BRE Digest

*Concise reviews of building technology*

**Digest 251**

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# Assessment of damage in low-rise buildings

## with particular reference to progressive foundation movement

**This Digest discusses the assessment and classification of visible damage resulting from structural distortion. The assessment is based on a description of work considered necessary to repair the building fabric; classification into six categories is recommended, taking into account the nature, location and type of damage.**

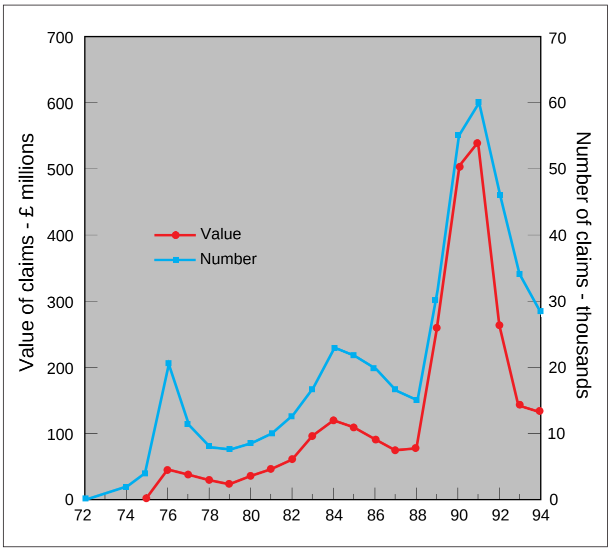
**The most common causes of damage are discussed. It is concluded that for damage of Category 2 or less, cracking may result from a combination of causes which are difficult to identify and the cost and effort involved in carrying out an identification would be disproportionate to the scale of the damage, except for circumstances where the movement is likely to be progressive. It is rare for damage to progress beyond Category 2; when it does ground movement is usually the cause. The various causes of ground movement giving rise to damage are described briefly and emphasis is placed on the identification of conditions where the movement might lead to progressive deterioration.**

**This Digest will assist building professionals, property valuers and insurance advisors both in putting building damage into its true perspective and in determining necessary action, either in the form of seeking expert advice or in recommending simple repairs.**

The severe droughts of 1975/6 and 1989/90 brought to the public's attention the fact that low-rise buildings are susceptible to cracking of the materials from which the buildings are constructed. That widespread publicity and some alarm were generated reflects not so much the severity of the damage as the general ignorance of both causes of damage and the amounts which masonry structures can tolerate. It is important to realise that very few buildings, if any, exist without some form of damage. How much can be tolerated depends on a number of factors: the type of building, the function it is to perform, the location and nature of the damage, the expectations of the user and the cost of repair work in relation to the value of the building. Many of the ways in which cracking can be produced in buildings are discussed in Digests 359 and 361.

One of the many causes of damage is foundation movement resulting especially from the drying shrinkage of clay subsoil. This is not a new phenomenon and has been experienced many times in the past. However, the 1975/76 drought, whilst admittedly being more extensive than previous dry spells,

**Fig 1** Annual value of insurance claims for subsidence and heave damage to housing
*Note the substantial increase following 1989 and 1990 – dry years*

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BRE Advisory Service
Garston, Watford, WD2 7JR
Tel: 01923 664664 Fax: 01923 664098

initiated a spate of damage claims on insurance companies out of all proportion to its severity. Indeed, cases of damage, whilst being geographically more widespread, were no more severe than have been identified by the Building Research Establishment in previous dry spells, such as the dry summers of 1946 and 1947. The growth in claims for subsidence damage from 1971, when insurance against subsidence damage became widely available, is shown in Fig 1 which was produced from data supplied by leading household insurers and the Association of British Insurers.

In a two-year period following the end of the drought in August 1976, BRE examined 90 properties which suffered damage during and soon after the drought. These were cases specifically brought to the attention of BRE, largely by professionals, and probably they represent the worse end of the spectrum of subsidence damage. In addition, case records supplied by NHBC (20) and major household insurers (30) were examined. The 'worst' examples were requested. The overall sample size was, therefore, 140.

