overseas building notes
Information on housing and construction in tropical and sub-tropical countries

No 191 February 1984

GUIDELINES FOR FOUNDATION DESIGN OF LOW-RISE BUILDINGS ON EXPANSIVE CLAY IN NORTHERN JORDAN

by T I Longworth, R Driscoll and I E D Katkhuda

Fifteen year old school in Irbid, Jordan, severely damaged by ground movement. The damage has resulted from shrinkage of expansive clay caused by extraction of moisture by a group of pine trees (off left of photo), planted at the time of construction.

Overseas Division
Building Research Establishment
Department of the Environment

A unique legacy

BRE Trust is a charitable company supporting research and education that advance built environment knowledge, innovation and communication for public benefit.

As the owner of the BRE Group of companies the Trust is not only engaged in funding the very latest research, but is also the custodian of nearly a century of built environment research and innovation. This extraordinary legacy provides a unique history of the development of almost every aspect of buildings and construction in the UK.

Opening the archive

In 2010 BRE Trust set up a project to make a substantial part of this printed archive available online for the public good.

These documents present a fascinating historical record and background to today's industry, but are not intended to provide guidance on current built environment projects. Much of the information they contain has been superseded by 'superseded by more recent research and standards'.

While we hope that you find this archive informative and useful, the BRE Group does not accept any responsibility whatsoever for any loss or damage, including – without limitation – indirect or consequential loss or damage arising from use, or loss of use, of data or profits arising out of, or in connection with, the use of this document.

Today's guidance and services

The documents in this archive provide the foundations for our current built environment information, guidance and services. These are available on the BRE Group's websites:

www.bre.co.uk	The BRE Group corporate website
www.brebookshop.com	The BRE Bookshop with our current range of publications
www.bretrust.co.uk	The BRE Trust website
www.greenbooklive.com	Green Book Live – environmental products and services
www.redbooklive.com	Red Book Live website – approved products and services

bretrust

SUMMARY

Many low-rise buildings on expansive clay in the highland area of northern Jordan have been damaged by ground movement. A four year investigation of the problem has proved that most damage results from vertical ground movements caused by local moisture content changes in the clay. Water infiltration from rainfall and domestic sources causes clay swelling, while moisture loss by evaporation and transpiration causes clay shrinkage. Moisture extraction by trees is the most common cause of damage. This note gives provisional recommendations for safe foundation design, taking account of the findings of the investigation and of present construction practice in Jordan. Types of foundation that isolate the building from the ground movement are considered to be the best design solution. Environmental control measures are suggested to prevent harmful moisture content changes near the foundations.

CONTENTS

OVERSEAS BUILDING NOTES

Overseas Building Notes are prepared by the Overseas Division of the Building Research Establishment in order to provide information and advice on housing and construction in tropical and subtropical regions. They are distributed throughout the developing world to a wide range of organisations with a professional interest in building.

Further copies are available to other organisations and individuals with similar interests and can be obtained by writing to:

Distribution Unit
Building Research Establishment
Garston, Watford, WD2 7JR
United Kingdom

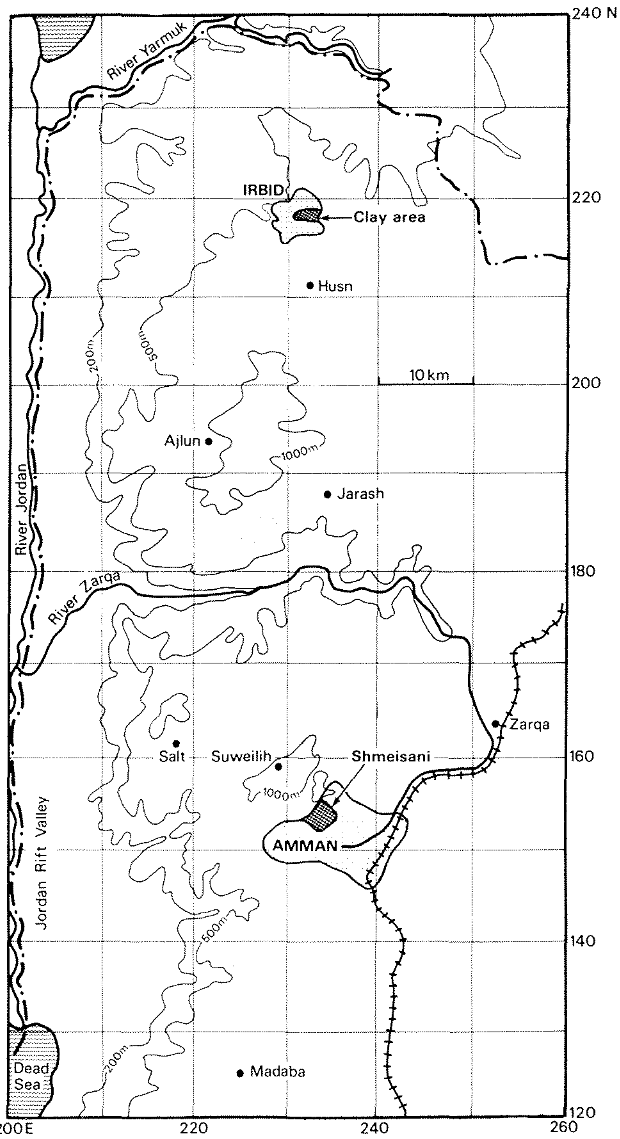

Figure 1 Location of study areas in Amman and Irbid, Jordan

GUIDELINES FOR FOUNDATION DESIGN OF LOW-RISE BUILDINGS ON EXPANSIVE CLAY IN NORTHERN JORDAN

by T I Longworth, R Driscoll and I E D Katkhuda

1 INTRODUCTION

Distortion and cracking of low-rise buildings caused by volume change movements in expansive clays under foundations is a serious worldwide problem, which affects both developed and developing countries. Damage tends to be most severe in areas where the climate is either arid or has pronounced wet and dry seasons. Swelling of the clay is caused by infiltration of water from rainfall or domestic sources, while shrinkage of the clay results from moisture loss by evaporation and transpiration. The scale of damage and consequent financial losses are vast. A study carried out in the USA (Krohn and Slosson, 1980) has shown that the annual loss resulting from damage to homes and commercial buildings is more than 2 billion dollars: expansive soils cause more damage than the combined effects of earthquakes, tornados, floods and landslides. A similar study in Sudan (Charlie, Osman and Edgar, 1982) reports damage to homes and factories exceeding six million dollars a year, a large financial burden for a developing country.

