Can Lessons be Learned from a Displaced Single Storey Staff Quarters Building Allegedly Due to Adjacent U-drain Construction?

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1. INTRODUCTION

Part of the perimeter drain under construction beside a completed single-storey staff quarters at a housing project site in Peninsular Malaysia was discovered to have cracked and displaced during a routine inspection. Exposed reinforced concrete stumps of the three front exterior columns also exhibited shear failure at connections to ground beams.

Within the next 48 hours, the distresses observable, without any uncovering, had progressed to include :-

- Column stump shear failure
- Collapsed drain brickwall
- Earth-slip cutting through below the front porch slab.

The design-and-build contractor for the staff quarters has alleged that these observed distresses were due to the nearby excavation for installation of precast U-drain segments (of 3.6m B x 3.0m D) carried out under a separate contract and on a later date.

Further uncovering revealed several columns at the rear of the staff quarters had also suffered shear failure at their stumps.

Following these discoveries, I was involved in the forensic investigation. The cause(s) of the displaced staff quarters were reported here.

2. AUTHOR'S OBSERVATIONS AND FINDINGS

Of the Exposed Stumps, Piled Foundations and Building Structure

These reinforced concrete stumps had sectional dimensions of 200mm x 200mm whereas the piled foundations were founded on smallish single reinforced concrete piles of 150mm x 150mm. Pilecaps were 800mm x 800mm in plan and 600mm thick.

The staff quarters building was of conventional reinforced concrete framing with infill brickworks and designed with suspended ground slab.

Of the Nature of the Original Ground and Its Impact on Engineering Works

Geologically, the lower lying area of the site is known to be of the Recent Alluvium. This Recent Alluvium typically has an upper layer of soft to very soft silty clay/clayey silt. This layer can be quite substantial towards the coast.

At the staff quarters area, this soft to very soft silty clay/clayey silt layer is known to be about 8.5m.

This soft to very soft silty clay/clayey silt has a high degree of consolidation when filled over.

Shear strength of this upper silty clay/clayey silt layer can varies quite substantially from area to area.

Where the staff quarters were sited, the fill thickness was about 2.5m.

Deep U-drain placed in such soils can be subjected to upheaving due to initial low shear strength of the soils or reducing shear strength following creep soil movement.

Even before they were fully backfilled to the design cross-section, those U-drain segments that had been placed earlier were showing sign of upheaving due to squeezing out of the soft to very soft silt clay/clayey silt material below the adjacent platform fill.

Replacement of the "unsuitable material" up to 2m below the soffit of the U-drain supporting base slab with "good earth" was instructed ; initial instruction was for 1m only.

The U-drain excavation level after removal of 2m unsuitable material before "replacement with good earth" was some 5m below the design fill platform level.

Notwithstanding the substantial excavation depth ignoring unplanned over-excavation was almost 5m, the excavation in the poor soil was carried out using only 6m long cantilever sheet piles in the short distance ahead of the placed U-drain segments, and adopting open excavation further ahead.

In that scenario the short cantilever sheet piles served no practical purpose in supporting the excavation.

The design U-drain invert level there was 3.6m below the final design platform level.

However it must be emphasised that the design U-drain cross-sectional details with only thin replacement of unsuitable material limited to directly below the supporting base slab, is also unconstructable. This is because even if a temporary propped sheet pile excavation for the U-drain installation has been successfully engineered the installed U-drain when completed to final design backfill would upheave when the temporary sheet piles were withdrawn.

To overcome this potential upheaving of the U-drain, the unsuitable material replacement ought to have been more extensive in plan and in depth. Moreover this unsuitable material replacement is only practical if it were carried out at commencement of general/bulk earthworks and not after general/bulk filling was practically completed.

On the Design of the Piled Foundations

The concept of the load-carrying behaviour of the single-pile foundations as understood by the appointed engineer, was quite irrational and alarming; lacking engineering understanding. He had assumed the pile and column to resist no bending moment through eccentricity, due to offset of pile from true position, up to 75mm (and over) was allowed. He had further assumed the bending moment to be somehow provided by the pilecap alone and that the whole assembly would be stable.