Examining the results of this survey it was apparent that one single factor had been responsible for the massive increase in damage claims: when house insurance cover had been enhanced in 1971 by insurance companies to indemnify against damage caused by ground subsidence, no qualifications had been placed on the amount of damage occurring. In consequence, many cases of damage hitherto regarded as of no great importance had become the subject of insurance claims. In addition, houses with cracks which would once have been disregarded were being significantly devalued unless expensive remedial measures were carried out.

It also became apparent that extensions to existing buildings and structural protrusions, such as bay windows and porches, were especially vulnerable to slight cracking where they joined the main structure. As will be discussed later, damage to extensions, usually ascribed to clay shrinkage, may well result from other causes.

The over-sensitivity of the housing market has also affected new construction. Local authority building inspectors are now much more cautious and it is evident that unnecessarily large sums of money are being spent on new foundations for no apparent reason other than in an attempt to prevent small cracks which, when they occur, may be totally unconnected with foundation movement. It is known, for example, that 3 m deep trench foundations have been used in a number of locations and even 5 m deep trench foundations have been reported for clay soils where 1 m deep trench foundations would have been regarded as adequate in the past.

During the course of the investigations it was concluded that inadequate attention was paid to describing building damage and that the essential first step in any assessment should be to ensure that all visible damage is properly recorded and classified in terms of an objective, widely accepted scale. The main purpose of this Digest is to discuss the recording and classification of damage to enable rational decisions to be made on such questions as severity of damage, its cause and appropriate remedial measures.

## REPORTING DAMAGE

The reporting of damage is frequently less than satisfactory for assessing the severity and cause of damage. Statements like 'extensive cracking to interior walls' are often the only description of damage given for a property. Furthermore, the subjective judgement of individuals on the seriousness of damage varies considerably, so that properties with similar levels of damage brought about by similar events may undergo vastly different degrees of remedial work.

A prerequisite for the objective classification of damage in a building is a thorough, well-documented survey. A suggested procedure for carrying out such a survey consists of:

***On a sketch of each damaged wall, draw the position and direction of any cracks***

Distinguish where possible between tensile cracks, compressive cracks (indicated by small flakes of brick squeezed from the surface and by localised crushing) and shear cracks (indicated by relative movement along a crack of points on opposite side of it). Note the direction of any crack taper, crack widths, and the frequency of cracks if they are too numerous to record individually. If both external and internal crack patterns are plotted (as full and broken lines respectively) on the same elevation drawings, the mode of distortion and cause of movement can be better understood. An example of such a plot is shown in Fig 2. Generally, cracks produced by foundation movement are not widely distributed throughout a building, but tend to be concentrated in areas where maximum structural distortion and structural weak points coincide. In these areas, cracks are usually few in number so that recording of crack density is not onerous. Photographs provide a useful record of crack patterns and density; Figs 3 and 4 are typical cases. Any movement on one side of a crack in relation to the other in a direction out of the plane of the wall will also help to identify the mode of distortion (see Digests 343 and 344).

**Fig 2** Crack plotting on building elevation

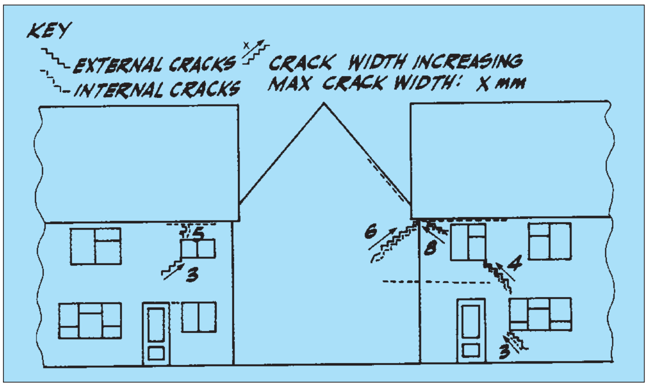


**Fig 3** Category 2 subsidence damage
*studs are used to monitor crack width*

**Fig 4** Category 3 damage
*movements predominantly rotational and horizontal*

***Try to determine the approximate age of the cracks***

This can be done by questioning the occupants on the date of discovery and by examining the fracture surfaces, particularly of external cracks, for signs of age. For instance, recent cracks in brickwork have a clean appearance, whereas older cracks show signs of dirt accumulation.

