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Effect of Foundation Deformations on the Damage of a Masonry Villa (Case History)

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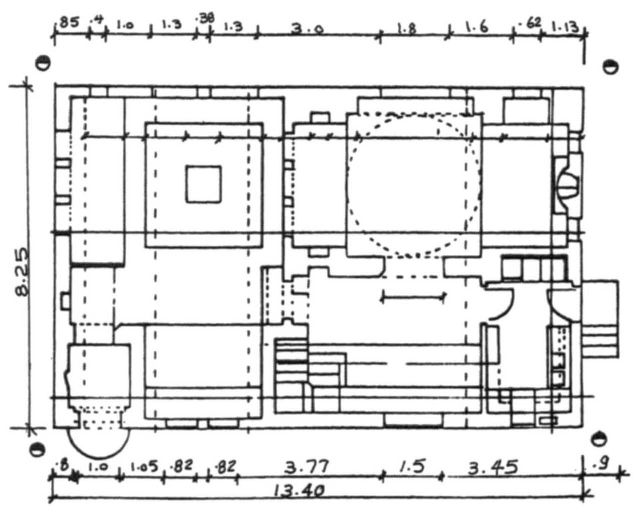
SYNOPSIS Cracks in the masonry walls of a one storey villa due to foundation deformations are investigated in this paper. In spite of the fact that the soil formation in the site was found to be almost uniform, hogging deformation profile took place in the strip foundation due to unequal loading. Analysis of the walls together with their supporting soil , as one integrated system , showed that very small foundation deformation can produce tensile stresses in the wall higher than it's tensile strength. Repair of the cracks was proposed and carried out successfully.

INTRODUCTION

The case history presented in this paper is of a masonry villa which has been constructed in a private farm less than one kilometre away from the Giza Pyramids, greater cairo zone, Egypt. The villa is a very small building of 8.25 x 13.40 m in plan. It can be considered in two parts , an open court of 8.25 x 4.70 m and a covered area of 8.25 x 8.70 m. The type of construction is load bearing walls using masonry as the building material. The building was the first to be built in this farm , however, due to the fact that the villa is very small and the expected loads are not much, the design engineer did not call for any soil investigations to be made. Six months after construction, visible cracks were noticed in the masonry walls of the villa. A soil investigation was then carried out in order to determine the soil nature of the site. Reasons of cracks were studied and a proposal of repair was given and carried out which performed satisfactory.



● Bore Hole

Fig. 1 Plan of The Building

THE BUILDING

The building was constructed in 1978. Fig (1) shows the plan of the building while fig.(2) and fig.(3) show elevations of the north and south walls respectively. The building consists of masonry walls with thicknesses varying from 250 to 500 mm as shown in plan. The walls are founded on a reinforced concrete continuous strip foundation. There is a mezzanine floor in the south east part of the building while the north east part has no intermediate slab and is covered with a masonry dome. All the west part is an open court as shown in plan.

DESCRIPTION OF THE DAMAGE

Six month after construction i.e. in 1979 some cracks were noticed on the exterior walls of the building. The crack widths were measured and were found to be increasing with time for a period of 15 months. Fig.(2) and fig.(3) show the pattern of the major cracks and their widths on the north and south walls when the cracks almost seized to increase in width. Fig.(4) and fig.(5) show photographs of the south wall and part of the north wall while cracked. The crack patterns on the walls , with wider cracks at top than at bottom , indicated that as if the foundations of the building underwent a hogging settlement profile. In order to study the reasons of cracks it was decided to undertake a soil investigation for the site.

