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V. S. Hope
University of Surrey, Guildford, U.K.

C. R. I. Clayton
University of Surrey, Guildford, U.K.

M. C. Matthews
University of Surrey, Guildford, U.K.

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AN INVESTIGATION INTO THE CAUSES OF BUILDING CRACKS ON THE REAR SCARP OF A MAJOR LANDSLIP

V.S. Hope
Department of Civil Engineering
University of Surrey, Guildford, U.K.

C.R.I. Clayton, M.C. Matthews
Department of Civil Engineering
University of Surrey, Guildford, U.K.

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ABSTRACT

The paper concerns a building constructed on the rear scarp of a major landslip in the London Clay. Since its construction, the structure has shown significant cracking which has worsened with time. The paper describes how, using a systematic process of observation and interpretation, the principal cause of cracking was eventually identified. This case history is of value to engineers as a cautionary tale in which the most obvious answer is not necessarily the correct one.

KEYWORDS

construction, foundations, landslips, monitoring, masonry cracking, thermal effects.

INTRODUCTION

Most new buildings show evidence of cracking in the period following construction. This cracking is mainly associated with drying shrinkage in the newly placed materials and the resulting damage is usually cosmetic (BRE, 1981) only. In some circumstances, damage increases with time. It is essential that the cause of such damage is accurately identified and that this is done before any remedial measures are undertaken. Aside from its inefficiency, inappropriate remediation can cause additional structural damage (Clayton and Hope, 1997). Correct identification of the origin of damage also has significance for the contractual and financial liabilities associated with remediation. Fortunately, there are well-established techniques for investigating structural failures. In the context of a busy commercial design practice, these techniques may be considered rather time-consuming and expensive. However, expert witnesses will usually have the time and resources to implement a thorough investigation: it may be prudent therefore to invest, sufficiently early, the effort necessary to preclude their later involvement.

This paper examines a case in which, based on a cursory or perhaps premature assessment of the situation, a wholly mistaken explanation of the origins of the structural failure may be obtained. The case study concerns a brickwork building in which cracks were observed to be increasing in quantity and magnitude after the initial effects of drying shrinkage would normally be expected to have curtailed. The building was constructed on the rear scarp of a series of landslips. Awareness of the difficulties of the site dominated foundation design, with heavy or high-rise structures being founded on piles reinforced to resist lateral ground movement. The building of interest was constructed on strip footings. The paper describes how, using established monitoring and investigation methods, it was recognised that the observed structural damage was not geotechnical in origin and how the principal causes of damage were eventually identified.

THE SITE

The site is a natural inland weathered slope in South East England, on the London Clay. This is an Eocene formation underlain, at depth, by the Woolwich and Reading Beds and the Chalk. The site investigation for the construction indicated a near-surface zone of soft yellow brown silty clay overlying 10-12 metres of stiff brown fissured silty clay, underlain by very stiff grey fissured silty clay to at least 20 metres below ground level. Since the Pleistocene period of glaciation, the brown London Clay at the hillside site has failed in a series of slips (Fig. 1) extending at most about 10 m below ground level, 500 m laterally and approximately 160 m from scarp to toe. The complex is formed from several coalescing landslips of different ages and sizes. The most recent slips have apparently occurred quite recently, and are believed to be less than a hundred years old. The overall slope of the hillside is approximately 9°, and ranges between 8° and 10°.