***Where possible, measure or estimate the magnitude of any distortion and movement of the building***

Examples are tilt and bulge of walls, slope of floors and slip on damp-proof course (Digest 344). The plotting of such values on a drawing of the building can be very helpful; Fig 5 shows a plot of the results of plumbing of walls. A series of level readings on a course of brickwork near ground level can provide an indication of both the direction of vertical movement and the part of the structure where it is concentrated. Figure 6 shows an example of a plot of relative levels around a building. Of course, care is necessary in interpreting such measures as the brick courses may not have been horizontal at the time of construction. Ideally, a series of measurements at different dates should be taken to show if movements are continuing. While this will not usually be practicable for full surveys of level and verticality (Digests 344, 386), it may be possible to obtain a series of measurements with time of the widths of cracks (Digest 343). Many cases of alleged subsidence damage take considerable time to be resolved so that such a series of measurements, over say six months to a year, may well be practicable and of immense value in determining cause. Evidence of building distortion is often hidden in lofts; the ends of roof joists and purlins should be examined to establish the extent of any movement. Movement in roofs can also be detected by observing gaps between tiles.

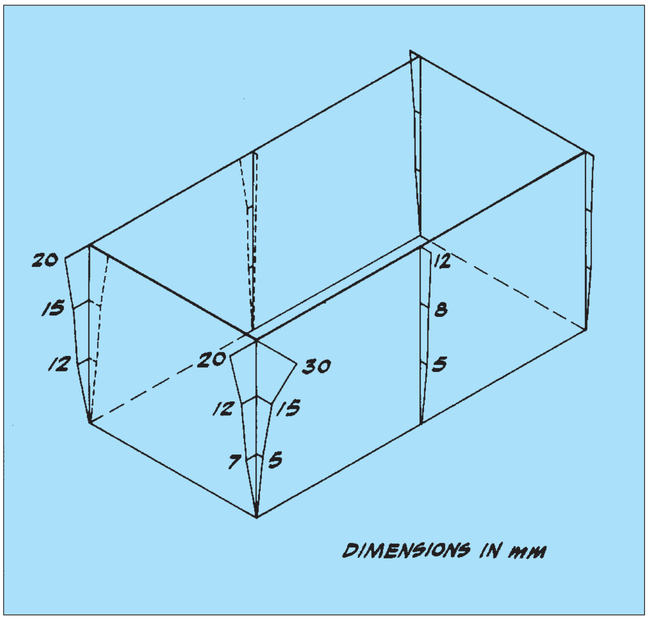



**Fig 5** Verticality plot for a pair of semi-detached houses

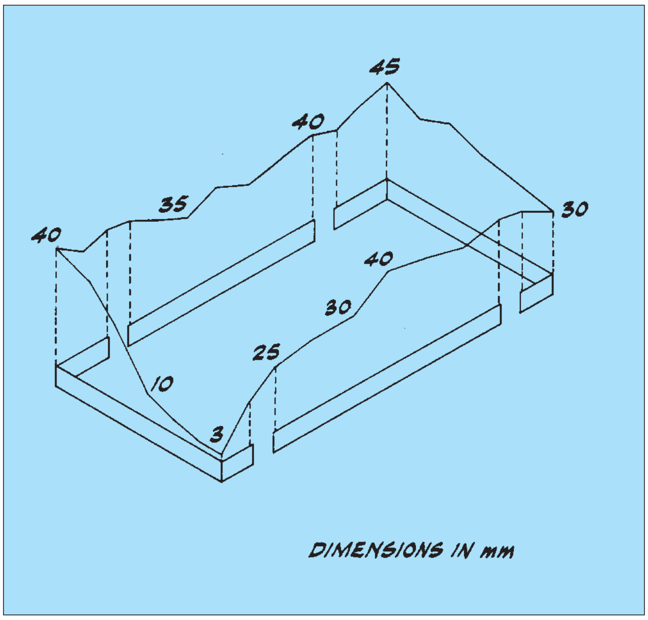



**Fig 6** Level plot for a pair of semi-detached houses

***Describe how the serviceability of the building has been impaired***

For example, doors and windows jamming, window panes cracked, draughts and rainwater penetrating cracks, and service pipes fractured.

