair cracks in plaster, possibly isolated slight fracture showing inside the building, not generally visible on outside. Cracks open up below skirting. Doors and windows may stick slightly. Cracks can be filled or masked. Repairs to decoration probably necessary.	Generally not noticeable.
3 Moderate	Slight fracturing apparent on the outside of the building (cracks up to 3mm wide); or one main fracture open 5-15mm. Doors and windows may stick. Service pipes may fracture. Foundation improvement or treatment may have been carried out under part of the building. Repointing of external brickwork may be required, and possibly a small amount of brickwork to be replaced.	Slight depression in open ground or highway, noticeable to vehicle users, but may not be obvious to casual observers. Repairs generally superficial, but may involve limited local pavement reconstruction.
4 Severe	Open fracture (15-25mm) develop which require breaking out and replacing section of walls. Bays may drop, Window and door frames distorted causing openers to stick badly. Floors slope noticeably, walls lean or bulge noticeably. Service pipes disrupted. Foundation improvement or treatment may be required to part or all of the building. Rebuilding of part of the structure may be required.	Significant depression, often accompanied by cracking, in open ground or highway. Obvious to the casual observer. Small open hole may form. Repairs to the highway generally require excavation and reconstruction of the road pavement.
5 Very severe	Severely cracked walls with open fractures, usually greater than 25mm. Widows and doors broken with distortion. Severely sloping floors and sagging ceilings. Service pipes dislocated. Foundation improvement probably required. Partial to complete rebuilding may be necessary.	Significant depression, often accompanied by cracking, in open ground or highway; open crater formed often with large void. Generally disruption of services in highways. Significant works may be required to repair road pavement.
6 Extremely severe	Very severe distress to buildings with dislocation of walls, partial or complete collapse may occur, and this may be sudden. Open void may develop which often extends to depth. Services severed. Infilling/capping of voids required. Foundation treatment or improvement required. Structure requires demolition/ major rebuilding.	Collapse of ground or highway, which may be sudden. Significant open void forms which requires partial or closing of highway. Services severed or severely disrupted. Infilling/capping of void followed by significant works to backfill and reinstate road pavement.
? not known	Damage not recorded	Details not recorded

Figure 6. The Howard Humphreys & Partners (1993) building damage recording scheme used in Norwich

2.4.3 The scheme used by the Institution of Civil Engineers and Building Research Establishment (1994) and Institution of Structural Engineers (1994)

The NCB 1975 scheme was the original, but it was followed by other organisations for subsidence caused by different mechanisms and deposits. The Institution of Civil Engineers and Building Research Establishment (Freeman, et al., 1994) published a similar scheme, to enable the assessment and classification of subsidence and heave caused by shrink-swell clay. Similarly, the Institution of Structural Engineers (1994) used almost the same scheme as a general assessment tool for damage to walls in low rise buildings. The 1994 schemes differ slightly from the NCB scheme in the wording and the fact that actual measurements of crack widths are given, but the categories and the nature of the damage recorded are remarkably similar.

Category of damage	**Description of typical damage** **(Nature of repair in italic type)**
0	Hairline cracking which is normally indistinguishable from other causes such as shrinkage and thermal movement. Typical crack widths 0.1mm. *No action required*
1	Fine cracks which can *easily be treated using normal decoration*. Damage generally restricted to internal wall finishes: cracks rarely visible in external brickwork. Typical crack widths up to 1mm.
2	*Cracks easily filled. Recurrent cracks can be masked by suitable linings.* Cracks not necessarily visible externally: *some external repointing may be required to ensure weather tightness.* Doors and windows may stick slightly and *require easing and adjusting*. Typical crack widths up to 5mm.
3	Cracks which *require some opening up and can be patched by a mason. Repointing of external brickwork and possibly a small amount of brickwork to be replaced.* Doors and windows sticking, service pipes may fracture. Weather-tightness often impaired. Typical crack widths are 5 to 15mm, or several of, say 3mm.
4	Extensive damage which *requires breaking-out and replacing sections of walls*, especially over doors and windows. Windows and door frames distorted, floor sloping noticeably*. Walls leaning or bulging noticeably; some loss of bearing in beams. Service pipes disrupted. Typical cracks widths are 15 to 25mm, but also depends on number of cracks.
5	Structural damage which *requires a major repair job, involving partial or complete rebuilding.* Beams loose bearing walls lean badly and require shoring. Windows broken with distortion. Danger of instability. Typical crack widths are greater than 25mm, but depends on the number of cracks.