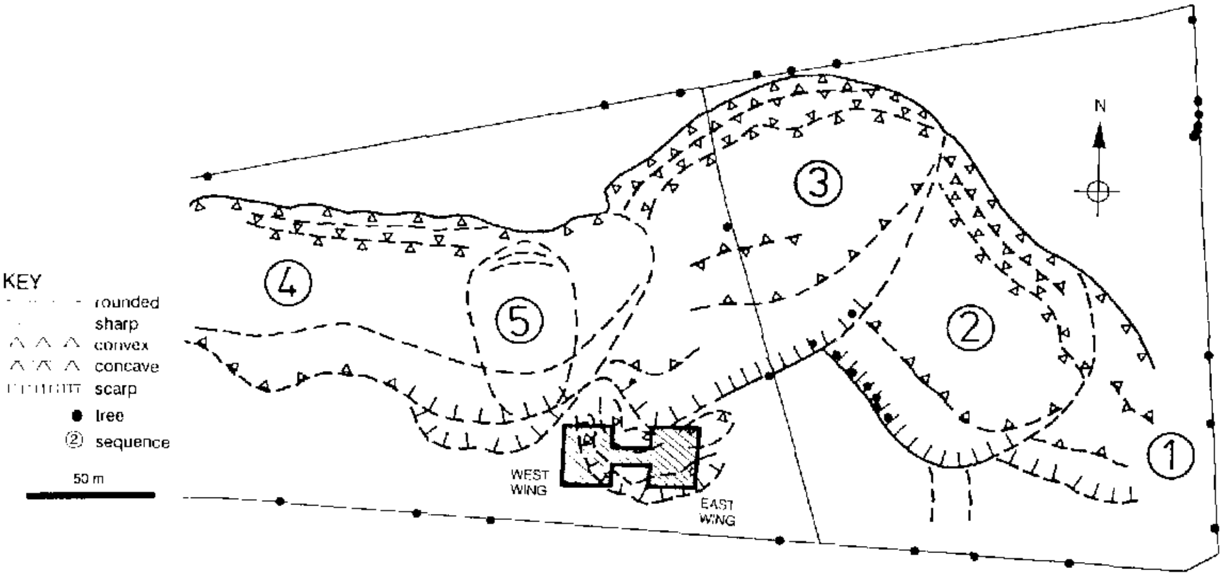

Fig. 1 Landslip complex, showing location of structure on rear scarp

The London Clay displays high plasticity, and is categorised has having medium to high shrinkage potential (BRE, 1980). The soil is thus prone to shrinkage arising from a deficit of moisture in the ground or, conversely, swelling due to excess moisture. The groundwater regime at the site has been deliberately altered from its natural state through pre-construction drainage measures intended to stabilise the slope (Simons *et al.*, 1987). Gravel-filled counterfort trench drains, 0.8 m wide, 5 m deep and at 6-7 m centres, were installed across the site. They reduced pore water pressures by 2-3 metres. The trench drains do not include filters and so their performance may deteriorate with time as they silt up. Soil moisture levels can also be significantly affected by the growth or removal of trees (Driscoll, 1981). Aerial photographs of the undeveloped site show no trees prior to construction. The grounds of the new building were landscaped with plantings of shrubs, which were not sufficiently large to present a problem.

MODE OF CONSTRUCTION

The building comprises two wings, the East and the West (refer to Fig. 1), each with a plan area of about 200 m^2. These three-storey blocks are connected at first-floor level by a steel frame link bridge. The blocks are constructed of load-bearing brickwork. The foundations comprise footings 1 m wide and 1 m deep. This depth is maintained on the hillside by stepping the foundation. The floors and internal beams are cast-*in situ* reinforced concrete, and the roof is constructed of steel I-beams and timber frames. The brickwork consists of two leaves, with a cavity between them. The outer leaf comprises fired-clay bricks. The inner leaf is of calcium silicate (sand-lime) brick. Across the wall cavity, the leaves are linked by twisted galvanised steel brick ties. Lintels above doorways and windows span both leaves of brick. The reinforced concrete floors and the steel roof members are built into the outer walls. Where the internal brickwork is seated on the concrete, it appears that no slip membranes are incorporated. No expansion or contraction joints are included in the building. In essence, the building can be characterised as being highly constrained against relative movement between its component elements. In particular, the load-bearing cavity walls, which are made of different types of brick, are highly restrained by the structure.

THE INVESTIGATIONS

Soon after completion of the construction of the building, cracks were observed in the internal walls. These were reported to be worse than would normally be anticipated in a new building undergoing drying shrinkage and settlement relative to itself or on its newly-loaded foundations. The cracking persisted and worsened with time, with the later cracks being mainly in the external leaf. Some cracks passed through bricks, rather than tracing through the mortar only. The internal cracks were not aligned with the exterior cracking. The majority of the cracks were narrow, although some had widths of up to 10 mm. Many cracks started at a feature, such as a lintel or an architectural opening in the brickwork. Some cracks were near damp-course level. The scale of cracking was not sufficient to present a hazard to the structural safety of the building but it was unattractive and in certain locations, particularly under eaves, the cracks permitted ingress of water. That the landslip was active was an obvious conclusion and fear. It was essential to determine whether the building would continue to deteriorate. This necessitated identifying the cause of the damage.