***Give a thorough description of the materials of walls and finishes and their condition, especially that of mortar***

Information of this type can often enable the identification of causes other than ground movement, for example shrinkage of concrete products, or differential thermal expansion of dissimilar materials, as well as assisting in the selection of suitable methods of structural repair.

***Record details of the construction***

This can have a very significant effect, on both degree and location of structural cracking. Every effort should be made to establish basic information about the structure, for example whether it has solid or cavity walls and the way in which the floor has been constructed. Whether or not the floor slab has been carried off the inner leaf, for example, or is floating (see Fig 7) can affect significantly the response of the structure to foundation movement, the way in which damage may occur and the form of remedial works.

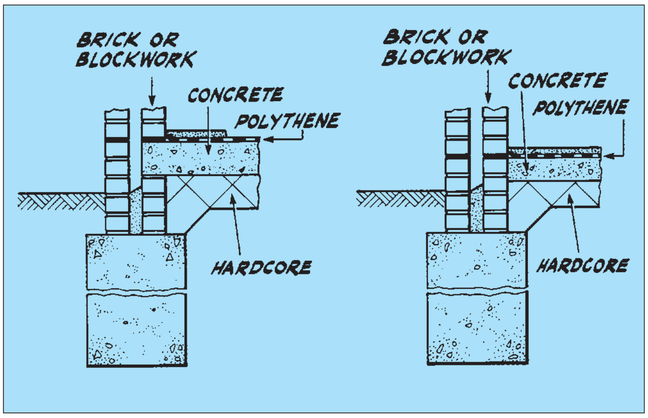



**Fig 7** Alternative forms of floor construction

***Where the cause of damage is believed to be foundation movement, additional factors may need to be considered depending on the scale of the damage sustained***

It may be necessary to carry out a thorough examination of the foundations in the area of most movement and also to determine the nature of the underlying ground (see *Assessing the possibility of severe damage due to progressive ground movement*). In both these cases it may be necessary to call for the services of a suitably qualified civil or structural engineer.

**CLASSIFICATION OF DAMAGE**

Three broad categories of damage should initially be considered: ‘aesthetic’, ‘serviceability’ and ‘stability’. The first comprises damage which affects only the appearance of the property. The second includes cracking and distortion which impair the weathertightness or other function of the wall (eg sound insulation of a party wall may be degraded), fracturing of service pipes and jamming of doors and windows. In the third category are cases where there is an unacceptable risk that some part of the structure will collapse unless preventative action is taken. Very often when damage is described, no distinction is made between these three categories, making it impossible to gauge the severity of the problem.

It is only a short step from the three, general descriptions of damage to the more detailed classification shown in Table 1; this defines six categories of damage, numbered 0 to 5 in increasing severity.

The classification is based on the ease of repair of visible damage to the building fabric and structure and has been derived from a number of previous studies[(1–5)]. In order to classify visible damage it is, therefore, necessary when carrying out the survey to assess what type of work would be required to repair the damage both externally and internally. The following points should be noted:

- The classification applies only to brick or blockwork and is not intended to apply to reinforced concrete elements.
- The classification relates only to visible damage at a given time and not its cause or possible progression which should be considered separately.
- Great care must be taken to ensure that the classification of damage is not based solely on crack width since this factor alone can produce a misleading concept of the true scale of the damage. It is the ease of repair of the damage which is the key factor in determining the overall category of damage for the whole building.
- It must be emphasised that Table 1 relates to visible damage and more stringent criteria may be necessary where damage may lead to corrosion, penetration or leakage of harmful liquids and gases or structural failure.

