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Diagnosis of Structural Damage and Movement Due to More Than One Cause

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Diagnosis of Structural Damage and Movement Due to More Than One Cause

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SYNOPSIS: A structural and ground investigation was carried out on a domestic property at Leigh, Lancashire, England. The settlement of the property was measured and showed a complex pattern of movement which was separated into: (i) an overall tilt towards the east; (ii) an outward tilt of the northern and southern ends; and (iii) severe tilting and cracking at the northern end. Following detailed investigation separate causes were assigned to each of these movements as: (i) preferential longwall mining to the east of the site; (ii) eccentric loading at the northern and southern ends; and (iii) moisture removal from the stiff clay beneath the northern end by the roots of a nearby tree. Details of the settlement of the property, soil conditions and mining situation are presented together with appraisal and analysis of the separated movements.

INTRODUCTION

The property, Nos. 38 and 40, was constructed in 1945/46. It comprises a traditional 2-storey loadbearing brickwork semi-detached building with a solid ground floor. No known serious damage was suffered until 1976 when because of severe cracking of the brickwork and distortion of the upper floors No. 38 had to be evacuated. No. 40 did not suffer any serious damage and was still occupied.

FOUNDATION AND GROUND CONDITIONS

Pits excavated around the outside and inside No. 38 showed the building to be supported on a simple concrete slab type foundation, about 0.1 - 0.15m thick with a thickened portion, 0.2m thick and 2.6m wide along the gable end. This thickened portion was probably provided because of the large amount of brickwork both downstairs and upstairs, see Figure 1, and presumably also exists along the gable end of No. 40. The underside of the slab was at about 0.4 - 0.5m below ground level.

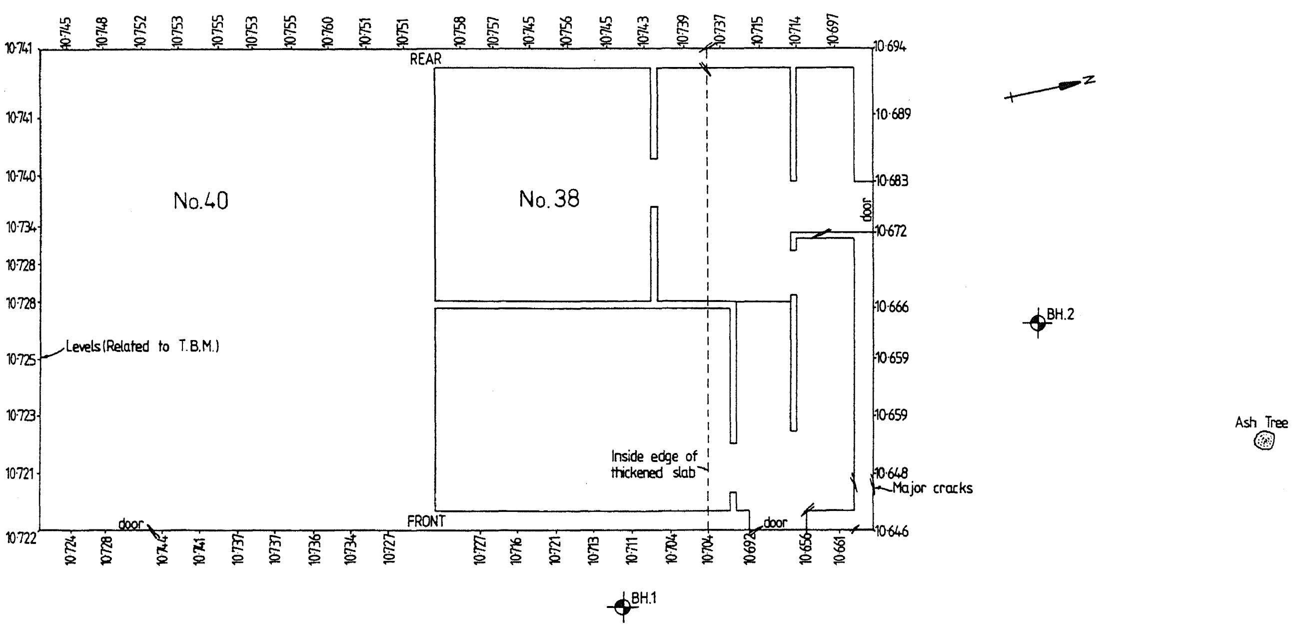

FIGURE 1 : Site Layout

The ground conditions proved below foundation level comprised three distinct layers of glacial clay, see Table 1 for their properties. Beneath these was a thick layer (8m) of very dense sand, gravel and cobbles which overlay the Bunter Sandstone bedrock. The water table existed within the sand and gravel at about 4m below ground level.