Important Note. Crack width is one factor in assessing category of damage and should not be used on its own as a direct measure of it. * Local deviation of slope, from the horizontal or vertical, of more than 1/100 will normally be clearly visible. Overall deviations in excess of 1/150 are undesirable.

Figure 7. Building damage categories used by The Institution of Civil Engineers, Institution of Structural Engineers and Building Research Establishment Scheme (1994).

2.4.4 The vanRooy building damage classification scheme

Crack width (mm)	Degree of damage	Risk
0	No damage	Very low
0-2.5	Slightly damaged	Low
2.5-5.0	Visibly damaged	Medium
5-10	Moderately damaged	High
>10	Badly damaged	Very high

Figure 8. The scheme by van Rooy (1989) for classifying building subsidence caused by sinkhole development in South Africa.

The scheme suggested by van Rooy works in a similar way to the NCB and subsequent schemes, but the classifications are out of step with them. The scheme shows that similar approaches are being applied in various parts of the world.

2.4.5 The Chiocchio et al., 1997 landslide building damage classification scheme

The scheme developed for landslide damage by Chiocchio et al. (1997) has similarities to the NCB scheme with the addition of two more categories to encompass more severe damage. It also has details for masonry structures and reinforced concrete structures in the same settings.

grade	damage level	load-bearing structure	damage				
			rigid settle-ment (cm)	rigid rotation (cm)	Distortion (%) and differential settlement (cm)	cracking	thrusting
0	none	masonry	0	0	0	none	none
		reinforced concrete frame	0	0	0	none	none
1	negligible	masonry	0	0	0	hairline cracks of the plaster	none
		reinforced concrete frame	0	0	0	hairline cracks of the plaster	none
2	light	masonry	2-3	2.5 ċ*h	3 ċ*1	small cracks through walls and partitions	none
		reinforced concrete frame		2.5 ċ*h	3 ċ*1	small cracks through perimetric and partition walls	none
3	moderate	masonry	10-15	4 ċ*h	4-5 ċ*1	open cracks in walls; wall disjunction; lintel deformation badly working casings	only in significant sites
		reinforced concrete frame	10-15	4 ċ*h	4-5 ċ*1	significant cracking in the beams; partition walls deformed and crumbling; badly working casings	not spread
4	serious	masonry	15-20	8 ċ*h	7 ċ*1	considerable disjunction of walls; space deformation partition walls collapsed; unusable casings	spread and remarkable
		reinforced concrete frame	15-20	8 ċ*h	7 ċ*1	perimetric and partition walls partly collapsed; deformed structures; spread cracking	spread and remarkable
5	very serious	masonry	>25	10 ċ*h	10 ċ*1	open cracks in floor; partition walls totally collapsed; seriously ruined lintels	very spread
		reinforced concrete frame		10 ċ*h	10 ċ*1	partition and perimetric walls collapsed; heavy deformation in the structures; cracking in floor and slab	very spread
6	partial collapse	masonry	u.d.	u.d.	u.d.	u.d.	u.d.
		reinforced concrete frame	u.d.	u.d.	u.d.	u.d.	u.d.
7	total collapse	masonry	u.d.	u.d.	u.d.	u.d.	u.d.
		reinforced concrete frame	u.d.	u.d.	u.d.	u.d.	u.d.

Figure 9. The scheme used by for landslide damage by Chiocchio et al., 1997.

2.4.6 The scheme used by (Geomorphological Services Ltd. 1991) for landslips at Ventnor, Isle of Wight

Class	Description
Negligible	Hairline cracks to roads, pavements and structures with no appreciable lipping or separation.
Slight	Occasional cracks. Distortion, separation or relative settlement apparent. Small fragments of debris may occasionally fall onto roads and structures causing only slight damage. Repair not urgent.
Moderate	Widespread cracks. Settlement may cause slight tilt to walls and fractures to structural members and service pipes.
Serious	Extensive cracking. Settlement may cause open cracks and considerable distortion to structures. Walls out of plumb and the road surface may be affected by subsidence. Parts of roads and structures may be covered with landslide debris from above. Repairs urgent to safe-guard future use of roads and structures.
Severe	Extensive cracking. Settlement may cause rotation or slewing of ground. Gross distortion to roads and structures. Repairs will require partial or complete rebuilding and may not be feasible. Severe movements leading to the abandonment of the site or area.