For most cases, Categories 0, 1 and 2 can be taken to represent ‘aesthetic’ damage, Categories 3 and 4 ‘serviceability’ damage and Category 5 ‘stability’ damage. However, these relationships will not always exist since localised effects, such as the instability of an arch over a doorway, may influence the categorisation. Judgement is always required in ascribing an appropriate category to a given situation.

## CAUSES OF DAMAGE

So far, only the reporting of damage and its classification have been discussed. However, it is the cause of the damage and whether it will be progressive that is of great concern. There are many causes of damage brought about by differential movements. Broadly, they can be divided into those associated with the structure itself, and those associated with the ground beneath the structure.

**Table 1 Classification of visible damage to walls with particular reference to ease of repair of plaster and brickwork or masonry**

*Crack width is one factor in assessing category of damage and should not be used on its own as a direct measure of it.*

| Category of damage | Description of typical damage *Ease of repair in italic type* |
|---|---|
| **0** | Hairline cracks of less than about 0.1 mm which are classed as negligible. *No action required*. |
| **1** | Fine cracks which can *be treated easily using normal decoration*. Damage generally restricted to internal wall finishes; cracks rarely visible in external brickwork. Typical crack widths up to 1 mm. |
| **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 5 mm. |
| **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 15 mm, or several of, say, 3 mm. |
| **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 crack widths are 15 to 25 mm, but also depends on number of cracks. |
| **5** | Structural damage which *requires a major repair job, involving partial or complete rebuilding*. Beams lose bearing, walls lean badly and require shoring. Windows broken with distortion. Danger of instability. Typical crack widths are greater than 25 mm, but depends on number of cracks. |

* *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.*

**Causes associated with the structure include such items as:**

- material shrinkage and creep;
- corrosion or decay;
- differential thermal movements in dissimilar materials;
- poor detail design or workmanship.

It is rare for damage due to such causes to exceed or to deteriorate beyond Category 2 in Table 1, except perhaps very locally in a building.

**Causes associated with the ground include:**

- ground subsidence and heave due to volume changes in clay soils;
- settlement and heave of floor slabs on unsuitable or poorly-compacted in-fill beneath the slab;
- instability of sloping ground;
- movement due to consolidation of poor ground or made-ground;
- mining subsidence;
- movement caused by nearby excavations;
- chemical attack on foundation concrete or erosion of fine soil particles due to the passage of water, for example from a leaking pipe.

Also included is differential settlement induced by unequal foundation pressures arising from such factors as extensions added to existing buildings or concentrations of load, for example under chimneys. Damage from these causes can fall within any of the categories described in Table 1.

Thus Category 2 damage can result from a variety of causes which are frequently very difficult to identify. Indeed, at this level damage may result from a combination of the above factors. If damage exceeds Category 2 it is often much easier to identify the cause (which is frequently associated with ground movement) and hence prescribe a suitable remedy.

Category 2 defines the stage above which repair work requires the services of a builder. For domestic dwellings, which constitute the majority of cases, damage at or below Category 2 does not normally justify remedial work other than the restoration of the appearance of the building. For the cause of damage at this level to be accurately identified it may be necessary to conduct detailed examinations of the structure, its materials, the foundations and the local clear ground conditions. Consequently, unless there are clear indications that damage is progressing to a higher level it may be expensive and inappropriate to carry out extensive work for what amounts to aesthetic damage.

Cases of progressive damage are rare and since they are mainly associated with ground movement a brief discussion of the factors involved follows. It should, however, be emphasised that it is a highly specialised topic usually requiring the advice of an expert structural or civil engineer. The aim of this discussion is to give advice on when to call in such an expert.

## ASSESSING THE POSSIBILITY OF SEVERE DAMAGE DUE TO PROGRESSIVE GROUND MOVEMENT

Two questions frequently confront those examining a damaged property: is the damage due to foundation movement, and will it get progressively worse?