Expansive clays have been the subject of geotechnical research in many countries for nearly three decades, and much has been learnt about the behaviour of buildings on such clays. Widespread damage to buildings still occurs, however, due to the difficulty of designing foundations and buildings which are both economical and appropriate for local ground conditions. It should be emphasised that sites in a given country may behave very differently due to changes in clay composition and thickness, and differences in the local environment which affect the amount of moisture in the ground under buildings. This note presents the conclusions of a study of damage to buildings on expansive clay in northern Jordan, which will add to global understanding of the problem, and will provide an example of the type of research needed for the development of safe building and foundation designs in other countries.

The Building Research Establishment has collaborated with the Building Research Center of the Royal Scientific Society, Jordan, in a four year study of damage to buildings constructed on superficial expansive clays in the highland area of northern Jordan. The research was concentrated in areas of Amman, the capital, and Irbid, a rapidly developing northern town, Figure 1. Traditional practice in these cities has been to build on hills where foundations can be constructed on exposed bedrock. Recent urban expansion has, however, necessitated development on low-lying areas too deeply covered by clay to allow this practice. Instead various types of foundation have been used, often with little understanding of the expansive behaviour of the clays. As a result foundation movements have severely damaged many low-rise buildings including homes, hospitals and schools.

The study was conceived with the aim of identifying the factors contributing to building damage and determining the geotechnical parameters necessary to design safe, serviceable and cost-effective foundations. A programme of research was carried out comprising four interrelated tasks:

(i) An engineering geology study to map the occurrence of the superficial clays and study their geological characteristics.

(ii) Regional surveys of damaged buildings to identify the main causes of damage by correlating the geographical occurrence and severity of damage with the geology, the type of construction and environmental factors such as the presence of trees.

(iii) A laboratory study of the expansive clays to determine soil composition and geotechnical properties affecting foundation behaviour.

(iv) Measurement, over a two year period, of the vertical movement of the ground and buildings at selected sites, to investigate the effects of climate and environmental changes on ground movement, and the relationship between building movement and damage.

This note summarises the principal conclusions of the investigation and gives provisional recommendations for safe foundation design, which take account of the research findings and of present construction practice in Jordan. Descriptions of the research methods used and the detailed findings have been presented elsewhere (see references). Whilst the detailed findings and authors' recommendations are directly applicable only to northern Jordan, the principles discussed in this note will be of widespread relevance to countries which have expansive soils and a climate with wet and dry seasons.

1 Building Research Establishment, Watford, Herts
2 Building Research Center, Royal Scientific Society, Amman, Jordan

2 FINDINGS OF THE RESEARCH STUDY

2.1 Geology and geotechnical properties

The expansive clays encountered in the areas of building damage are brown superficial clays which have weathered over millions of years from the Cretaceous limestone and marl bedrock of the northern Jordanian highlands, and accumulated in hollows and on flat-lying areas. Figure 2 shows a typical clay deposit in eastern Irbid. The ground surface is level but the contours of clay thickness (isopachytes) indicate that the clay fills a broad depression in the bedrock, with a maximum depth of about 10 m.

Analysis of the clay has shown that nearly half of it consists of the very expansive clay mineral smectite-illite. Typical geotechnical index properties are: Liquid Limit 70%, Plasticity Index 40% and Clay Fraction 60%. Comparison with internationally used classifications indicates that the clay is of 'high' to 'very high' potential expansiveness. In the Mediterranean climate of the northern highlands of Jordan the clay may thus be expected to shrink substantially in the long hot, dry summers (average maximum temperature 32°C, rainfall nil); swelling back by similar amounts in the cool wet winters (average maximum temperature 15°C, rainfall 350–700 mm).

2.2 Ground movements

Field observations on clay sites in Amman and Irbid have shown that the seasonal moisture content changes and consequent shrinkage and swelling movements decrease with the depth below ground surface: The magnitude of the changes and depth of ground affected depends, however, on the nearness to environmental features, such as trees, which affect local moisture content. Open ground covered with grass or garden plants is subject to seasonally cyclic movements decreasing in magnitude with depth from about 50 mm at the surface to negligible below about 2.5 m. In contrast, near to trees substantial ground movements can extend down to at least 5 m, the movements again being seasonally cyclic, but additionally ground shrinkage tends to increase progressively with time as tree growth produces a permanent moisture deficit in the ground. Ground near to sources of water infiltration, such as leaking pipes, can show an opposite trend of long term movement, with progressive swelling being superimposed on the seasonal movement.