Figure 10. The scheme used by (Geomorphological Services Ltd. 1991) for landslips at Ventnor, Isle of Wight

2.4.7 Correlation between the schemes and the information about the applicability of the hybrid scheme to damage caused by all sorts of causes.

Proposed scheme	NCB 1975 Coal mining subsidence	Inst Civils, Inst. Stuructural, BRC 1994 Shrink-swell clays and general damage	Chiocchio et al. landslide damage	Geomorpho-logical Services Ltd. *1991* Ventnor landslide damage	Norwich Chalk mining subsidence 1993	European Macroseismic Scale 1998	Medvedev-Sponheuer-Karnick earthquake damage	Wood and Neumann 1931 modified Mercalli
		0	0 none		0 negligible			I, II, III,1V, V no significant damage
1 very slight	1 very slight or negligible	1	1 negligible		1 very slight			
2 slight	2 slight	2	2 light		2 slight	1 negligible to slight	1 slight damage	VI
3 moderate	3 appreciable	3	3 moderate	negligible	3 moderate	2 moderate damage	2 moderate damage	VII
4 severe	4 severe	4	4 serious	slight	4 severe			
5 very severe	5 very severe	5	5 very serious	moderate	5 very severe	3 substantial to heavy damage	3 heavy damage	
6 partial collapse			6 partial collapse	serious	6 extremely severe	4 very heavy damage	4 destruction	VIII
7 total collapse			7 total collapse	severe		5 destruction	5 total damage	IX
								X
								XI
								XII Total devista-tion

Figure 11. Correlation between various building damage assessment schemes.

Tabulating the most useful schemes in the table above shows that there is a considerable amount of agreement between many of the schemes. The subsidence schemes based on the NCB procedures range from 1 to 5 or 1 to 6 and the landslip recording scheme of Chiocchio et al., from 1 to 7. Amalgamating the most similar classifications produces a hybrid scheme that runs from 1 to 7. This scheme is applicable to recording damage from subsidence, shrink-swell, and landslips, it is less applicable to recording earthquake damage.

More thought to go into it especially the inclusion of the modified Mercalli, that column is not sorted and may be better excluded since it mixes numerous factors in addition to building damage. By comparison the Medvedev-Sponheuer-Karnick earthquake damage scale actually uses a sub-scale of building damage which is directly comparable to the other schemes. Note the Landslide scheme is further down the table than the other schemes.