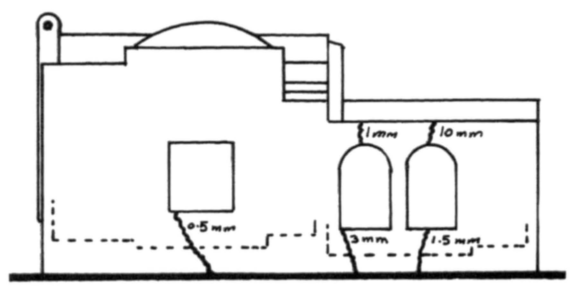


Fig. 2 North Elevation

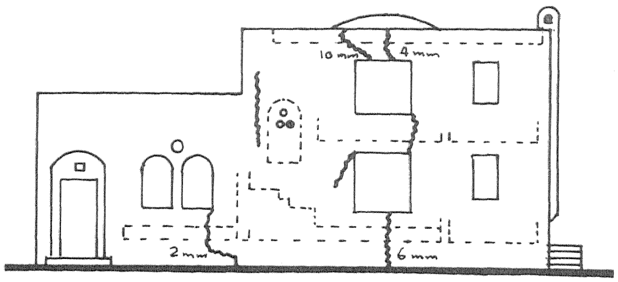


Fig. 3 South Elevation

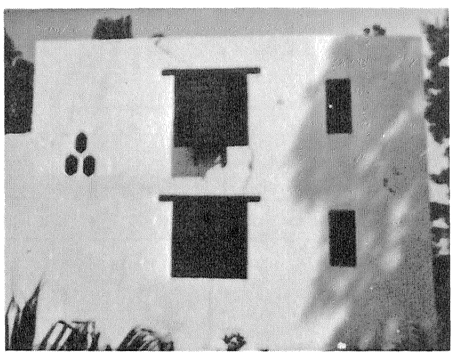


Fig. 4 Photograph of The South Wall
(Before Repair)

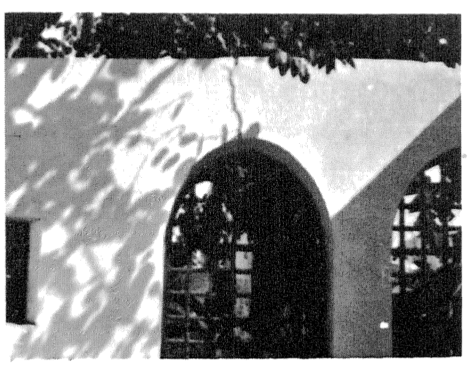


Fig. 5 Photograph of Part of North Wall (Before Repair)

SOIL DATA

Using shell and auger drilling equipment , four boreholes were sunk to a depth of 20 m below the existing ground level at the locations shown in fig.(1). The soil strata at the site , as revealed by the site investigations, were found to be almost uniform. A typical soil section is illustrated in fig.(6). Standard penetration tests were carried out in the sand layers at 1.0 m intervals , the results are presented in fig.(7). The two upper sand layers were found to be medium dense whereas the bottom layer is medium dense to dense. As far as the clay layers are concerned , values of the undrained shear strength (Cu) and the coefficient of volume compressibility are included in fig.(8).

