Failure of Buildings Founded on Fills

Iqbal H. Khan
Jamia Millia Islamia, New Delhi, India

S. M. A. Kazimi
I. I. T. (Hauz Khas) New Delhi, India

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Iqbal H. Khan
Professor of Civil Engineering, Jamia Millia Islamia, New Delhi, India

S. M. A. Kazimi
Professor of Applied Mechanics, I. I. T. (Hauz Khas) New Delhi, India

SYNOPSIS A number of cases have come to light in Delhi recently where partial or total failure of buildings has occured. Two cases of failures due to excessive settlement are discussed. The nature of distress and the geotechnical factors leading to failures were investigated. It was found that in both cases the foundations were resting on fills, resulting in excessive settlement. Remedial measures were considered and in one case, these have been successfully implemented. A large number of structures were thus rehabilitated.

INTRODUCTION

Like all metropolises, Delhi is also witnessing a rapid increase in its population. Consequently there is a pell-mell construction activity going on for building houses and other infrastructures. Tens of thousands of houses and other office and commercial buildings have been constructed by government and other private agencies during the last two decades, and the pace is accelerating to cater for the ever-increasing demand for buildings.

Inevitably, a number of cases have come to light where distress or failure has occured inflicting heavy financial loss as well as hardship on the occupants. The social image of engineers has also suffered especially as such reports appear in the press with disturbing frequency. The irony is that most of these failures could be avoided if only simple precautions were taken at the proper time.

Building failures due to geotechnical causes have been reported by many workers eg Khan & Layas (1984), Khan & Hasnain (1981), Yen & Scanlon (1975). Most failures occur due to one or more of the three main causes ie excessive settlement, or faulty design, or poor workmanship or materials. But many other causes have also been reported eg weak soils, subsidence, unauthorised additions or alterations. (D Appolonia, 1970; Lenczner, 1973; Prakash, 1984; Prakash, 1988, etc.)

This paper discusses some cases of recent building failures in Delhi due to geotechnical causes. The specific cause of failure and remedial measures where undertaken to salvage such structures are also presented.

CASE-1: FAILURE OF A DOUBLE STOREY BLOCK OF FLATS

About seven hundred houses were constructed for people of low income group in an area south-east of Delhi. These are generally two storey blocks with two flats on each floor. (Fig.1) Two years after their construction several blocks suffered cracks especially in the load bearing walls. In one particular block, cracking progressed rapidly and cracks as wide as 8.0 mm, appeared on the external as well as internal partition walls. Extensive damage has since occured. (Fig.2).

To ascertain the causes of this failure, soil investigation work was carried out. Three boreholes each 10.0 m deep were drilled in the immediate vicinity of this block. S.P.T. N-values were recorded at every one metre and soil samples collected were analysed in the laboratory.

The soil at this site is loose silty sand (SM-ML) with N-values less than 4 upto 7.0 m depth; followed by medium-dense sandy-silt with $N > 10$. (Fig.3) In one borehole at 5.0 m depth, the sampler penetrated the full length under its own weight. Ground water table was not met with upto the depth of excavation.

Based on the soil investigation as well as a thorough study of relevant documents eg working drawings, contour maps of original ground, drainage patterns of the area, the following was concluded.

Foundations of the failed blocks are located at 1.5 m depth whereas soil is loose and very weak upto a depth of at least 7.0 m at this location. Comparison with the original contour map of this location revealed that some of the blocks are standing on a filling. Uneven features with many depressions and a deep ravine existed at this site before the filling and levelling operations were carried out.

Several remedial measures were considered eg soil stabilisation, jacking up the walls, or providing piles. (C.B.R.I: 1980 Bureau of Indian Standards, 1985; Chand, 1979) But in each case the estimate of cost of providing the remedy was prohibitive. There is, therefore, no alternative but to demolish such blocks.