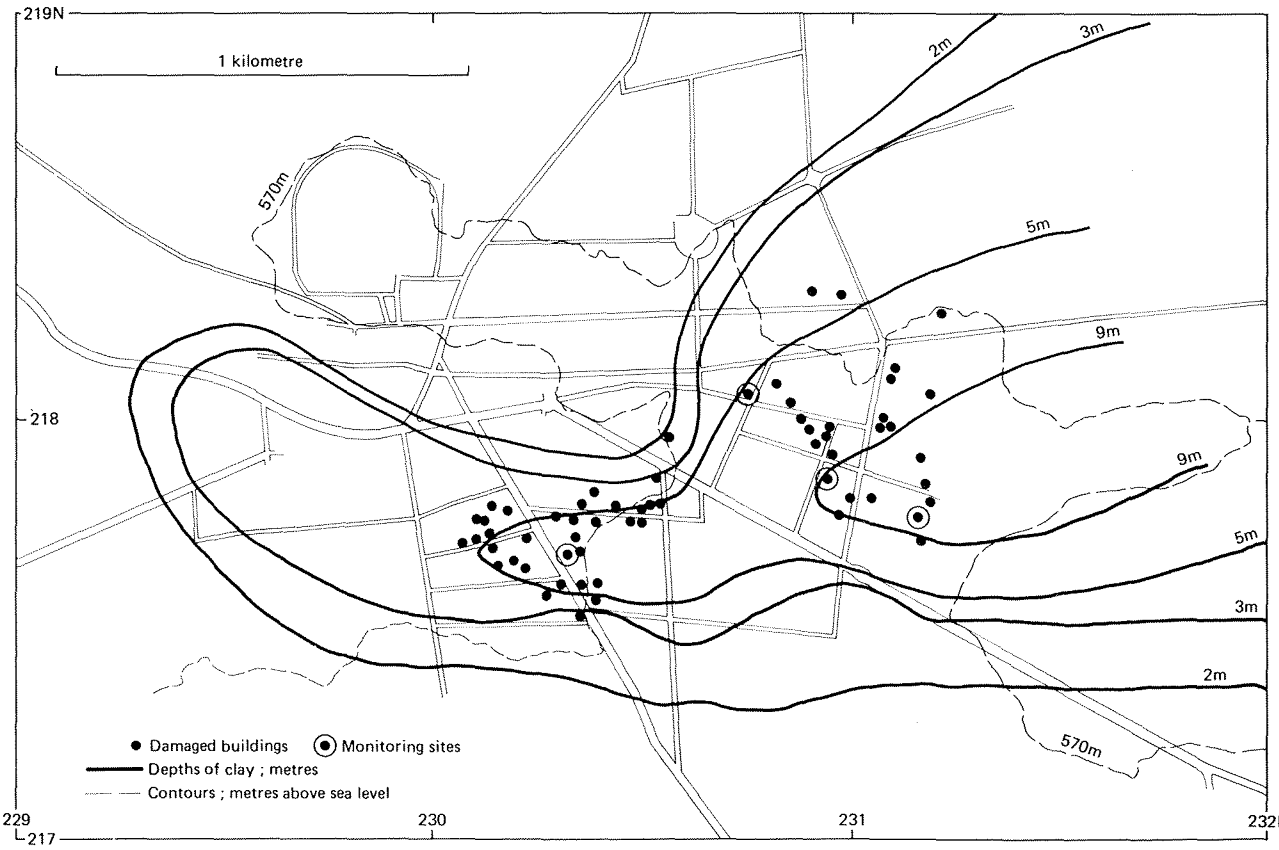

Figure 2 Map of eastern Irbid showing the thickness of expansive clay and the location of damaged buildings

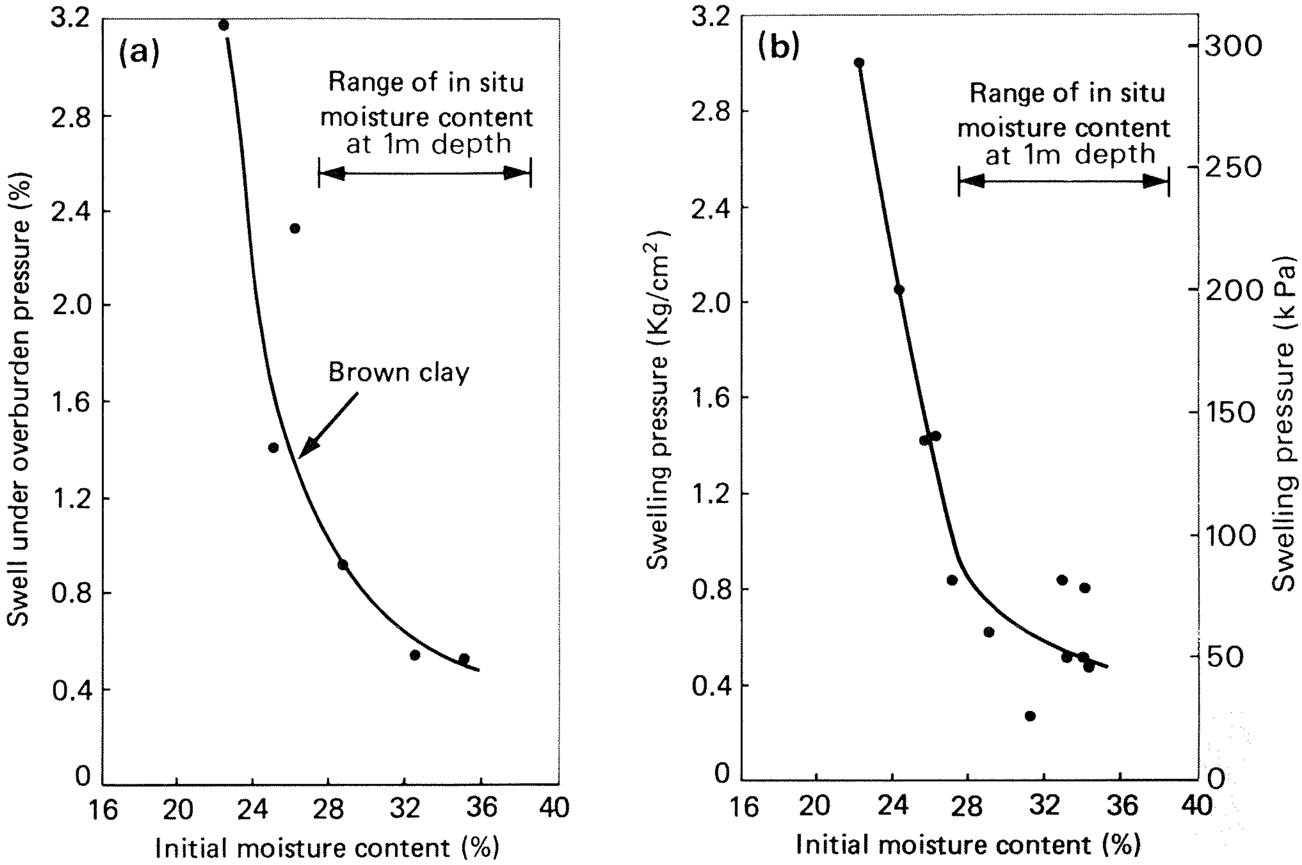

Figure 3 Swelling tests on Irbid clay with different initial moisture contents

Figure 3(a) shows the amount that samples of clay from Irbid swell when wetted at different initial moisture contents. Also shown is the typical annual range of in situ moisture contents observed in open ground at 1 m depth. Clay which is initially at the lowest moisture content (end-of-summer value) swells vertically about 1%, ie equivalent to 10 mm per metre thickness of clay. For the same samples, Figure 3(b) shows the upward 'swelling pressure' which is generated if swelling movement is initially restrained. It is evident that a swelling pressure of approximately 100 kPa can be developed in clay initially at typical end-of-summer moisture content. The swelling pressure can be considerably higher in clay desiccated by exceptionally long dry summers, especially in ground near to trees.