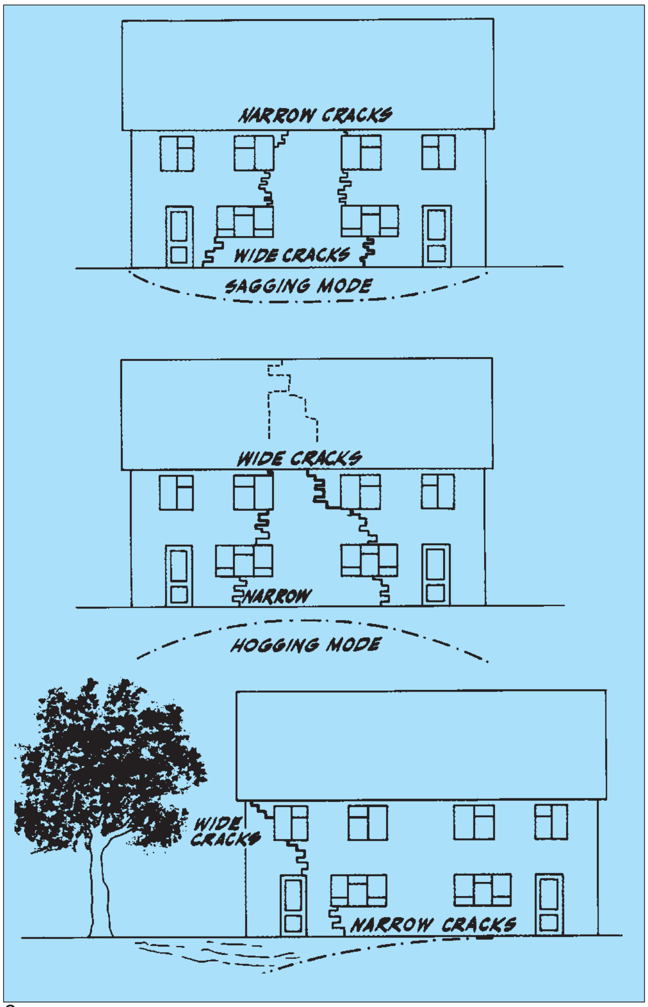
### Damage due to foundation movement

It is essential to carry out a thorough survey, described in *Reporting damage*, from which records of damage and distortion should be seen to be reasonably consistent with foundation movement. The following observations would indicate such movement:

- Cracks usually show externally and internally and may extend through the dpc and down into the foundation, though this is unlikely for Category 2 damage or less.
- Crack tapers should be consistent with differential foundation movement; see, for example, Fig 8.
- Crack patterns should be reasonably consistent with observed or measured distortions (see *Reporting damage* and Fig 8).
- Floors slope, walls tilt, window and door openings distort producing uneven clearance and jamming.

The survey summarised in Figs 2, 5 and 6 points to foundation settlement at the near corner of the building.

**Fig 8** Crack patterns associated with different modes of distortion




### Progressive movement

If the damage is reasonably consistent with foundation movement it is then necessary to assess the likelihood of it becoming progressively worse. The main causes of foundation movement are listed in *Causes of damage*; some comments on the more common ones are:

***Clay soils***

A major factor discussed in detail in *Shrinkage and heave due to clay soils.*

***Floor slab movement*** (See Table 2)

This is a common cause of damage and results from inappropriate or poorly compacted under-floor fill. Damage is generally confined to the slab and the junctions between it and external walls and also to internal partitions carried on the slab. The problem usually manifests itself early in the life of the building although it may not be discovered at the time it occurs; if not serious at this stage it is unlikely to give rise to long-term progressive deterioration.

***Chemical attack***

Attack by sulphates (Digest 363) or acid substances in the natural ground is rarely, if ever, sufficiently destructive to cause significant damage to the shallow foundations of low-rise buildings since these are usually sited above groundwater level. However, attack by aggressive chemical compounds in fill material (Digest 276) has resulted in numerous cases of disintegration and expansion of ground bearing slabs and foundation brickwork, particularly where burnt colliery shale has been used as under-floor filling. How far any damage will progress depends on the depth and nature of the fill material.

***Instability of sloping ground***

Ground movement due to slope instability usually results in cracking of roads, garden walls, services etc as well as the building itself. If progressive movement of sloping ground is thought to be the cause of damage the advice of a suitably qualified civil or structural engineer should be obtained.