In addition he had erroneously equated the unfactored column loading to the ultimate axial load capacity of a 125mmx125mm reinforced concrete column with 4 nos. 12mm diameter high yield deformed bars when the actual column was 200mm x 200mm.

As the piles were only 150mm x 150mm they are obviously the weakest link of the foundation assembly. But this was not appreciated by the designer.

The axial load-moment capacity envelopes as determined by the author of the 150mm x 150mm reinforced concrete pile with Grade 45 concrete and 4 nos. 9mm diameter high yield deformed bars are presented in Figures 1 & 2.

Records of the as-built piling shows a maximum piling offset of as much as 103mm in the diagonal direction of the 150mmx150mm r.c. pile. With the said (large) offset the design ultimate axial load of the pile would be only 80 kN. If this diagonal offset were limited to 75mm the corresponding design ultimate axial load of the pile would be 122 kN.

Where the piling offset is 75mm in the direction parallel to any pile face, the design ultimate axial load of the pile would be 141 kN.

Estimated maximum unfactored foundation load was 142 kN and that due to permanent loads alone was 121 kN.

The as-built piling records also showed 14 out of the 20 pile points had resultant offsets exceeding 75mm.

Thus the single-pile foundations as designed and constructed with the many shortcomings elaborated above cannot be said to be structurally sound.