The magnitude of the swelling pressure is important in relation to the pressure that the foundation of a building exerts on underlying clay. If foundation pressure is less than swelling pressure the building will be subject to upward (heave) movements since the clay will swell when wetted. This explains why low-rise buildings are more likely to be damaged by movement of expansive clays than tall, heavy buildings; generally they have shallow foundations with low bearing pressures (typically 50 kPa for present Jordanian low-rise buildings). Obviously, all buildings whatever their bearing pressure, will also be affected by any shrinkage in clay under their foundations.

2.3 Building damage

More than one hundred buildings damaged by ground movement have been examined in the study. The location of damaged buildings in relation to the clay distribution (eg eastern Irbid, Figure 2) indicates that damage only occurs where the clay is at least 2 m deep, and that most damage occurs where clay depth exceeds 4 m.

The damage most commonly found was cracking of internal and external walls. Most crack damage was assessed as 'slight' to 'moderate', Category 2 to 3 on the BRE damage classification (BRE, 1981). About 10% of buildings had 'severe' or 'very severe' damage (categories 4 and 5). The most common crack pattern found was one arising from relative downward movement of the corners of buildings, the cracks starting at ground level near the centre of walls and rising diagonally to the top of a corner. The cracks generally tend to zig-zag, picking out weaknesses in the structure, particularly mortar joints and window and door openings.

Careful observation with time of selected damaged buildings has proved that most damage has resulted from differences in the vertical ground movements which have occurred from place-to-place under the foundations. The principal causes of damage have been correspondingly identified as those environmental factors which cause large local ground movements; excessive infiltration of water from domestic sources, and moisture extraction by tree roots being the worst culprits. Damage from trees is likely when they are nearer to the building than the tree height, though the severity of damage depends on the number and type of trees, clay thickness and foundation depth. Figure 4 shows a house with typical corner-down cracking caused by growth of an 8 m high pine tree approximately 4 m away. The damage occurred many years after construction of the building as the tree reached mature height.

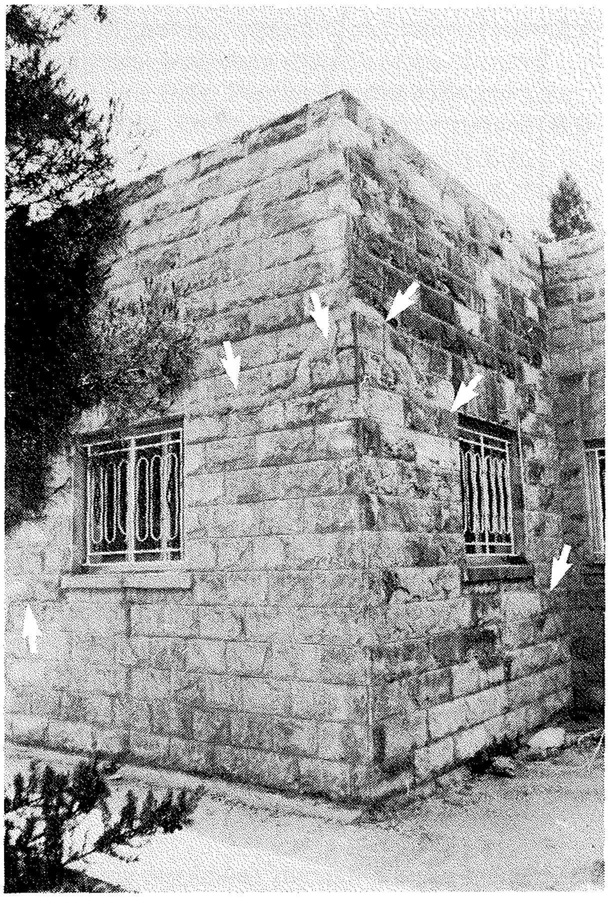

Figure 4 Irbid building with crack (arrowed) which has been caused by corner settlement near to a large pine tree

Three types of foundation have been found to be commonly associated with building damage, viz:

(a) Strip footings of reinforced concrete which support the building walls directly at depths ranging from 1 to 3 m.

(b) Pier footings and ground beams, the piers being 1 to 2 m in section and 2–5 m deep, while the ground beams sit directly on clay at shallow depth.

(c) Pad footings with columns and ground beams, the pads being of reinforced concrete 1–2 m square and up to 4 m deep, while the ground beams are seated directly on clay near ground level.

These three types of movement-susceptible foundations have an important design deficiency: all have parts of the foundation (either footings or ground beams) seated at relatively shallow depths on clay affected by ground movement. A contrasting lack of damage to buildings with full basements, which penetrate through the zone of ground movement, is particularly noteworthy.

Apart from cracking of walls the most common damage seen in the study was the distortion of floors. In nearly all cases the floors appeared to have subsided relative to the walls, Figure 5. One possible cause for this subsidence is compaction settlement of clay fill under the floors. When clay is in a dry condition in summer it is not possible to compact it fully. Subsequent absorption of ground moisture then causes it to settle over a period of several years. The problem can be minimised by non-cohesive backfill, or prevented by using suspended floors.

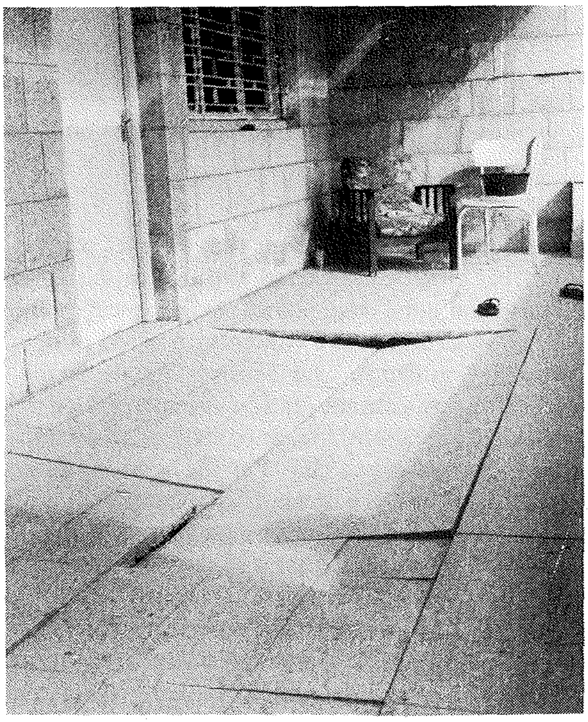

Figure 5 Subsidence of the floor of a house in Amman, probably due to dry compaction of clay fill