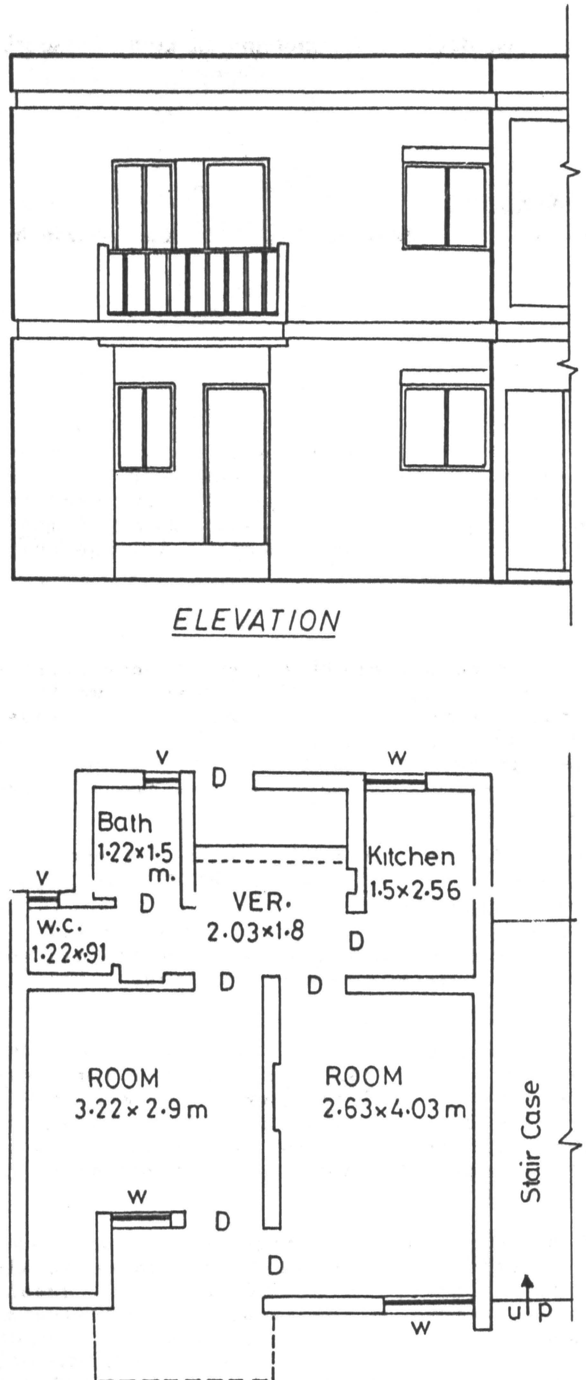

Fig.1. Case I: Plan & Elevation of the Building.

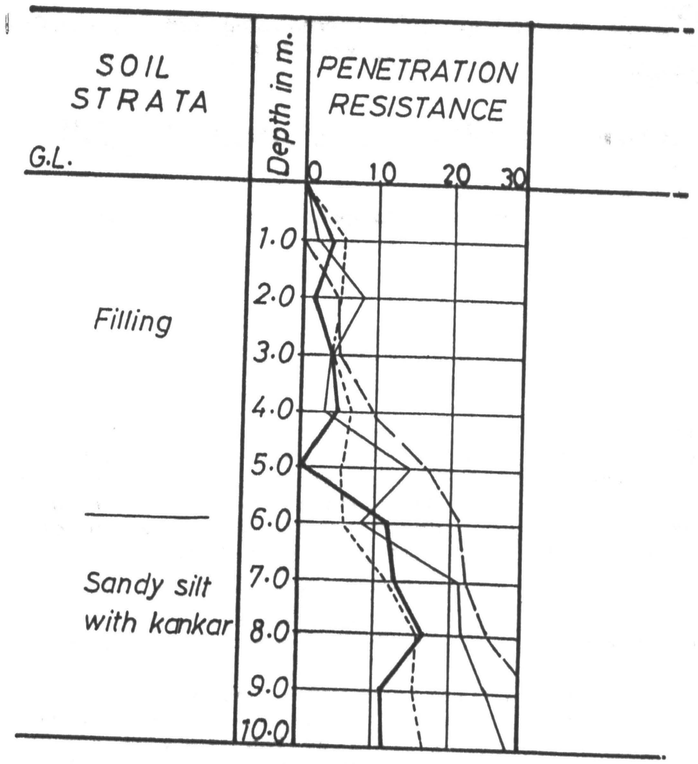

FIG. 3. CASE I: VARIATION OF SPT & CPT.