Three crack surveys were conducted during the first and second years after construction. The third of these reported

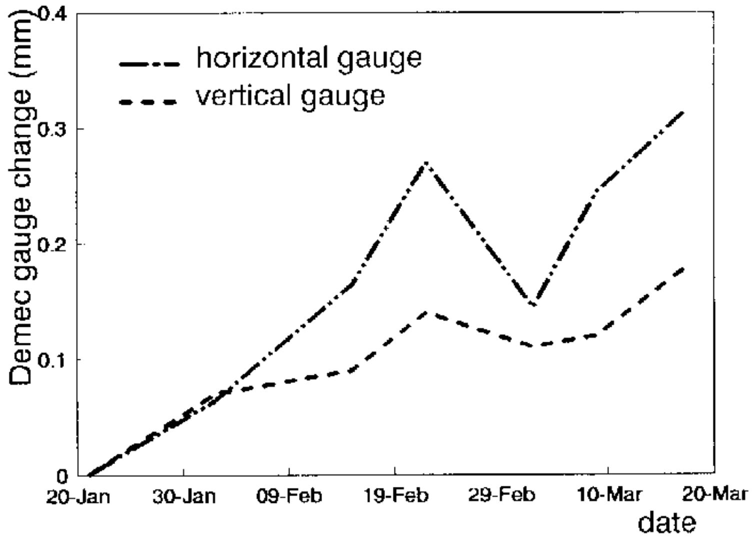

Fig. 2 Change in width of a crack, between January and March, from Demec measurements

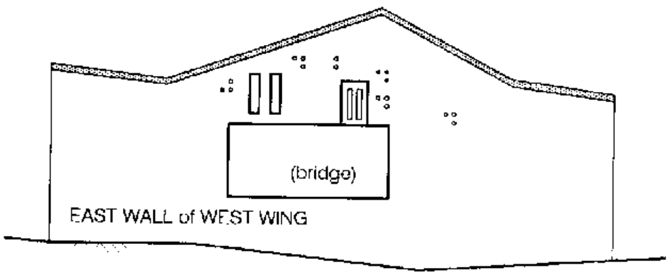

Fig. 3 Demec stud pairs on the East Wall (West Wing). Data given in Figs. 2 and 4 are for studs marked ●

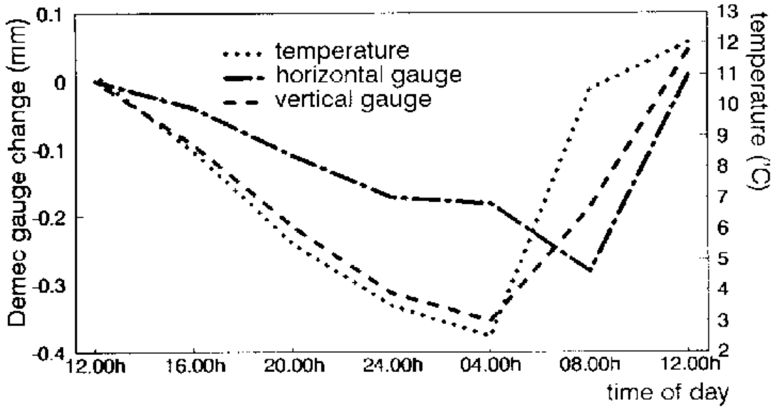

Fig. 4 Change in width of crack over 24 hour period

that the crack damage had not worsened since the first two surveys. A fourth survey, in the fourth year after construction, reported significant cracking in the internal walls. Two further surveys were carried out in the seventh and eighth years, respectively, after construction. These showed significant and, in the interval between the surveys, increasing levels of damage. As in the earlier surveys, visual mappings of the cracks were made but these were augmented by detailed measurements of diurnal changes and seasonal movements over periods of several months. Specifically, the investigations included crack mapping surveys; monitoring of the temporal variation of crack widths (using demountable mechanical "Demec" gauges); monitoring of piezometer levels; temperature measurements; precise levelling, particularly above foundation level; and distortion surveys. The latter is a mapping of the true three-dimensional shape of the building. Any shape irregularities due to construction faults will in general be random, whereas distortions due to post-construction movements will produce a consistent pattern of deformation. These more detailed investigations provided data which disclosed a pattern of behaviour in the structure from which identification of the causal problem could be formulated.