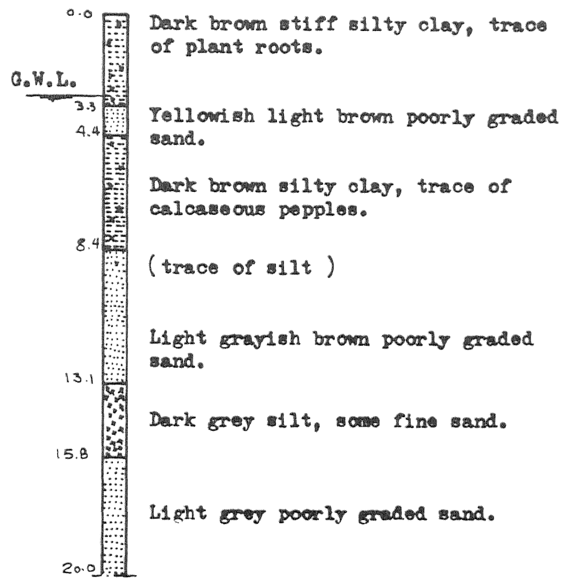


Fig. 6 Typical Soil Section

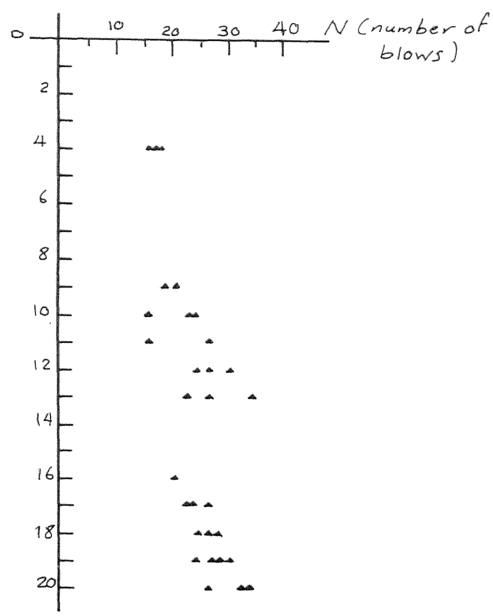


Fig. 7 Standard Penetratio Test Results

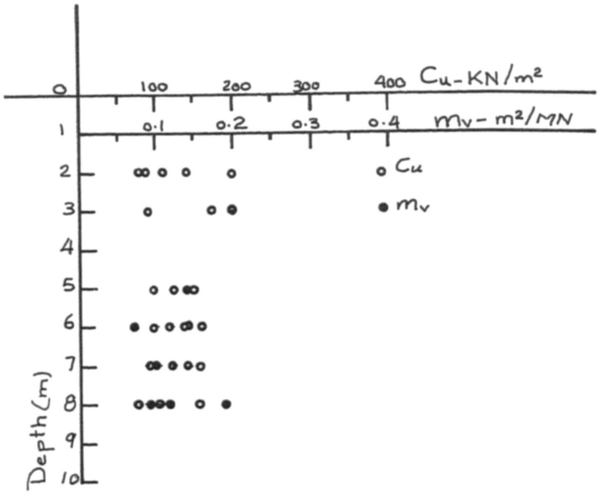


Fig. 8 Some Properties of The Clay Layers

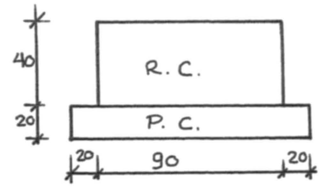


Fig. 9 Cross Sectional Dimensions of The Strip Foundations.

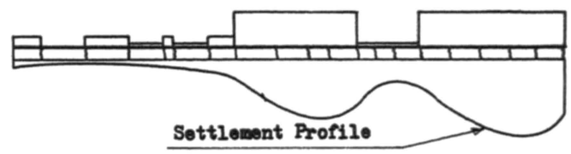


Fig. 10 Loading and Settlement Profile For The Prelemenary Analysis.

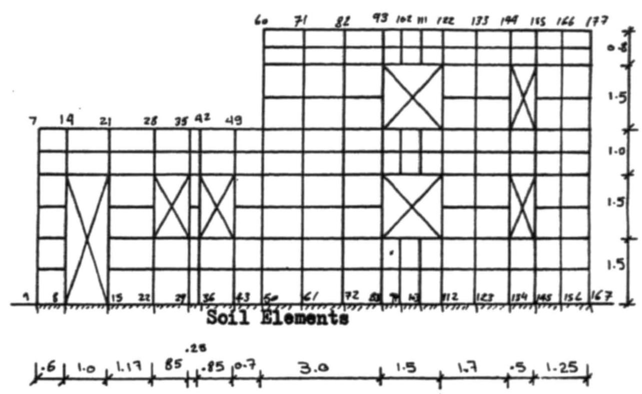


Fig. 11 Finite Element Mesh Used in The Analysis.