TABLE 1 : Soil Properties

Layer	Description	Thickness m	Liquid Limit %	Plastic Limit %	Mean Moisture Content %		Estimated change in Thickness mm
					BH.1	BH.2	
1	Silty clay with gleyed fissures	1.8	61-72 66	22-24 23	22.1	21.1	30
2	Laminated Clay	0.7	50-63 57	21-23 22	28.5	24.1	50
3	Sandy clay with gravel inclusions	2.0	29-38 33	14-17 15	13.0	12.8	8

OBSERVED DAMAGE

No. 40 - some relatively minor cracking existed both externally and internally over the front doorway and the staircase had a detectable tilt. The remainder of this dwelling had suffered no damage.

No. 38 - significant cracking had occurred in the brickwork, mainly within a strip about 2.5 - 3m away from the gable end with the largest movements at the front of this property.

SETTLEMENTS

By levelling along a brickwork course the differential shape of the property could be ascertained. From an inspection of surrounding houses it appears reasonable to assume this property was built horizontally and the measurements obtained reflect differential settlements. Obviously total settlement measurements were not available but these would be estimated to be small, apart, of course, from the mining subsidence. The measurements are given on Figure 1 and the profile along the front and rear are plotted on Figure 2. From these profiles it was considered that there were three quite distinct types of movement, namely

(i) an overall tilt of about 20mm across the building towards the east, about 1 in 400,

(ii) a local tilt or rotation parallel to the gable end of No. 40 (southern end) of about 15 - 20mm over the 2.6m wide thickened raft portion (and presumably also at the northern end), about 1 in 150, and

(iii) a differential settlement in a northerly direction across No. 38 of about 60mm at the rear and about 90mm at the front and from an examination of the structure, ground conditions and surroundings these movements could reasonably be assigned to three different causes, namely :

(i) preferential coal mining beneath

(ii) eccentric loading of the thickened raft portion along the ends of the building

(iii) removal of moisture from the clay beneath by the roots of a nearby ash tree.

MINING SITUATION

Coal extraction has been carried out beneath this area from the nineteenth century but since 1945 when the property was built most of the coal mining within the support area of the site took place by longwall working between 1953 and 1965 so a considerable amount of vertical subsidence would have occurred but movements would have virtually ceased by 1976. However, the most significant factor affecting these workings is the presence of a major geological fault, the Pennington Fault, which runs in a NNW-SSE direction, outcropping about 250m west of the site. This fault plane dips steeply at about 1 : 3 (horizontal : vertical) in an easterly direction with a fairly large throw on the eastern side of the fault. The records show that some workings were taken up to the fault but several were terminated east of the site, see Figure 3.

From the above it would be reasonable to expect that the property would retain an easterly tilt after mining ceased, and this was assigned to be the cause of the tilt observed. However, it should not be forgotten that the small differential level measured may not be a tilt but simply the out of level laying of the brickwork originally.

ECCENTRIC LOADING

It is estimated that the load from the gable wall is about 40% of the total load on the 2.6m wide thickened portion of the slab and since it lies at the edge (with little or no projection of the slab outside the brickwork) a significant moment is applied.