The short-term and long-term movements derived from Demec gauges were revealing. In the late winter period from January to March, no significant foundation movements were detected by the precise levelling (which was carried out with a precision of better than 0.1 mm). However, during this time cracks in the building opened by, on average, 0.2 mm (that is, 100 divisions on a Demec gauge). For example, Fig. 2 presents data obtained from gauges located above the bridge (Fig. 3). In the absence of any other data, it would be difficult to decide whether this constitutes a progressive increase or a seasonal change from winter to spring. This ambiguity was resolved using data from the intensive monitoring carried out over a 24-hour period. The opening and closing of the cracks as they warmed and cooled through the day and night was evident (Figs. 3 and 4). This behaviour was repeated at all the East Wall measurement points (Fig. 5). Temperature effects were also observed through precise levelling of the roof parapets above the inter-connecting bridge on the west side: in summer the parapet lifted off the lower brickwork, as a result of arching action.

DISCUSSION

A significant conclusion from the fifth and sixth investigations was that the origins of the damage sustained by the building had changed since its construction. Initially, the observed cracking would have been due to drying shrinkage. Later, these effects lessened, and the subsequent cracking was a result of the construction details incorporated in the building. The combined use of fired-clay bricks and sand-lime bricks was identified as a key contributory factor. These materials have differing initial drying shrinkage and thermal expansion properties. When they are used together, movements should be permitted *via* butterfly ties and joints above the damp course. Also, beams, lintels and slabs should be isolated from the sand-lime bricks. The final investigations concluded that

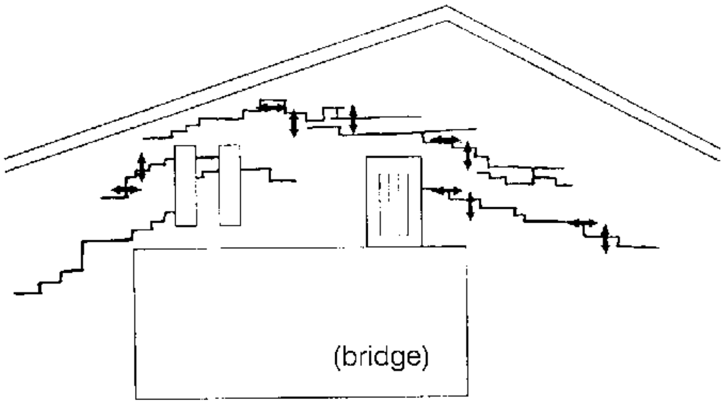

Fig. 5 Pattern of behaviour on East Wall (West Wing). Arrow indicates that crack widens with increasing temperature.

the progressive damage to the outer leaf arose largely from diurnal and seasonal thermal expansion and contraction acting in combination with the highly restraining nature of the structure. These cracks increased with time due to crack creep, which is associated with particles of débris falling into open cracks and preventing their closure upon cooling.

Visual inspection of cracking in the structure was, on its own, an inadequate diagnostic tool in this case. Detailed measurements, using established but nonetheless exacting and time-consuming surveying methods, were also required in order to determine the cause of damage to the building. Intensive measurements made over relatively short periods (here, 24 hours) as well as extended, less intensive monitoring were needed. Given that the origin of the damage sustained by the building may have altered since its construction, the timing of a monitoring survey may be significant. It is possible that the thermal mechanisms detected in the eight-year old building may not have been readily apparent during the initial surveys, when drying shrinkage of the new building was at its peak.

CONCLUSIONS

The principal causes of crack damage in this case were drying shrinkage and, later, thermal cycling and crack creep associated with the structural design. This determination is based on a knowledge of the history of the damage, the details of the site geology and its geotechnical characteristics, and the results of surveys of the damage augmented by detailed measurements taken over a prolonged period in order to include seasonal changes. The mechanism of damage appears to have changed with time. Any remediation based on foundation repairs would have been both expensive and useless. Despite the rather alarming cause of damage that was originally postulated, no remedial measures beyond those needed to maintain the weathertightness and appearance of the building have been necessary.

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