DISCUSSION AND ANALYSIS OF THE PROBLEM

In spite of the fact that the soil strata at the site were found to be almost uniform and the values of the settlements were very small due to the light weight of the building , wide cracks were developed in the walls as previously mentioned. These cracks caused anxiety to the owners and hence the building was considered to reach a serviceability limit state where repair had to take place. The absence of concrete top beams on the masonry walls increased the suseptibility of these walls to cracking even due to very small foundation deformations. It should noted that masonry as a building material is weak in resisting tensile stresses and that the vertical joints are usually weaker than horizontal joints. It should also be noted that although the villa may be considered in two parts as described earlier with one part heavier than the other , cracks did not develop in the connecting area but it appeared at the edges of the openings.

The problem was then analysed twice. Both the two analyses were qualitative rather than quantitative in order to furnish an insight into the behavior of the walls. At first a prelemenary analysis of the strip foundation , shown in fig.(9) , as a beam on elastic support was carried out. The modulus of subgrade reaction was estimated from the soil data. The loading on the strip foundation of the south wall and the resulting profile of deformation underneath it are shown in fig.(10). The deformation profile indecates that although all settlements are downward , there are local hogging profiles underneath the openings caused by the difference in loading. From this settlement profile , one can expect that the connecting masonry beams on top of the openings may be subjected to tensile forces. In order to verify this expectation a more sophisticated analysis for the walls was carried out using the finite element method. Plane stress quadrilateral hybrid elements, developed by Green (1972), were used in the idealization of the walls while half plane surface elements, developed by Macleod et al. (1980), were used in idealizing the soil. Fig.(11) shows the mesh used for the south wall. The results showed that the connecting beams are subjected to tensile stresses much more than the tensile strength of the masonry.

REPAIR OF THE DAMAGE

The proposed repair for the damage in our case was as follows :

- Casting top concrete beams properly connected to the masonry walls all around the building.
- All cracks wider than 0.3 mm were injected with epoxy mortar.
- All smaller cracks were just sealed with epoxy paint.

Periodical observation of the building showed that the performance of the carried out repair was satisfactory and no further cracks were developed. Fig.(12) and fig.(13) show the walls after repair.

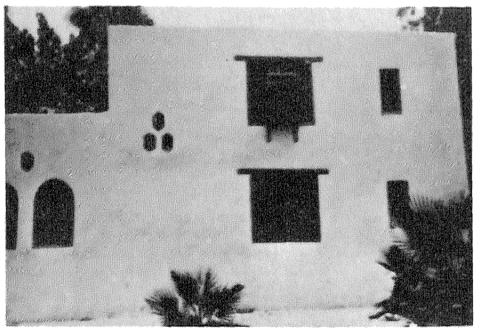


Fig. 12 South Wall After Repair

Fig. 13 Part of North Wall After Repair.

CONCLUSIONS

In low rise buildings , type and dimensions of foundations are generally governed by the bearing capacity conditions rather than by deformation considerations. Designers need to appreciate that a uniformly loaded strip or raft foundation does not produce a uniform settlement. They need also to appreciate that although the weight of low rise buildings is relatively small resulting in small foundation deformations , their rigidity are also rather small reducing their ability to resist such deformations. The weakness of lightly compressed brickwork in tension increases the vulnerability of low rise brick structures to tensile cracks at the eaves level under hogging profiles of deformations. Hogging settlement occurs frequantly even in sites where the soil formation seems to be almost uniform. Aprons between windows , where the vertical loads are relatively small , are more likely to crack than peirs. Proper measures , such as top concrete beams well connected to the masonry walls, can improve the performance of masonry buildings in resisting tensile cracks. Increasing the stiffness of the foundation by providing an inverted T-section rather than a flat strip will also help in reducing the deformations and hence the susceptibility of the walls to cracking.

REFERENCES

Green, D. (1972) , "Flash" A general finite element programme , developed at the Swiss Federal Institute of Technology , Zurich.

Macleod, I. and Abo-El Magd, S. (1980) , " The behaviour of brick walls under conditions of settlement ", The Structural Engineer, Vol. 58A, No.9, Sept.