3 PRINCIPLES OF DESIGN TO PREVENT DAMAGE

Damage to low-rise buildings can be avoided either by installing foundations which penetrate through the zone of ground movement, or by constructing foundations and superstructures which are tolerant of ground movement. However, in some situations, for example where there is likely to be deep seated ground movement, designs which completely eliminate damage can be prohibitively expensive in relation to the value of the building, and a compromise approach may be necessary which limits damage to minor cracking. In such cases the foundation and building should be designed to be safe against shallow seasonal ground movements, and environmental control measures introduced to minimise the long-term deep-seated changes of moisture content and resulting ground movement.

Two types of design which are tolerant of ground movement may be appropriate for ground and climatic conditions in northern Jordan. The first approach is to use a very stiff raft foundation and rigid superstructure, which moves as a unit, minimising distortion and cracking when subject to differential ground movement. Such a foundation can be installed at shallow depth, but for it to be cost-effective it needs to be carefully designed, taking into account the likely magnitude and pattern of both seasonal and long-term ground movements. These ground movements cannot be reliably predicted from the soil properties, as at present we have insufficient knowledge about changes of moisture with time under rafts in Jordan. For example, it may be that moisture increases with time under the centre of the raft due to moisture diffusion from the edges in winter and prevention of evaporation in summer. This would tend to produce a doming of the raft which must be considered in the design. Until further data relating to raft behaviour under Jordanian climatic and soil conditions becomes available this type of foundation cannot be recommended.

The other approach to movement-tolerant design is to ensure sufficient flexibility of the foundation and superstructure to accommodate the ground movements without damage. This requires the provision of carefully designed movement joints in the structure. Practical procedures for this have been discussed elsewhere by Jennings and Evans (1962). Difficulties may be encountered in technical details such as weatherproofing and compliance with seismic codes. Also the design may not satisfy aesthetic requirements, bearing in mind that differential vertical movements of the order of 100 mm may occur in some buildings, often producing a very noticeable tilting. This type of design may be more applicable to small low-cost buildings.

The most cost-effective way of preventing building movement and damage is to provide foundations deep enough to penetrate through the zone affected by clay movement to stable ground below. Away from trees, and provided there is no excessive water infiltration near the building, foundation depth should be about 3 m. If large trees are present or are likely to grow in the future, foundations must be substantially deeper, at least 5 m. It is essential that all parts of the foundation (including ground beams) which lie in the zone of shrinking and swelling be isolated from the ground movement. Appropriate design details to ensure this are discussed below.

4 RECOMMENDED TYPES OF FOUNDATION DESIGN

Four types of foundation design are available which satisfy the criterion of isolating the building from the ground movement zone:

(a) A **basement** approximately 3 m deep over the full area of the building. This option is already used very successfully in Jordan. It is attractive in that it provides additional accommodation, whilst also giving the necessary foundation depth. There are however disadvantages; basements require a large volume of excavation and need special attention to avoid water leakage and dampness. They are also expensive to construct, so this option is usually not suitable for low-cost housing.

(b) **Pile-and-beam-foundation.** This type of design, shown in Figure 6, has not been used previously in Jordan but has proved very successful on expansive clays in other parts of the World, for example, in India (Mohan, 1973), Israel (Zeitlen and Komornik, 1980), South Africa (Jennings and Evans, 1962) and the USA (Chen, 1975).

The piles are small diameter bored piles usually drilled by a mechanical auger. They are installed to a depth well below the zone of clay movement by inserting a reinforcing cage and concreting to the ground surface. The drilling and installation process can be quite rapid and it is possible to install 20 piles or more in a day. The reinforced concrete 'ground' beams which span between pile heads must be kept well clear of the ground so that ground swelling pressure is not transferred to the beams. Possible ways of doing this are to cast the ground beams on a void former (a box made of material which disintegrates with time), or on compressible material, such as expanded polystyrene. Alternatively precast suspended ground beams can be used. Floors usually consist of precast units which span between the ground beams with a void below.

In this way the building is virtually isolated from the moving ground except for the upper portions of the piles which, being reinforced, resist internal tensile stresses. Such tensile stresses may develop if upward shaft friction produced by swelling clay generates an internal force which exceeds the compressive force due to external pile loading. Piles are thus at most risk of tensile failure in the period between pile installation and the construction of the building, particularly so if the piles are