The rotation of a rigid strip subjected to moment loading can be calculated from equation 1, given by Muskhelishvili (after Poulos and Davis, 1974) :

$$\text{Rotation } \emptyset = \frac{16M\,(1 - \nu'^2)}{\pi\, E'\, B^3} \qquad (1)$$

M = moment applied

ν' = poisson's ratio

E' = soil modulus

B = width of strip

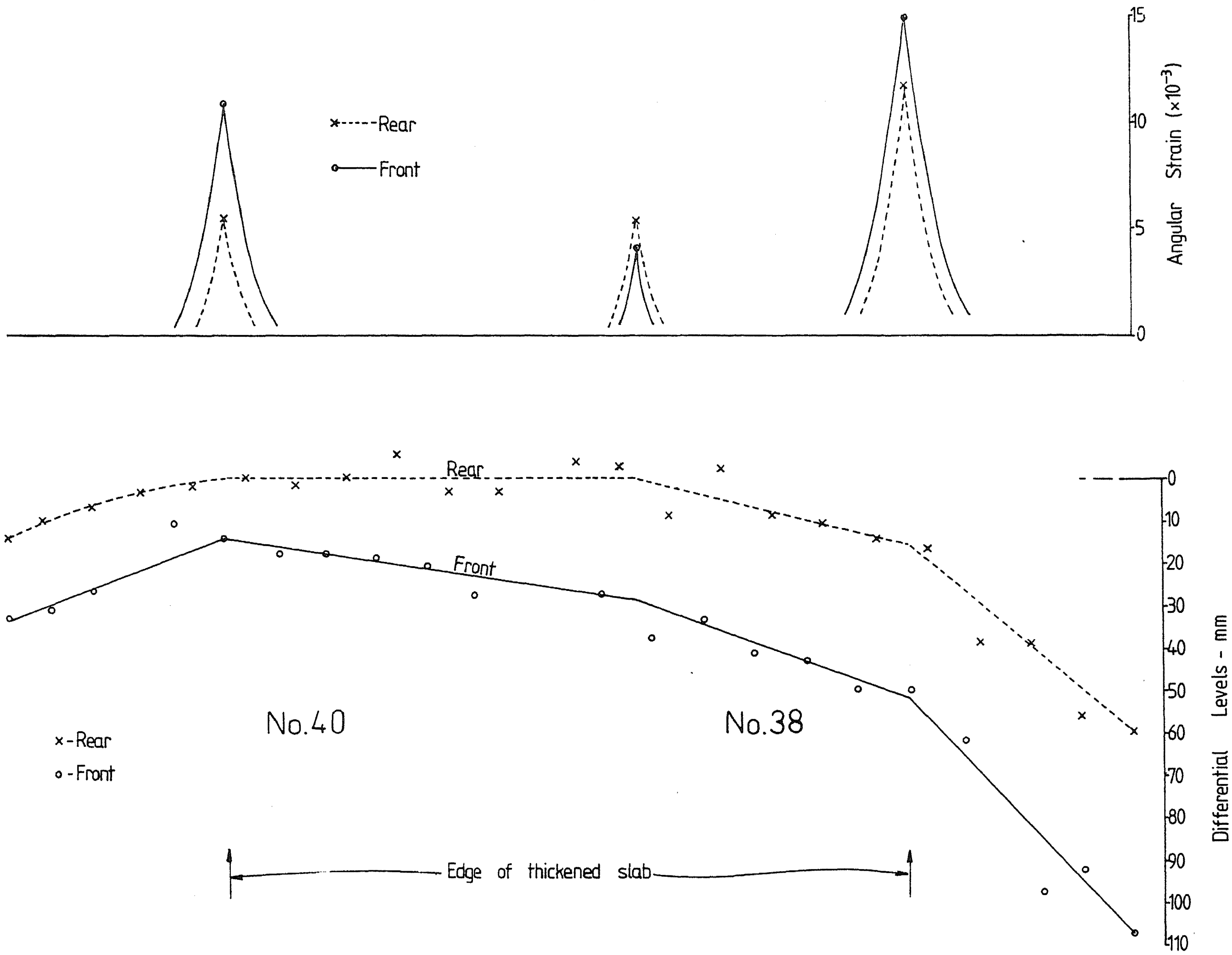

FIGURE 2 Differential Shape and Angular Strain

Assuming 'elastic' conditions to pertain and using drained parameters, ' and E', the total rotation can be calculated. The soil modulus has been obtained from the results of oedometer tests using equation 2 (from Burland, Broms and de Mello, 1978).

$$E' = \frac{0.9}{M_v} \quad (2)$$

M_v = coefficient of volume compressibility, m^2/MN

With an average value for soil layers 1 and 2 of $0.25 m^2/MN$ a rotation of about 0.005 is obtained which compares reasonably well with the measured rotation of 0.006. Eccentric loading is, therefore, considered to be the cause of the rotation at the gable end of No. 40 and consequently must be part of the rotation at No. 38.

