

Rework in Projects: Learning from Errors

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ABSTRACT

Design and construction errors can have serious consequences in construction project systems, including various failures. Recent studies by the authors revealed that the root causes of human errors are diverse and the consequences may vary. Moreover, late discovery of errors and unfound errors will have more serious impacts. Although "to err is a human nature", most of the project-based human errors are avoidable by having adequate knowledge, better management practices and relevant systems. A set of case-study based research findings on some human error-based rework occurrences in design and construction phases are described in this paper, i.e. three examples of design/construction errors from recent projects are explained. The first example illustrates a rework case due to late discovery of a setting out error. The second example is about a rework occurrence from wrong assumption of a standard practice. The third case presents a rework instance from a late discovery of a drafting related design error. The case-study discussions outlined in this paper include key lessons learnt such as basic inferences on consequences and avoiding future occurrences for improved project performance.

KEYWORDS

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Error
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Project Performance

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INTRODUCTION

Construction projects are mainly multi-disciplinary and involve several consultants and contractors. Project success is mainly propelled by essential understanding of the design principles and construction methods by various team players (Love and Smith, 2003). Moreover, effective coordination frameworks and efficient arrangements for information and communication are essential for project success (e.g. Love et al. 2004). Reduction of rework and wastages is crucial for achieving good performance in project systems (e.g. Love and Li, 2000; Fayek et al. 2004; Palaneeswaran et al. 2005). Rework occurrences in construction projects are mostly avoidable as these are mainly unnecessary redoing/rectifying efforts of incorrectly implemented processes or activities (Love, 2002).

Human errors are among the leading causes for defects, rework and wastages in construction projects (Kaminietzky, 1991; Atkinson, 1999; Love and Josephson, 2004). Thus, errors in construction projects can be costly and even become a social problem due to future repairs, inconveniences, and other perils including safety (Rimer, 1976). Uncontrolled rework and wastages can affect the project success. Reduction of such damaging items can be targeted by effective management of design (Rounce 1998; Acharya et al. 2006; Palaneeswaran et al. 2007) and construction (Love et al. 1999; Fayek et al. 2003), which can ultimately yield sustainable whole-life values including stakeholder satisfaction.

Drawing threads from such requirements, an ongoing Hong Kong based research has targeted to consolidate useful knowledge-sets for developing a knowledge portal of project-based lessons, including those on managing rework in design works. In this exercise, a hybrid research method with triangulation approach (e.g. surveys, interviews, data-

mining, and case-studies) is used. The discussions in this paper mainly integrate some useful overview regarding three noteworthy cases of human errors occurred in recent projects.

CASE – 1: LATE DISCOVERY OF SETTING-OUT ERRORS

Basic description of the error

The setting-out tasks of various building elements and corresponding verifications are normally vested with the contractors. The managerial practices in the Hong Kong construction industry are reasonably sound. In addition, due to the mandatory requirement of several clients, quality management systems are implemented extensively in both design and construction organizations. Furthermore, with professional staff and modern survey equipments, even minor mistakes are usually avoided in the setting-out works. Thus, errors of serious consequence owing to incorrect setting-out instances are not common in the Hong Kong construction industry. However, if such serious setting-out errors are not detected and rectified in time, there will be severe cost and time impacts, e.g. due to temporary setbacks and lasting implications. Moreover, several design changes would have to be implemented to redress such errors. A case-study regarding one such occurrence of a serious late discovery of a significant setting-out error, which occurred in a recent private building project is reported in this section.

Project details

The referred project is a low-rise building project situated in a remote site. The civil and building services works of this project included two contract packages, i.e. (i) foundation contract and (ii) superstructure contract. The foundation contract included related works such as site formation and drainage diversion in addition to construction of piles, whereas

the superstructure contract included construction of pile caps, associated excavation and lateral support works, construction of superstructure, all electrical and mechanical services (including internal and external drainage works), and approach roads. Both contracts followed traditional procurement approach (i.e. design-bid-build) with lump-sum arrangements. Moreover, the private client employed a project manager to manage both design and construction phases. The project site is featured with a hillside slope at the rear side.