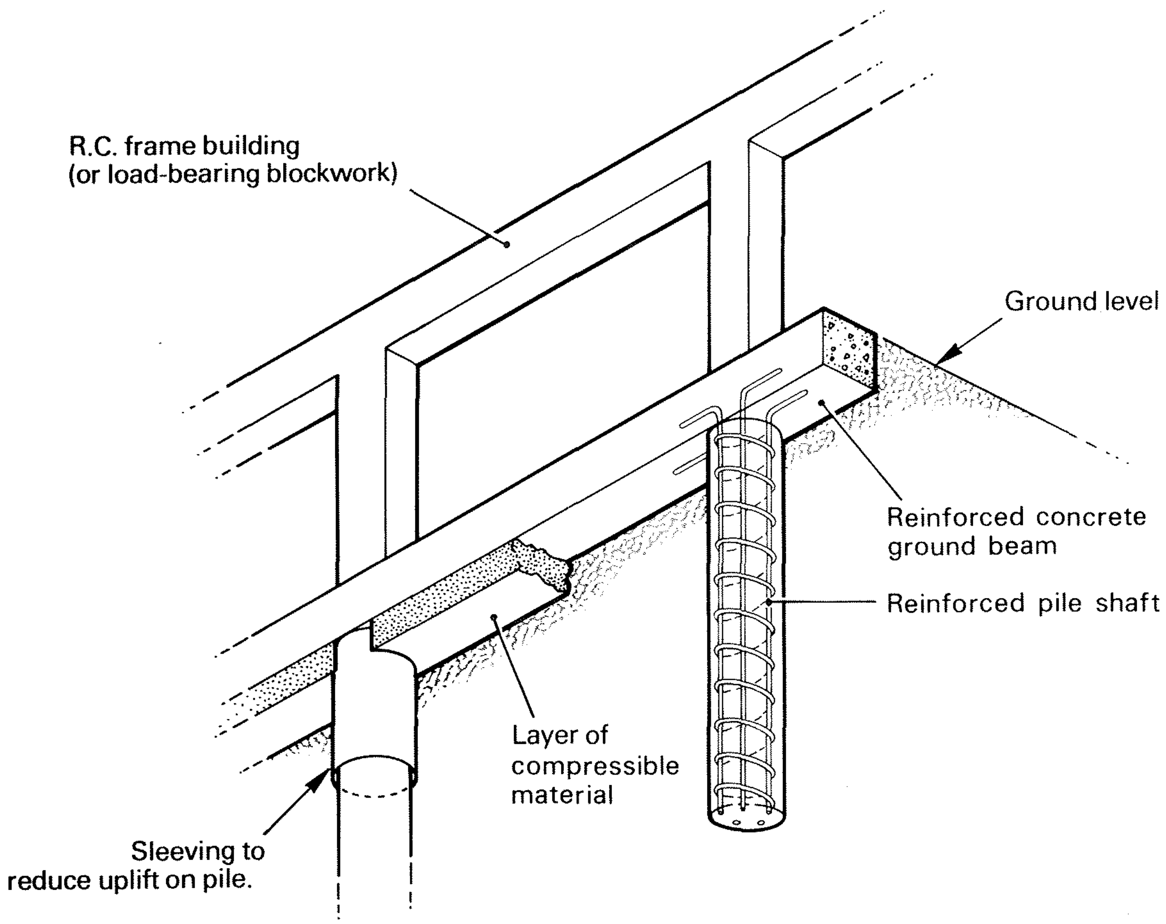

Figure 6 Main design features of pile-and-beam foundation for expansive clays

installed at the end of summer when the clay is desiccated. Since accurate calculation of upward shaft friction is difficult, there will often be uncertainty as to whether or not the piles will experience tension. Empirical design methods do, however, exist (eg Zeitlen and Komornik, 1980), but these only apply to the local conditions. It may, therefore, be expedient to minimise the influence of swelling clay on the pile shaft by sleeving the upper part of the shaft over a length equal to the depth of the zone of swelling clay. One possible technique is to use a double tube of roofing felt, with the annular space filled with bitumen (Kassiff et al., 1965). Sleeving has an additional advantage of preventing enlarged tops to the piles.

An alternative to sleeving is to make a conservative estimate of tensile force in the pile, add sufficient reinforcement for this over the full pile length, and then ensure anchorage of the pile by extending it a sufficient length into the stable clay stratum. A useful criterion for minimum pile depth to avoid uplift has been given by David and Komornik (1980) as 1.5 times that depth at which swelling pressure is equal to overburden pressure. On typical treeless clay sites in Jordan this would indicate a minimum pile depth of about 5 m.

The end-bearing and (below active zone) shaft-friction components of the pile bearing capacity should be calculated by standard pile design methods, eg Burland and Cooke (1974), based on the shear strength of the clay as measured in appropriate triaxial tests. A review of piling experience in other countries with soils similar to Jordan indicates that straight-sided piles of 0.3–0.6 m diameter are likely to be the most suitable for Jordanian expansive soils. Under-reamed piles are not recommended due to the need for more specialised boring equipment, and the difficulty of reliably forming adequately shaped bulbs in ground which, more often than not, contains large cobbles of chert.

(c) **Pad-and-beam foundation.** This consists of pad footings on stable ground below the movement zone (ie a minimum of 3 m deep) from which rise reinforced concrete columns which support a ground beam. The design is similar to foundations widely used in Jordan at present, but with the very essential incorporation, as with pile foundations, of suspended ground beams to accommodate ground heave. A typical design is shown in Figure 7. Disadvantages compared with pile foundations are the greater volume of excavation and the need for shuttering. However it does not require an expensive drilling rig.

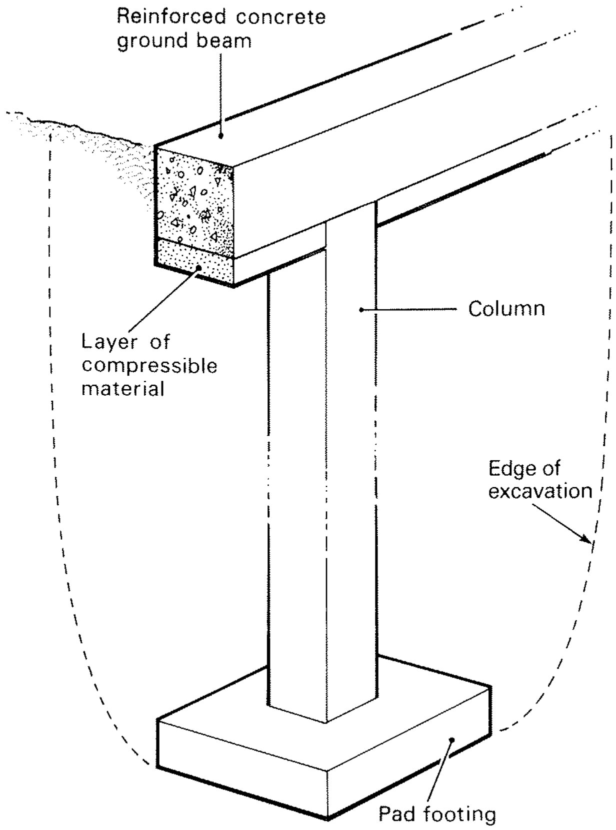

Figure 7 Pad-and-beam foundation design for expansive clay

(d) **Pier-and-beam foundation.** This is similar to (c) above but with mass concrete piers supporting the suspended ground beams instead of pads and columns. For deep foundations this has the disadvantage of requiring relatively large amounts of concrete as the piers must be designed with sufficient bearing area.