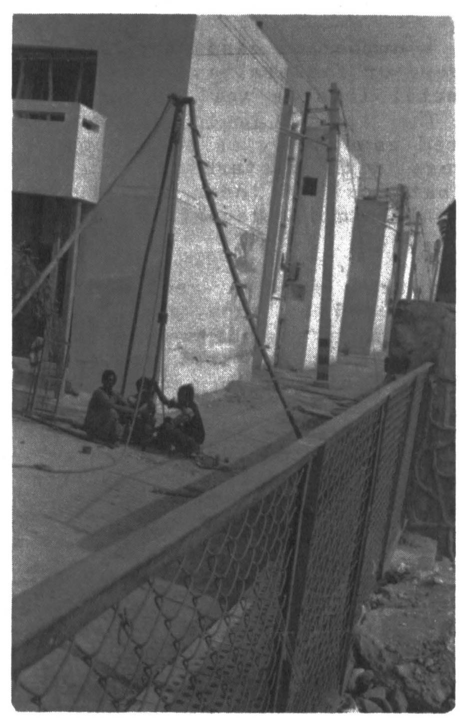

Fig 2: Cracking on Walls - Case I

CASE II: FAILURE OF SEVERAL FOUR STOREY BLOCKS OF HOUSES

In 1985, a housing colony was planned on a 5.0 acre plot of land, south-west of Delhi. Construction of 300 houses in blocks four storey high, began early in 1986. Even before the construction was completed, distress signals started appearing eg. cracking, tilting and sagging of various members. Soon after the contractor abandoned the work and the case went under arbitration.

From the records it was found that the loads on the walls was 10.0 to 15.0 t/m², and the foundations were 0.9 m wide. The water table was at a depth of 10.0 m below the ground level. The bearing capacity was assumed as 15.0 t/m².

The nature of distress was noted as follows.

i) Outer load bearing walls, (23.0 cm thick) suffered extensive cracking due to sinking. Tilting of walls resulted in their getting out of plumb. At several locations there was differential settlement as well. (Fig.4).

ii) Interior partition walls, 11.5 cm thick, suffered cracking in most cases, and substantial sinking in some cases.

iii) Beams on various floors sagged.

iv) Cracking occured in the slabs at most of the junctions. There was excessive sagging (3.0 to 4.0 mm) at the center of many slabs. Lintels also showed shear cracks.

v) Staircases separated from the main walls and the gap increased with height.

Enquiries revealed that a brick kiln existed at this site. The kiln was demolished and the area filled up with earth without proper compaction. The contractor who also happened to be the designer as well, started construction without proper site investigation. The result was that wherever the foundations happened to be on the hard kiln foundation, no distress was observed. But in places where foundations of houses came to rest on filled up area, it suffered extensive settlements manifesting distress noted above.

The nature and extent of cracking was such that the occupation of these houses was absolutely unsafe. Due to the high cost already incurred, the clients also did not wish to abandon the project at this stage. It was therefore, decided to undertake remedial measures.

The work was entrusted to a reputed firm of architects who, after preliminary studies, estimated that the remedial measures would cost about 20% of the total cost of the project.

Site investigation carried out subsequently. Local enquires were made and studies of relevant documents eg. the design, drawings and original contour maps were undertaken. It was revealed that the natural soil is sandy-silt with S.P.T N-values in the range of 5 to 6 only. Hence the safe bearing capacity works out to only about 6.0 to 7.0 t/m², at the depth of existing foundations. The actual load on the filled up soil at the foundation level was, approximately, twice as much.

CORRECTIVE MEASURES

The objective of the corrective measures was therefore to transfer the major portion of the load to the firm strata existing at -2.0 to -7.0 m, so as to relieve the existing foundations of at least 60.0 to 70.0% of the load.

Several schemes were considered.

Alternative(1)
Construction of piles on both sides of the walls at appropriate intervals and then to push precast beams across the walls atop the pile caps. The beams would thus transfer the wall load to the firm strata below, through the piles.

This proposal was found to be impractable. The houses were already constructed and it was not possible to carry the piling rig inside due to limitations imposed by the ceiling height etc.

Alternative(2)
Excavation of longitudnal trenches along the walls on either side of it and constructing piers 1.0 to 2.0 m wide upto the required depth (-2.0 to -7.0 m). Precast beams shall then be pushed across the walls atop the piers. Here the load is to be transferred to the firm strata below through the piers supporting the beams. Originally it was contemplated to keep the beams at foundation level. However, it soon became apparent that it would require excessive excavation. This proposal was therefore, modified so as to keep the precast beams at the plinth level. Thus the wall segments were to be cut at the smallest thickness with consequent ease in pushing the precast beam(Fig.5).