Causes and Impacts

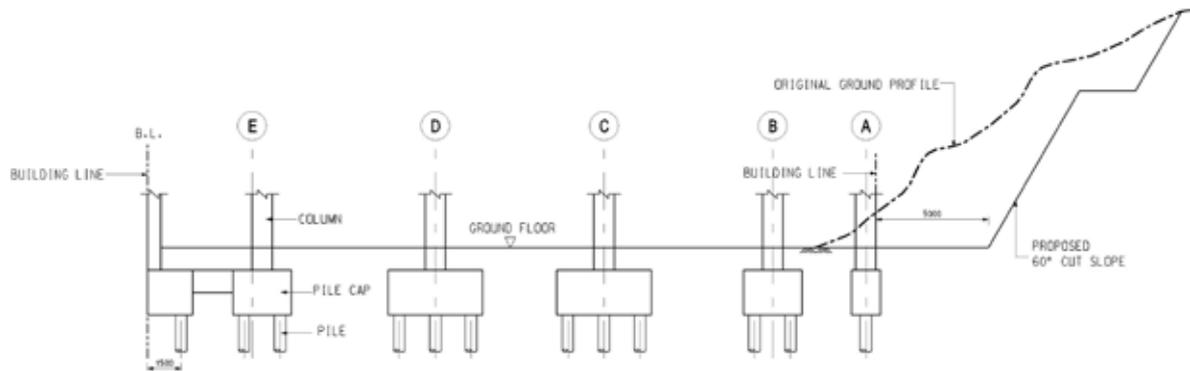
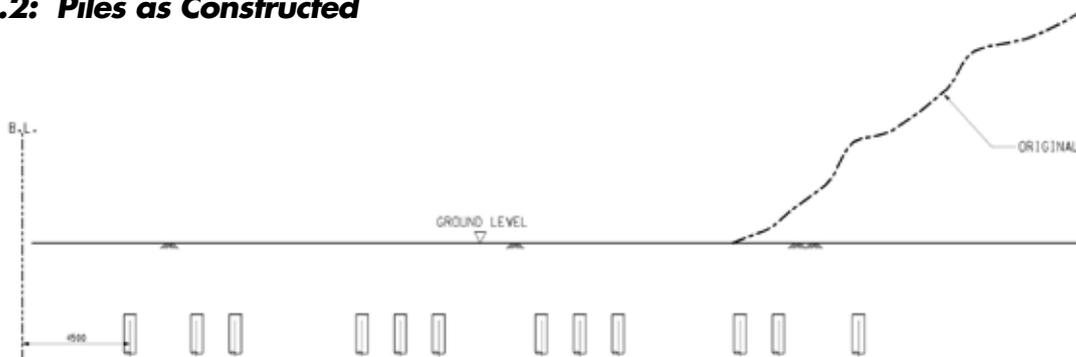
The setting-out of any construction work is normally carried-out by the contractors and most of the contract documents in Hong Kong affix sole responsibility with contractors in clear terms. Hence, 2 to 5 resident surveyors will be employed by the contractors and the number of surveyors at site will be based on the size and complexity of the project. In many cases, the engineers, architects and other supervisory personnel may not be adequately proficient to precisely verify the correctness of the setting-out. Occasionally, the project manager may employ an independent surveyor to verify the contractor's outline setting-out before commencement of the work.

In this reported case, the foundation contractor commenced the foundation works soon after the contract was awarded. Initially, the foundation contractor had incorrectly set-out the building outline. Due to some poor managerial practices and inadequate quality management in his part, this error was not detected and rectified immediately. Consequently, all the longitudinal gridlines (i.e. alphabetical notations A, B, C, D, and E as in Figure 1.1) and the piles along those gridlines were wrongly set-out, offsetting by 3 meters away from their intended positions towards the hillside. Subsequently, all the piles were constructed in wrongly set-out locations. Apart from this undetected error, the 3-months

duration of piling work activity was delayed earlier with 2 weeks extension of time for some other excusable delays.

Normally, minor setting-out errors of some piles (i.e. offsetting by few centimeters) may be deemed acceptable or easily rectifiable and many cases with such occurrences have been identified in this research. Wherever necessary, some redesigning of (a) pile caps and/or (b) connecting ground beams may be resorted for such minor errors. However, the extra costs will be mostly borne by the foundation contractors in such minor error instances. However, major setting-out errors including wrong setting-out of whole set of piles as found in this case is typically uncommon in the local industry. Hence, knowing the background of this particular case of a major error occurrence as well as particulars of managing the subsequent consequences will be useful.