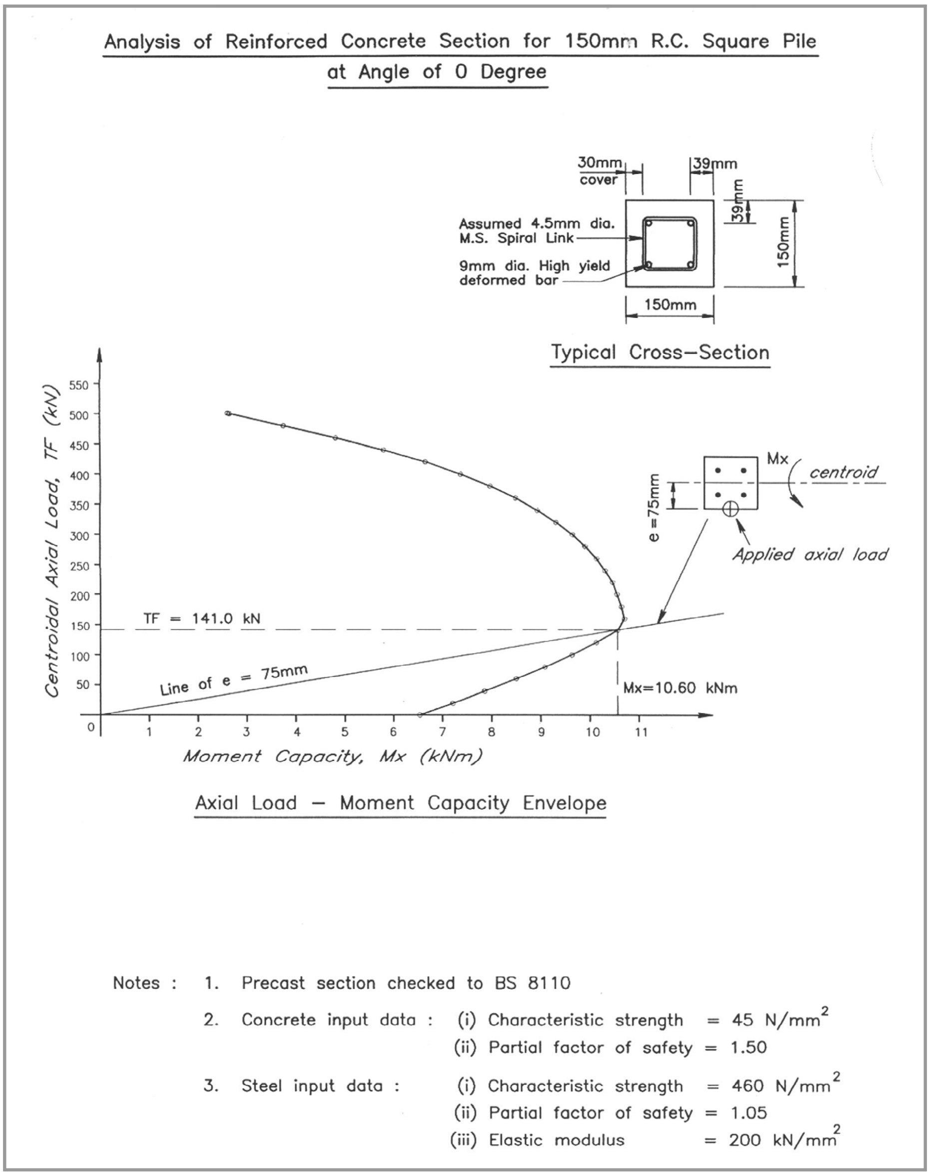

Figure 1

Moreover in the geotechnical design of the piles the designer ignored the eventuality that the soft upper layer would cause negative downdrag to the piles due to time-dependent consolidation of this soft layer. Calculations presented assumed the soft upper layer is always capable of contributing to the positive resistance to the pile's axial loading.

Consequently the piled foundations of the staff quarters were inherently in distress even before the incident and that these foundations were in precarious conditions since practical completion of the staff quarters.

The adjacent U-drain construction, separated 21m to 25m from the staff quarters, had obviously compounded the distresses by first causing the distresses to be exposed due to earth slip and then caused additional lateral loading to the piled foundations.

More disturbing was the designer's response to queries on why the many small sized single-pile foundations were used and how the expected piling offsets were to be accommodated by the single piles.

With regard to piling offset, the designer had circumvented logics and basic engineering understanding as elaborated in para. 2.3.1.

On the matter on small sized single-pile foundations, his reply was roughly "in the housing industry everybody is using these" or something to the same effect. This is notwithstanding Clause 7.3.3.6 of BS 8004 on eccentric loading of piles states:-

"The load carried by a stanchion or column is seldom a simple axial load. A single pile is seldom placed with such accuracy that the axis of the pile will coincide with the point of application of the resultant force. Thus there is the likelihood of some degree of eccentric loading on the piles in a foundation consisting of only one or two piles. The piles should be designed to resist the bending which results or the pilecap should be effectively restrained from lateral or rotational movements. The restraint and the pile section or both should be sufficient to resist the moments due to eccentric loading or other causes"