The authors consider that pile-and-beam foundations will prove in time to be the most cost-effective type. However, in the short term, installation costs may be higher than for traditional types due to contractor inexperience and the need for new high-cost drilling plant. Some development work on trial foundations will also be needed for choice of optimum pile diameter and depth, design of sleeving, and the pile spacing (the closer the piles the less the ground-beam section).

An important precaution when installing any of the above types of 'isolated' foundations is to prevent large moisture content changes at the base of the excavation. Concrete should be poured as soon as possible after excavation to avoid the exposed base becoming desiccated in hot dry weather, or saturated by heavy rainfall. Both conditions may cause subsequent building damage due to movements below foundation level.

5 RECOMMENDED ENVIRONMENTAL CONTROL MEASURES

Environmental factors which influence local ground moisture content and movement fall into two groups, those which put water into the ground, and those which take water out of the ground. Sources of water can include: leakage from water supply pipes, water tanks, sewer pipes, cesspits, septic tanks, swimming pools and ornamental ponds; run-off from roofs and paved areas; and garden irrigation. The second group usually consists only of trees, but could also include furnaces which heat the ground and dry it out. Some changes in ground moisture around buildings following construction are unavoidable. These changes (and resultant ground movements) can, however, be minimised by careful control of environmental factors; the aim being to eliminate moisture changes at foundation depth. Figure 8 shows diagrammatically the principal control measures.

The most important requirement is to keep trees well away from buildings with relatively shallow foundations. The study has indicated that buildings with foundations 3 m deep can be damaged by trees when they are situated within a distance equivalent to the tree height; and buildings with foundations up to 5 m deep can be damaged by trees nearer than half their height.

Prevention of excessive moisture infiltration requires the inclusion in building design of some simple but important construction features:

(1) Ensure that all water supply and sewer pipes are watertight and have flexible joints to accommodate ground movement, particularly at the interface of the building and the ground.

(2) Ensure that all water tanks, septic tanks and pools are reinforced to minimise cracking and have flexible water-proofing.

(3) Provide a watertight drainage system which collects the rainwater falling onto roofs and paved areas and conducts it well away from the foundations.

(4) Provide an outward sloping pavement around the building to minimise seasonal moisture changes near to the wall foundations. The pavement serves to move the zone of maximum differential movement away from the building, so reducing the distortion and damage of the building. Recommended width is about 2 m and outward slope 1:15. The pavement should be made completely waterproof by laying it on thick polythene or PVC sheeting. A watertight sliding joint should be installed where the pavement meets the building.

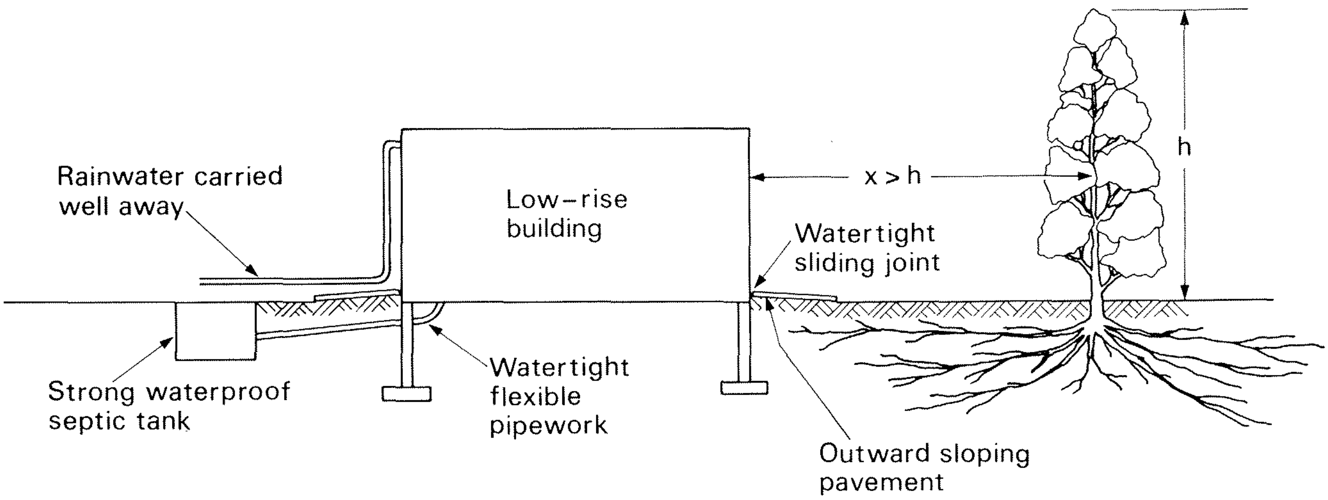

Figure 8 Environmental control measures to minimise building damage

Some practical design details for these construction features are given by Jennings and Evans (1962), and Holtz and Hart (1978).

Besides including environmental control measures at the time of construction, it is important to educate building owners and occupants about possible damage from expansive clays, and the need to avoid excessive garden watering and planting of trees close to foundations. This could be done by producing a booklet explaining the problem in simple, non-technical language. An example of such a publication is that issued to homeowners in Colorado, USA (Holtz and Hart, 1978).

6 CONCLUSION

A four year study of damage to low-rise buildings on superficial expansive clay in northern Jordan has provided sufficient understanding of the problem to enable provisional guidelines to be drawn up for safe foundation design. This note gives recommendations based on the study findings, taking account of present local construction practice. The preferred way of avoiding damage is to isolate the structure from the upper moving ground layer, basing the foundation on stable ground below. Improved types of pad-and-beam and pier-and-beam foundations are suggested; the installation of these should be within the present capabilities of small builders, as well as major construction firms. Pile-and-beam foundations are recommended as a technique new to Jordan which could prove cost-effective in the longer term. Site trials of the suggested design options will be necessary before design details can be optimised. The note also emphasises the importance of environmental control to minimise moisture change around the foundations; the responsibility for this resting jointly with the construction engineer or builder and the building occupants.

The above recommendations are strictly applicable only to buildings on superficial clay in the northern highlands of Jordan. The principles discussed, however, are of general relevance to all expansive clay areas. Notably, the study has highlighted the need to design buildings and foundations which cater for the effects of local environment (especially trees) on ground moisture, as this has proved the main cause of damage to buildings. In this respect the Jordanian study has confirmed recent studies elsewhere in the world, for example, South Africa (Williams and Pidgeon, 1983) and Australia (Richards, Peter and Emerson, 1983).