Figure 1.1 portrays an indicative cross-section of the design intent and Figure 1.2 portrays the piles as constructed with 3 meters offset of setting-out error. Upon completion of pile driving, chosen piles were load tested and the local authority granted consent to proceed with excavation and pile cap works. Subsequently, the superstructure contractor excavated for pile cap construction and the error was discovered as piles had been driven-in at wrong locations. The project manager instructed both the contractors (i.e. the two designated for foundation and superstructure works) to carry out a joint survey and the foundation contractor confirmed that they had wrongly set-out the building outline and that consequently, all the longitudinal gridlines and piles are also not in correct positions. Upon the late discovery of this error, the project manager immediately issued a 'Certificate of Non-Completion' to the foundation contractor. Additional unwarranted impacts included design and construction rework, the time and cost impacts, need for additional resources and wastages.

Figure 1.1: Design Intent**Figure 1.2: Piles as Constructed**

Management measures

For managing this atypical rework scenario, the design team considered various options and two viable alternatives, both of which are presented in this section. The first option (i.e. 'Option 1') as portrayed in Figure 1.3 was to keep the building footprints unchanged by designing a combined pile cap with additional piles wherever required (e.g. in the front portion of the structure). Moreover, in this option, there was no need for the locations of columns and walls to be drastically changed as the foundation could be redesigned with piles already driven and additional piles as required for the new arrangement. However, this option raised some concerns such as programme impacts and statutory approvals and consents.

In Hong Kong, the private building works are strictly controlled by the Building Authority (BA).

Hence, the client was required to appoint an Authorized Person (AP) and a Registered Structural Engineer (RSE) who could submit the plans and requisite forms to BA for necessary approvals/consents and who could oversee the construction works. According to this arrangement, the foundation works and superstructure works, including the interface, were carried out in the following sequence: (i) submission of foundation plans by AP/RSE; (ii) approval of foundation plans by BA; (iii) completion of foundation work; (iv) submission of as-built foundation plans by AP/RSE; (v) selection of pile/raft for loading test by BA; (vi) satisfactory completion of loading test; and (vii) BA granting consent to commence pile cap and superstructure works. When this setting-out error was discovered, all the above-mentioned approval/consent steps had already been carried-out.

Fresh set of approvals and consents were

Figure 1.3: Option 1 - Piles Displaced, Combined Pile Cap (Additional Piles Required)

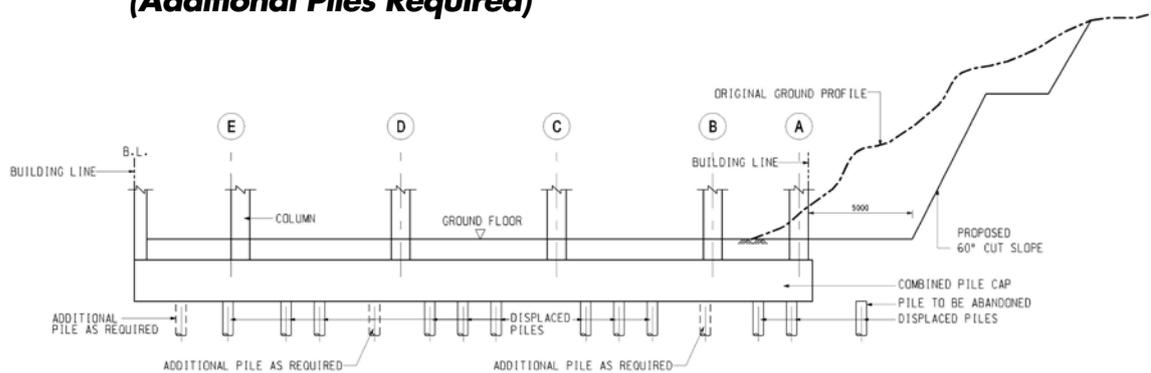
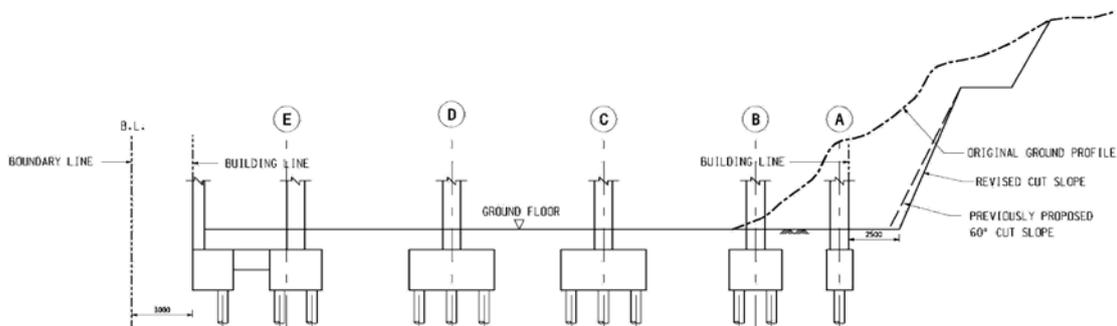