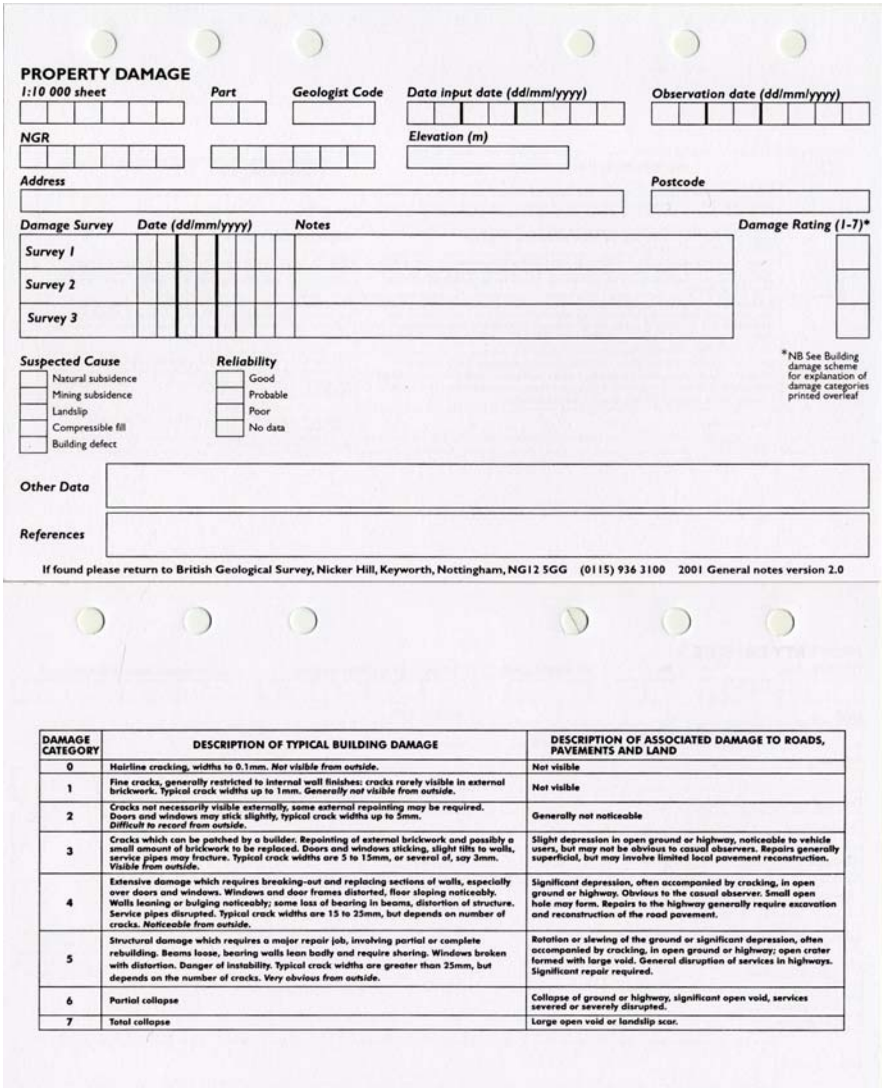
3 The Building Damage Scheme for use in BGS

CLASS	TYPICAL BUILDING DAMAGE	SUBSIDENCE GROUND DAMAGE	LANDSLIDE GROUND DAMAGE
0	Hairline cracking, widths to 0.1mm. Not visible from outside	Not visible	Not visible
1	Fine cracks, generally restricted to internal wall finishes: rarely visible in external brickwork. Typical crack widths up to 1mm. Generally not visible from outside.	Not visible	Not visible
2	Cracks nor necessarily visible externally, some external re-pointing may be required. Doors and windows may stick slightly. Typical crack widths up to 5mm. Difficult to record from outside.	Not visible	Not visible.
3	Cracks which can be patched by a builder. Re-pointing of external brickwork and possibly a small amount of brickwork to be replaced. Doors and windows sticking, slight tilt to walls, service pipes may fracture. Typical crack widths are 5 to 15mm, or several of say 3mm. Visible from outside.	Slight depression in open ground or highway, noticeable to vehicle users, but may not be obvious to casual observers. Repairs generally superficial, but may involve local pavement reconstruction.	Negligible. No damage likely to be noticed in vegetated ground. Tight cracks in hard surfaces, paths, roads, pavements and structures with no appreciable lipping or separation.
4	Extensive damage that requires breaking out and replacing sections of walls, especially over doors and windows. Windows and door frames distorted, floors sloping noticeably; some loss of bearing in beams, distortion of structure. Service pipes disrupted. Typical crack widths are 15 to 25mm, but also depends on number of cracks.	Significant depression, often accompanied by cracking, in open ground or highway. Obvious to the casual observer. Small hole may form. Repairs to the highway generally require excavation and reconstruction of the road pavement.	Slight. Stretching of roots, tension changes on wires and fences. Open cracks, distortion, separation or relative settlement. Small fragment falls cause slight damage to roads and structures. Remedial works not urgent.
5	Structural damage, which requires a major repair job, involving partial or complete rebuilding. Beams lose bearing capacity, walls lean badly and require shoring. Windows broken with distortion. Danger of instability. Typical crack widths are greater than 25mm, but depend on the number of cracks. Very obvious from outside.	Rotation or slewing of the ground or significant depression, often accompanied by cracking, in open ground or highway; open crater formed with large void. General disruption of services in highways. Significant repair required.	Moderate. Widespread tension cracks in soil and turf. Ground surface bulged and/or depressed. Settlement may tilt walls, fracture of structures, service pipes and cables. Remedial work necessary.
6	Partial collapse	Collapse of ground or highway, significant open void, services severed or severely disrupted.	Serious. Extensive ground cracking with minor scarps, ground bulging and soil rolls. Minor flows, falls and slides may affect roads and structures. Settlement causes cracks and distortion to structures and roads. Remedial works urgent.
7	Total collapse	Large open void.	Severe Extensive ground cracking, major scarps and grabens. Major debris/earth/ mud flows and slides and falls. Settlement causes rotation/slewing of ground, gross distortion and destruction of structures. Major remedial works may not be feasible.