The slabs also needed to be strengthened as these were showing excessive deflection under this self weight. For this purpose the existing slabs were cut at 1.5 m. upto the reinforcement level. Generally two to five cuts were required in each room depending on its size. A vertical steel section with a horizontal plate was then spot welded to the reinforcement to serve as a shear key. A 50.0 mm thick 1:2:4 cement mix was then poured over the existing 100.0 mm slab. The existing slab thus integrated with the freshly poured mix through the shear key and formed one monolithic slab.

The rehabilitated structure is shown in Fig.6.

The work was carried out by a competent agency under strict supervision. Special care was required in the allignment of beams across the wall and in its levelling. The slab corners were fixed at their proper place by making holes through the walls and inserting RSJ's extending over the walls by 100.0 mm on either side and embedded into the fresh poured concrete.

These minor details were of utmost importance in the successful implementation of the corrective measures.

The corrective measures adopted increased the final cost of construction by about 14%.

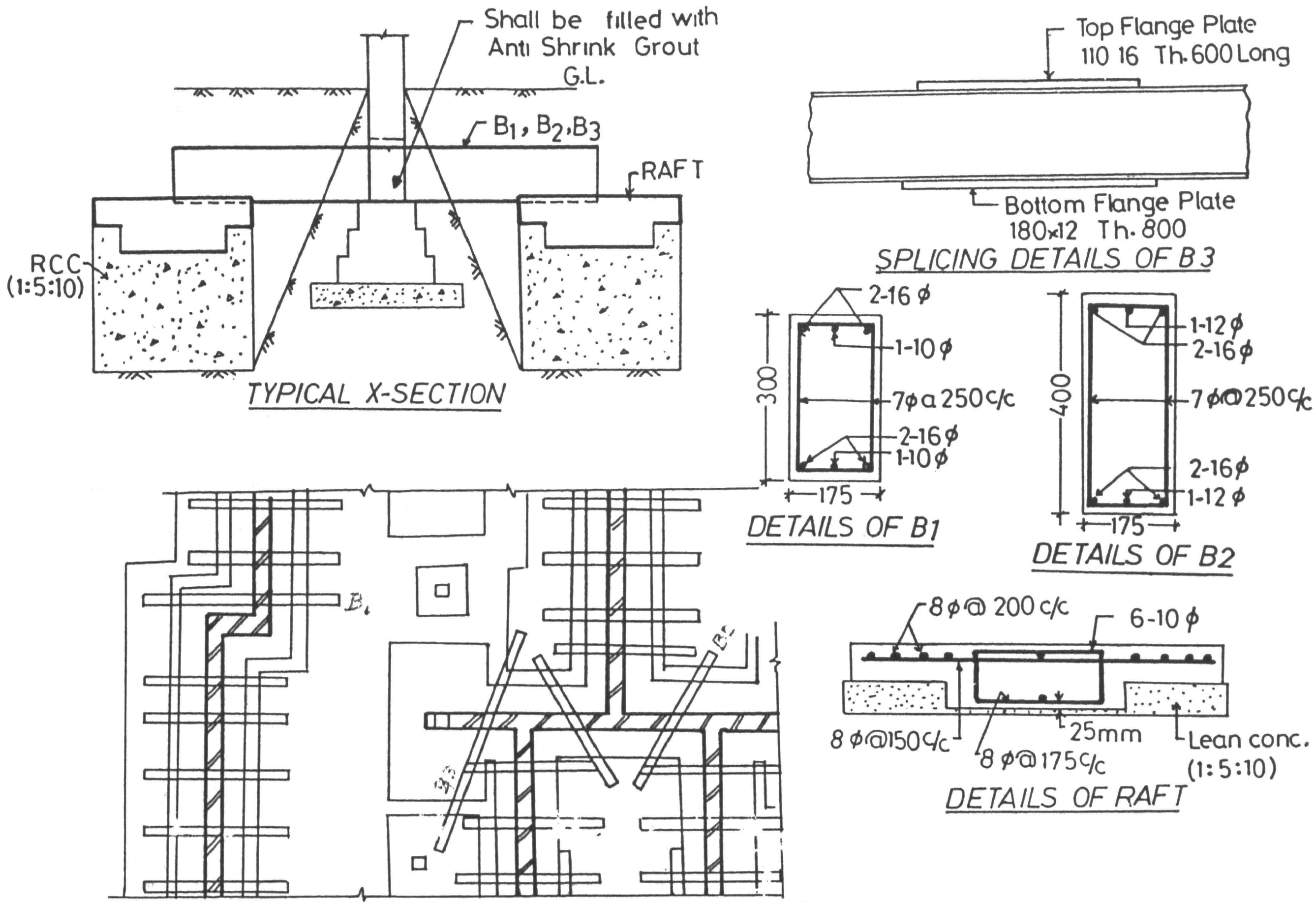

Fig. 5 FOUNDATION PLAN with Rectification Proposal. CASE - II

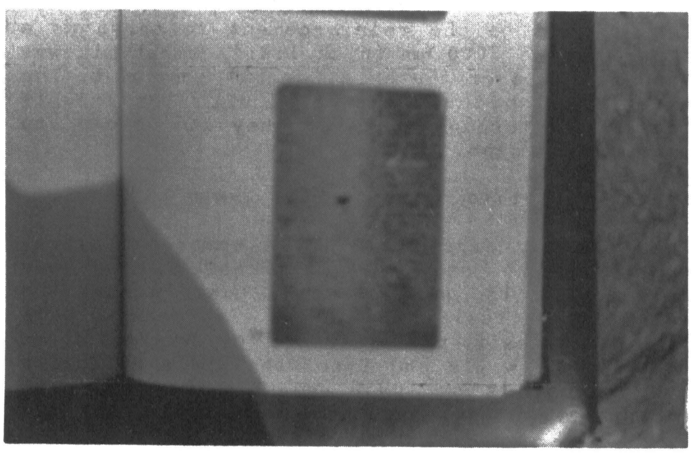

Fig: 4 : Cracks on Outer Walls - Case II

Figs. 6 Rehabilitated Structures - Case II

DISCUSSION

Two cases of foundation failures have been presented. In both cases the foundation was resting on fills. In the first case, there was, as is usual in most cases, considerable time lag between filling and start of construction. The filled up areas was mistaken as natural ground. The original ground profile or contour maps were not taken into consideration. The designer should have shifted the ill-fated blocks away from the positions of depressions and ravines. Remedial measures after failure were not feasible in this case, especially as the natural soil happens to be at large depth. Consequently the cost of such measures would have been prohibitive.