7 ACKNOWLEDGEMENTS

The research study on which these guidelines for safe foundation design are based was carried out jointly by the Geotechnics Division of the Building Research Establishment, and the Laboratory Department of the Building Research Center, Amman. The authors are grateful for general support given by their colleagues in the BRE Overseas Division and in the Royal Scientific Society. Particular thanks are due to Mr A Salem of the Building Research Center, who carried out much of the site and laboratory work and Dr R Sharif, Director of Building Research Center, who gave guidance throughout the project. The BRE contribution to the research was funded by the UK Overseas Development Administration as part of technical aid to Jordan.

8 REFERENCES

Building Research Establishment. Assessment of damage in low-rise houses. *BRE Digest* 251. London, HMSO, 1981.

Burland J B and Cooke R W. The design of bored piles in stiff clays. *Ground Engineering,* 1974, 7 (4) 28–35.

Charlie W A, Osman M A and Edgar T V. Expansive soils in Sudan. *Building and Road Research Institute, University of Khartoum Report.* Khartoum, 1982.

Chen F H. *Foundations on expansive soils. Developments in geotechnical engineering 12.* Amsterdam, Elsevier, 1975.

David D and Komornik A. Stable embedment depth of piles in swelling clay. *Proceedings of the 4th International Conference on Expansive Soils, Denver, Colorado, 1980.* Volume 2, pp 798–814.

* **Driscoll R, Katkhuda I E D, Salem A and Longworth T I.** Geotechnical properties of expansive clay soils in northern Jordan. *Proceedings of the 5th International Conference on Expansive Soils, Adelaide, 1984.* (To be published)

Holtz W G and Hart S S. *Home construction on shrinking and swelling soils.* Denver, USA, Colorado Geological Survey, 1978.

Jennings J E and Evans C A. Practical procedures for building in expansive soil areas. *South African Builder,* 1962, 40 (10) 15–23.

Kassiff G, Komornik A, Wiseman G and Zeitlen J G. Studies and design criteria for structures on expansive clays. *First International Research and Engineering Conference on Expansive Clay Soils, College Station, Texas, 1965.*

Krohn J P and Slosson J E. Assessment of expansive soils in the United States. *Proceedings of the 4th International Conference on Expansive Soils, Denver, Colorado, 1980.* Volume 1, pp 596–608.

* **Longworth T I, Salem A and Driscoll R.** Case studies of movement and damage to buildings on expansive clays in northern Jordan. *Proceedings of the 5th International Conference on Expansive Soils, Adelaide, 1984.* (To be published)

* **Longworth T I, Salem A and Sunna B.** Correlation of building damage on expansive clay in Jordan with geology, local environment and type of construction. *Proceedings of the 5th International Conference on Expansive Soils, Adelaide, 1984.* (To be published)

Mohan D. Foundation practice in expansive soils of India. *Proceedings of the 3rd International Conference on Expansive Soils, Haifa, 1973,* pp 319–324.

Richards B G, Peter P and Emerson W W. The effects of vegetation on the swelling and shrinking of soils in Australia. Symposium on the influence of vegetation on the swelling and shrinkage of clays. *Geotechnique,* 1983, 33 (2) 127–140.

Williams A A B and Pidgeon J T. Evapotranspiration and heaving clays in South Africa. Symposium on the influence of vegetation on the swelling and shrinkage of clays. *Geotechnique,* 1983, 33 (2) 141–150.

Zeitlen J G and Komornik A. A foundation code for expansive soil conditions. *Proceedings of the 4th International Conference on Expansive Soils, Denver, Colorado, 1980,* Volume 1, pp 609–616.

---

*Papers which present the detailed research findings of the collaborative BRE/BRC study. Available from BRE as Reprint R1/84.

OVERSEAS BUILDING NOTES—Titles available

132	June 1970	Admixtures in concrete
139	August 1971	Problems of concrete production in arid climates
143	April 1972	Building in earthquake areas
145	August 1972	Durability of materials for tropical building
146	October 1972	Timber in tropical building
148	February 1973	The durability of metals in buildings
150	June 1973	The manufacture and use of concrete blocks for walls (J D McIntosh)
153	December 1973	Properties and production of concrete (J D McIntosh)
154	February 1974	Calcium silicate bricks (G E Bessey)
160	February 1975	Low cost housing in urban and peri-urban areas
161	April 1975	Production and use of lime in the developing countries (G E Bessey)
162	June 1975	Board linings to walls
163	November 1978 (rev)	Building research centres and similar organisations throughout the world
164	October 1975	The thermal performance of concrete roofs and reed shading panels under arid summer conditions (Adil Mustafa Ahmad)
165	December 1975	Buildings and the environment (Miles Danby)
169	August 1976	Developments in paints and surface coatings
170	October 1976	Termites and tropical building
171	December 1976	Protection of steelwork in building
173	April 1977	Bricks and mortar
174	June 1977	Sewage treatment in hot countries (Duncan Mara)
176	October 1977	Building materials in the Arabian Gulf (T R Allison)
177	December 1977	Avoiding faults and failures in building (G E Bessey)
178	February 1978	Village water supplies (A M Cairncross)
180	June 1978	Bitumen coverings for flat roofs (W Kinniburgh)
181	August 1978	The management of resources on construction sites (Roger A Burgess)
182	October 1978	Roofs in hot dry climates (Y A Mukhtar)
183	November 1979	Preservation of timber for tropical building (C H Tack)
184	February 1980	Stabilised soil blocks for building (M G Lunt)
185	April 1980	Current activities of the Overseas Division, BRE
186	June 1980	Fire protection and building regulations (R E H Read and H L Malhotra)
187	August 1980	The design of septic tanks and aqua-privies (John Pickford)
188	April 1981	Buildings and tropical windstorms (Keith J Eaton)
189	May 1982	Sanitation for developing communities (R F Carroll)
190	July 1982	Earthquake risk to buildings in the Middle East
191	February 1984	Guidelines for foundation design of low-rise buildings on expansive clay in Northern Jordan (T I Longworth, R Driscoll and I E D Katkhuda)

Printed in the UK for HMSO
Dd8839178 2/85 10170 (198)