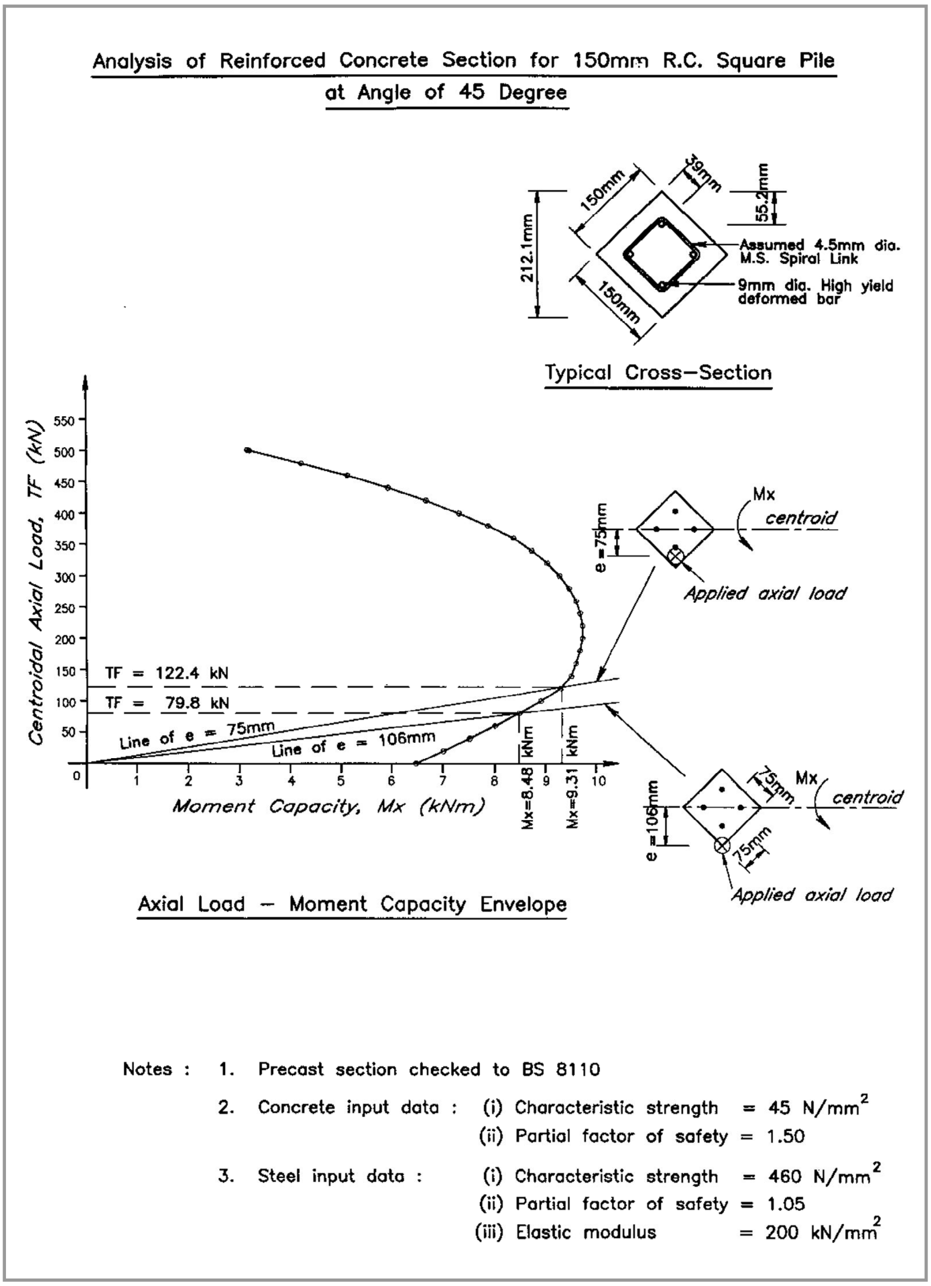

Figure 2

Findings and Summary

The piled foundations of the staff quarters were inherently in distress even before the reported incident. These foundations were in precarious conditions since practical completion of the staff quarters.

The adjacent U-drain construction had obviously compounded the distresses by first causing the distresses to be exposed due to earth slip and then caused additional lateral loading to the piled foundations.

The constructability of the U-drain to the final design details without subsequent upheaving of the U-drain and consequential disturbance to the piled foundations of the staff quarters has also been questioned.

3. CAN LESSONS BE LEARNED

Professor Ralph B. Peck has said "For engineers to make a mistake in the first place does not necessarily mean they are poor engineers. To make the same mistake twice they have not learned from experience".

I agree with Professor Ralph B. Peck but the apparent lack of skill and care exhibited by the various parties here should cause any thinking engineer to concur that it was indeed very poor engineering.

Are we making the same mistake twice and again by continuing to qualify engineers with such poor skill and care?

A thinking engineer would not allowed himself to be seduced by virtual lowest or lower cost alone without thinking through and investigating viability, safety and other issues.

The lesson I learned from this forensic investigation is:-

For engineers to carry out a design without adequate thinking through, would mean they are on the way to become poor engineers.

For an engineer to be able to adequately think through his design he needs to have good knowledge of engineering fundamentals. In recent interviews, the majority of current civil engineering graduates show lack of such knowledge. This shortcoming must be urgently addressed by the institutions providing tertiary education, otherwise we are likely in the near future to become a very poor lot indeed.

More often, engineers give little or no attention to the important lessons they can learn from small scale engineering failures like this case, when these failures do not incur large economic loss or loss of life. Unfortunately, most engineering failures are of small scale and their lessons overlooked, thus poor engineering is being continually practised.

This forensic investigation clearly shows why concrete piles of 150mm x 150mm and below are totally inappropriate for use in single-pile foundations. Even if a next bigger size concrete piles are substituted, the need to downgrade the pile structural load carrying capacity is obvious as some degree of eccentric loading on the piles is unescapable due to practical accuracy / limitation in pile positioning and installation.

Civil engineering designs of infrastructural and building works must also not be compartmentalised without considering the various interactions (eg. soil-structure) and phasing of the works. ■