In the second case, the main cause was lack of proper site investigation prior to the construction and poor control and monitoring during the construction. The large differential settlements could be estimated and avoided eg. by designing foundations resting on firm soil or by compacting the fill properly before starting the construction (Grant, 1974; Grim, 1975; Polshan et al, 1957; Zeevaert, 1972) Pre-loading, or other measures are also available. However, most such measures are easy to adopt only if the filling depth is small. Where filling is deep, piles or piers are more appropriate to transfer the load to a firm strata below.

The available remedial measures were analysed for the present case to keep the cost of corrective measures low and to ensure ease of construction. The measures finally adopted were successful in rehabilitating the structures and strengthening them against future settlements.

Only two cases have been presented here but these are typical of a large number of such failures that have been reported in this area in the recent past.

CONCLUSIONS

i) Where the natural ground profile is uneven filling may be required prior to construction. Designer must carefully note the depth of filling at the site before deciding the location and depth of footings. Contour maps and profiles of original ground should be available for this purpose.

ii) Where filling depth is small, properly controlled compaction measures or other soil stabilising techniques may be adopted. Alternatively the foundation should be laid at a depth of at least 0.5 m below the natural ground.

iii) Where filling depth is large; load has to be transferred to the firm strata below through piles or piers.

iv) Where post-construction distress occurs remedial measures should be considered as the cost already incurred may be too high to abandon the project. The choice of such measures depends on the specific nature of the problem encountered and the soil properties. Final decision requires consideration of various factors eg. cost, ease of implementation, and competence of the agency involved. Careful supervision is also necessary during the salvaging operations.

v) The need for proper site investigation cannot be overemphasised.

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