Figure 12. The BGS building damage recording scheme

The building damage classification scheme proposed for BGS builds on the established NCB damage scheme with the addition of information included in the Norwich subsidence recording scheme. It also builds on the Chiocchio et al (1997) landslide damage recording scheme, with which it is compatible. Chiocchio et al (1997) present details of how that scheme applies for both masonry buildings and reinforced concrete buildings. It must be noted that the degree of damage a building suffers will vary considerably depending on the structure and its foundations. Consequently, a modern reinforced building on substantial foundations will not show the same degree of damage as a masonry building on shallow foundations. These differences have been addressed in the European Macroseismic Scale (Grunthal, 1998) and could be incorporated into a general building damage recording scheme. However, the majority of the building damage schemes, including the hybrid scheme presented here, are based on damage to conventional brick and masonry buildings and strong reinforced concrete structures are not included.

The scheme presented above has been used by BGS to record damage into the BGS karst geohazards database and proforma field notebook sheets have been printed to comply with the scheme (Figure 13). In addition, the GSD/GSD2 (Geological Spatial Database) has been developed (Cooper et al., 2001) to allow the information to be digitised directly into the database using the GIS ArcView3.3 GSD interface or the ArcMap8/9 GSD2 interface.


PROPERTY DAMAGE

1:10 000 sheet | Part | Geologist Code | Data input date (dd/mm/yyyy) | Observation date (dd/mm/yyyy)

NGR | Elevation (m)

Address | Postcode

Damage Survey | Date (dd/mm/yyyy) | Notes | Damage Rating (1-7)*

Survey 1

Survey 2

Survey 3

Suspected Cause: Natural subsidence; Mining subsidence; Landslip; Compressible fill; Building defect

Reliability: Good; Probable; Poor; No data

*NB See Building damage scheme for explanation of damage categories printed overleaf

Other Data

References

If found please return to British Geological Survey, Nicker Hill, Keyworth, Nottingham, NG12 5GG (0115) 936 3100 2001 General notes version 2.0

DAMAGE CATEGORY	DESCRIPTION OF TYPICAL BUILDING DAMAGE	DESCRIPTION OF ASSOCIATED DAMAGE TO ROADS, PAVEMENTS AND LAND
0	Hairline cracking, widths to 0.1mm. *Not visible from outside.*	Not visible
1	Fine cracks, generally restricted to internal wall finishes: cracks rarely visible in external brickwork. Typical crack widths up to 1mm. *Generally not visible from outside.*	Not visible
2	Cracks not necessarily visible externally, some external repointing may be required. Doors and windows may stick slightly, typical crack widths up to 5mm. *Difficult to record from outside.*	Generally not noticeable
3	Cracks which can be patched by a builder. Repointing of external brickwork and possibly a small amount of brickwork to be replaced. Doors and windows sticking, slight tilts to walls, service pipes may fracture. Typical crack widths are 5 to 15mm, or several of, say 3mm. Visible from outside.	Slight depression in open ground or highway, noticeable to vehicle users, but may not be obvious to casual observers. Repairs generally superficial, but may involve limited local pavement reconstruction.
4	Extensive damage which requires breaking-out and replacing sections of walls, especially over doors and windows. Windows and door frames distorted, floor sloping noticeably. Walls leaning or bulging noticeably; some loss of bearing in beams, distortion of structure. Service pipes disrupted. Typical crack widths are 15 to 25mm, but depends on number of cracks. *Noticeable from outside.*	Significant depression, often accompanied by cracking, in open ground or highway. Obvious to the casual observer. Small open hole may form. Repairs to the highway generally require excavation and reconstruction of the road pavement.
5	Structural damage which requires a major repair job, involving partial or complete rebuilding. Beams loose, bearing walls lean badly and require shoring. Windows broken with distortion. Danger of instability. Typical crack widths are greater than 25mm, but depends on the number of cracks. *Very obvious from outside.*	Rotation or slewing of the ground or significant depression, often accompanied by cracking, in open ground or highway; open crater formed with large void. General disruption of services in highways. Significant repair required.
6	Partial collapse	Collapse of ground or highway, significant open void, services severed or severely disrupted.
7	Total collapse	Large open void or landslip scar.