***Consolidation of poor ground or made ground***

This problem usually manifests itself within the first ten years of the life of the building, in the form of progressive damage. If it is suspected as the cause of the damage the advice of an expert civil or structural engineer should be obtained. It is helpful to assemble all readily obtainable information about the history of the site such as the geological map and current and old Ordnance Survey maps. Aerial photographs are particularly valuable in revealing previous uses of the site. Local residents can often provide useful historical information about past activities on or near the site. These sources of information are easily obtainable and can be extremely valuable in assessing whether the site has been in-filled or whether soft marshy conditions prevailed earlier (Digests 318 and 348). If the available evidence points to a risk of progressive settlements, it will usually be necessary to carry out a ground exploration with trial pits and/or borings located in the areas of greatest movement.

**Table 2 Classification of visible damage caused by ground floor slab settlement**

*The classification below attempts to quantify the assessment of floor slab settlement damage in a way similar to that for superstructure damage, given in Table 1. It has not yet been used extensively to determine its applicability. It should be noted that the categorisation may be qualified by the possibility of progression to a higher category; this should arise only when examination has revealed the presence of voids or areas of loosely compacted fill (or degradable material) beneath the floor slab such that more settlement can be expected.*

| Category of damage | Description of typical damage | Approximate (a) crack width (b) gap * |
|---|---|---|
| 0 | Hairline cracks between floor and skirtings | (a) NA<br>(b) up to 1 mm |
| 1 | Settlement of the floor slab, either at a corner or along a short wall, or possibly uniformly, such that a gap opens up below skirting boards which can be masked by resetting skirting boards. No cracks in walls. No cracks in floor slab, although there may be negligible cracks in floor screed and finish. Slab reasonably level. | (a) NA<br>(b) up to 6 mm |
| 2 | Larger gaps below skirting boards, some obvious but limited local settlement leading to a slight slope of floor slab; gaps can be masked by resetting skirting boards and some local rescreeding may be necessary. Fine cracks appear in internal partition walls which need some re-decoration; slight distortion in door frames so some 'jamming' may occur, necessitating adjustment of doors. No cracks in floor slab although there may be very slight cracks in floor screed and finish. Slab reasonably level. | (a) up to 1 mm<br>(b) up to 13 mm |
| 3 | Significant gaps below skirting boards with areas of floor, especially at corners or ends, where local settlements may have caused slight cracking of floor slab. Sloping of floor in these areas is clearly visible; (slope approximately 1 in 150). Some disruption to drain, plumbing or heating pipes may occur. Damage to internal walls is more widespread with some crack filling or replastering of partitions necessary. Doors may have to be refitted. Inspection reveals some voids below slab with poor or loosely compacted fill. | (a) up to 5 mm<br>(b) up to 19 mm |
| 4 | Large, localised gaps below skirting boards; possibly some cracks in floor slab with sharp fall to edge of slab; (slope approximately 1 in 500 or more). Inspection reveals voids exceeding 50 mm below slab and/or poor or loose fill likely to settle further. Local breaking-out, part refilling and relaying of floor slab or grouting of fill may be necessary; damage to internal partitions may require replacement of some bricks or blocks or relining of stud partitions. | (a) 5 to 15 mm but may also depend on number of cracks<br>(b) up to 25 mm |
| 5 | Either very large, overall floor settlement with large movement of walls and damage at junctions extending up into 1st floor area, with possible damage to exterior walls, or large differential settlements across floor slab. Voids exceeding 75mm below slab and/or very poor or very loose fill likely to settle further. Risk of instability. Most or all of floor slab requires breaking out and relaying or grouting of fill; internal partitions need replacement. | (a) Usually greater than 15 mm but depends on number of cracks<br>(b) greater than 25 mm |

* *'Gap' refers to space — usually between the skirting and finished floor — caused by settlement after making appropriate allowance for discrepancy in building, shrinkage, normal bedding and the like.*

***Mining subsidence***

In districts where mining subsidence is anticipated, it is advisable to seek the help of experts in mining subsidence.

Lowering the water table by the action of brine pumping can also cause ground subsidence.