It is feasible that part of this rotation could be due to seasonal moisture variation in the underlying clay, particularly as the slab foundation is very shallow. However, there was no evidence along the front and rear of the property to support this view.

MOISTURE REMOVAL BY TREE

A single fairly mature tree of the Ash family existed about 6m to the north of the front corner of the gable end of No. 38. Pits excavated at the gable end proved thick fresh roots (up to 15mm diameter) and numerous fine roots within the silty clay underneath the foundation. Open fissures in the clay were also observed. Tree roots or open fissures were not observed in pits excavated at the front and rear of the property. Thus the lateral extent of the tree root system was limited to the gable end and no further.

Evidence of the removal of moisture from the clay strata was obtained from comparison of the moisture contents from Boreholes 1 and 2 sunk outside and within the tree root extent, see Figure 1. Average moisture contents are given in Table 1 and show lower values near the tree. It can be seen that the differences are small and could be within the variation to be expected for a natural soil, especially one of glacial origin. Nevertheless, it is also shown that if these are to be considered reductions in moisture content then the change in (vertical) thickness of each layer

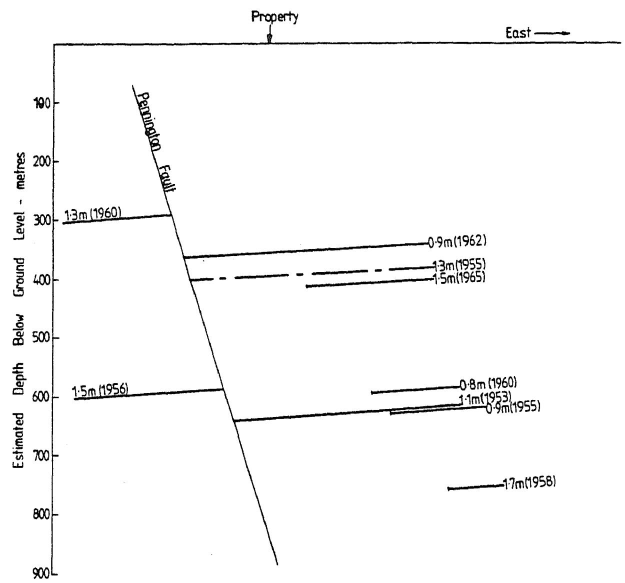

FIGURE 3 Coal Extraction After 1945

calculated simply from the loss of moisture (and assuming no effects from plasticity, suction, horizontal movements etc.) is significant, see Table 1. The total change in thickness is also comparable to the observed settlement at the front of the gable end of No. 38 when the movements due to other causes are removed.

During the summer of 1976, exceptional drought conditions were experienced in the U.K. which obviously aggravated this situation.

STRUCTURAL DISTORTION

Criteria for the onset of visible cracking have been given for loadbearing brickwork structures (Burland et al, 1978) and it has been shown that the hogging mode of deformation is the most critical. These authors give a critical hogging ratio,

Δ/L, of 2×10^{-4} where

Δ = central deflection

L = length of structure

The overall hogging ratio at the rear and front of the property (No. 38) is calculated as 30 and 34 ($\times 10^{-4}$), respectively, which is far in excess of the critical value and obviously represents very severe cracking, as found. Ignoring the effect of the tree, i.e. solely due to eccentric load rotation, the overall hogging ratio would be 11×10^{-4}, still above critical and compatible with the observed settlement and cracking at the southern end of No. 40.

Where the settlements are non-uniform, as in this case, their effects can be better depicted by plotting the angular strain, see Figure 2.

The locations of high angular strain relate well to the zones of more severe cracking.

CONCLUSIONS

The author considers there are two main conclusions from the above

1. Ground movements and associated structural distortions are not always attributable to one cause, which provides the geotechnical engineer with the difficult task of separating the causes and their effects and attributing responsibility,

2. the effects of moisture removal by tree root systems and to a lesser extent eccentric loading provide the most serious consequences for brickwork structures since they produce the more critical hogging mode of deformation.

ACKNOWLEDGEMENTS

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