Figure 13. The BGS building damage notebook sheet proforma, front and back sides.

4 References

Most of the references listed below are held in the Library of the British Geological Survey at Keyworth, Nottingham. Copies of the references may be purchased from the Library subject to the current copyright legislation.

Audell, H.S. 1996. Geotechnical nomenclature and classification systems for crack patterns in buildings. *Environmental and Engineering Geoscience.* Vol 2, No 2.

Bhttacharya, S. and Singh, M.M. 1985. Development of subsidence damage criteria, final report. Engineers International Inc. Westmont for U.S. Department of the Interior, Office of Surface Mining Reclamation and Enforcement. 229pp.

Chiocchio, C., Iovine, G. and Parise, M. 1997. A proposal for surveying and classifying landslide damage to buildings. 553-558 *In* Marinos, P.G., Koukis, G.C., Tsiambaos, G.C. and Stournaras G.C. (eds.) *Engineering Geology and the Environement*. Balkema, Rotterdam.

Cooper, A.H., Farrant, A.R., Adlam, K.A.M. and Walsby, J.C. 2001. The development of a national geographic information system (GIS) for British karst geohazards and risk assessment. 125-130 *In* Beck, B.F. and Herring.J.G. (eds.) *Geotechnical and environmental applications of karst geology and hydrogeology.* Proceedings of the eighth Multidisciplinary Conference on Sinkholes and the Engineering and Environmental Impacts of Karst, April 1-4th Louisville, Kentucky, USA. Balkema Rotterdam.

Freeman, T.J., Littlejohn, G.S. and Driscoll, R.M.C. 1994. *Has your house got cracks: a guide to subsidence and heave of buildings on clay*. Institution of Civil Engineers and Building Research Establishment. 114pp.

Geomorphological Services Ltd. 1991. *Coastal Landslip Potential Assessment: Isle of Wight Undercliffe*, Ventnor. Technical Report for the department of the Environment. Research Contract RECD 7/1/272

Grunthal, G. 1998. *European Macroseismic Scale.* Conseil de l'Europe, Cahiers du Centre Europeén de Geodynamique et du Seismoligie. Vol. 15. 101pp [http://seismohazard.gfz-potsdam.de/projects/ems/ems98.pdf]

Howard Humpreys and Partnersl. 1993. *Subsidence in Norwich.* Report of the study on the causes and mechanisms of land subsidence, Norwich, carried out for the Department of the Environment, (Research Contract PECD7/1/362), London, HMSO. 99pp.

Medvedev, S., Sponheuer, W. AND Karnick, V. 1965. *The MSK Intensity Scale,* Veroff Institute für Geodynamic, Jena, 48, 1-10.

N.C.B. (1975) *Subsidence Engineers' Handbook.* National Coal Board Mining Department. UK, 111 pp.

The Institution of Structural Engineers. 1994. *Subsidence of low rise buildings*. The Institution of Structural Engineers, London . 106pp.

Van Rooy, J.L. 1989. A proposed classification system for dolomitic areas south of Pretoria. *Contributions to engineering geology*, Vol. 1. 57-65.

Von Schonfeldt, H., Wright, F.D. and Unrug, K.F. 1979. Subsidence and its effect on longwall mine design. Presentation at the annual AMC Coal Convention. St Louis, May 20-23. 19p.

Wood, H.O. and Neumann, F. 1931. The modified Mercalli scale of 1931. *Bulletin of the American Seismological Society,,* 21, 277-283.