***Soil erosion***

In silty, sandy soils a leaking water or drain pipe can, over many years, bring out localised subsidence damage by slowly washing fine particles from the soil. Pressure and acoustic testing can readily identify the source of the problem and repairs of the broken pipe will stop the subsidence.

**Shrinkage and heave due to clay soils**

*(Digests 240, 241 and 242)*

This is the major cause of damage due to foundation movement, but in the majority of cases the damage is only of Category 2 magnitude or less. (Of the 140 cases described earlier, about 70% fell within Category 2 or less). If clay subsoil is suspected of being the cause of damage the following three distinct situations must be recognised:

**1** open ground away from major vegetation;

**2** buildings near existing trees;

**3** buildings on sites newly cleared of trees.

In all these situations the following investigations are recommended:

- *Record the damage;*
- *Establish that it is consistent with foundation movements;*
- *Investigate the subsoil by means of trial pits which must reveal the depth of foundations, the presence of clay and, in the case of (2) and (3) above, the presence of fine roots below the foundations;*
- *Ascertain the history of the site (including previous vegetation), building and dates of observed movement and damage;*
- *Record the position, species and approximate age of all nearby trees and shrubs;*
- *Record the position and condition of nearby drains;*
- *Monitor.*

***Open ground***

For foundations less than about 1 m deep in clay soils, seasonal foundation movements take place which may give rise to slight cracks which open and close seasonally. Though sometimes unsightly, these cracks are easily masked.

### *Buildings near existing trees* (Digest 298)

Where the action of existing trees has been identified as the principal cause of foundation subsidence, care and experience are required in assessing the likelihood of progressive movement and hence in planning remedial action.

The following factors should be noted:

- *Where the trees have reached or are close to maturity*, although seasonal shrinkage and swelling movements can be anticipated, larger movements are likely to occur only in exceptional spells of dry weather. Felling of such trees can lead to worse damage due to swelling of the clay. Tree pruning may offer an acceptable way of reducing the influence of the tree
- *If the trees are still far from mature* there is a possibility that progressive foundation movement will take place giving rise to increasingly severe damage. Specialised advice on remedial action should be obtained and it may be necessary to consider pruning or felling the trees that are positively identified as the cause of the movement. Small alterations in the environmental conditions such as the repair of a leaking drain can lead to further root growth and the possible effects should be considered.

For buildings damaged by shrinkage of clay the likelihood of recurrence of damage (not necessarily progressive) in very dry weather may depend on whether or not structural damage extends down into the foundations. If a foundation is completely fractured, a hinge can develop at the point of fracture which may produce recurrence of structural damage in the future. However, such a foundation fracture is unlikely to occur for damage of Category 2 or less.

### *Building on sites recently cleared of trees* (Digest 298)

When trees and shrubs are removed from a shrinkable clay site, any deep zone of desiccated clay induced by the roots will tend to absorb moisture and the ground will swell. Sometimes the swelling may continue for many years. If damage is consistent with foundation movement, there is a risk of progressive movement if there is evidence of previous large vegetation on the site and trial pits reveal desiccated clay with fine roots beneath the foundation; specialist advice from a structural or civil engineer should be obtained.

Despite the qualifications mentioned above, in the light of long experience at BRE over several droughts and the examination of the 140 cases arising from the 1975/76 drought, it can be said that progressive subsidence damage is most uncommon. Only seven of the cases were regarded as involving progression extending beyond the duration of the drought; of these, three or four involved tree removal which has been clearly identified as a situation where progression can occur. Consequently, any precipitate action by interested parties on a case of subsidence damage due to clay shrinkage, whether this action be in the form of removal of suspect trees or underpinning of the affected area of the structure, would be unwise for levels of damage of no more than Category 2. The only certain way of confirming the progression of damage is to take a series of measurements with time.

**Acknowledgement**

*The Building Research Establishment is grateful to Professor J B Burland, Imperial College of Science and Technology, for his valuable contribution to this Digest.*

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**Other BRE Digests**

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Technical enquiries to:
BRE Advisory Service
Garston, Watford,
WD2 7JR
Telephone 01923 664664
Facsimile 01923 664098