Figure 1.4: Option 2 - Piles Displaced, Whole Building Shifted (Adopted Scheme)



required for the rework and related mending changes which arose from the late discovery of the setting-out error. These above-mentioned statutory approvals and consents had to be repeated. As the 'Option 1' required redesigning of foundation with additional piles, fresh approvals/consents were necessary (including load tests for additional piles), which would delay the superstructure works as well, i.e. till that time the superstructure contractor who had already commenced his works should wait. However, the 'Option 1' had some advantages too. By keeping the building footprint unchanged, statutory resubmissions were not necessary for the superstructure part. Moreover, the original proposal for slope cutting works need not be revised (i.e. on the rear side). Thus, an originally proposed footpath behind the building could be retained and the hillside slope could be stabilised to the required standards as planned. However the disadvantage of programme impact was the

dominating decision criterion for this private client and hence 'Option 1' was not pursued.

The second option (i.e. 'Option 2') proposed by the design team was mainly to shift the whole building by the erroneous offsetting distance (i.e. 3 meters) towards the hillside slope. Figure 1.4 portrays the details of 'Option 2', which was finally considered in this project. The set of pile caps and columns by this option could be built right above the existing 'wrongly-driven' piles. Moreover, the structural framework of the building remains unchanged, though shifted. In addition, the required revisions to architectural and structural layout were minimal. However, additional slope cutting and revision of stabilisation measures for the slopes behind the footpath were required. The width of the footpath was reduced to satisfy the minimum requirement in planning regulations, which reduced the extent of the additional slope cutting. Then

the superstructure contractor continued with the pile cap works as per 'Option 2' and in the meantime statutory approval for shifting the building and additional slope cutting was obtained. Thus, no substantial time delay was experienced. However, the design team had to revise relevant drawings for the building shift and slope cutting changes. These design changes involved additional design costs. In addition, the revised slope works related to cutting and stabilisation measures involved additional construction costs. The costs for all such rework and revisions were recovered from the erring foundation contractor in this project, i.e. about 17% of his total contract amount was recovered which was much higher than his own profit markup for this project.

Lessons learnt

This case-study illustrates the significance of verifying the setting-out. In most of the public projects in Hong Kong (including government and quasi-government projects), a team of resident site staff are employed including a set of surveyors. But, in private sector developments, only the services of respective contractor's surveyors are relied upon. However, the Buildings Department (BD) has recently strengthened safety and quality supervision requirements. Quality Supervision Plan (QSP) for foundation works is mainly to ensure that piles/rafts are founded in a stratum as intended in the design. According to this QSP arrangement, a fulltime resident engineer nominated by RSE and to be agreed by BA, among his other responsibilities, has to verify the setting out of every single pile before commencement. Such checking arrangements would be helpful in avoidance of drastic errors and preventing resultant rework and wastages. Nevertheless, the construction industry may benefit considerably by choosing to appoint an independent land surveyor to periodically verify the contractor's setting-out works and to avoid serious late discoveries.

CASE – 2: ERROR OF WRONGLY ASSUMING A STANDARD PRACTICE

Basic description of the error

As a standard practice, construction drawings normally contain various general notes and typical-detail drawings. Such notes and details are generally typical for many similar projects. Thus, some notes and details are normally 'reused' with minor modifications in comparable projects. Although this is a common practice in building projects, as numerous common details might be similarly relevant for many cases, necessary care should be exercised while applying such standard references. Additional notices (e.g. warnings, disclaimers) and necessary distinctive information should be included for individual cases, e.g. for elaborating specific items that are substantially different from assumed standards.

Project details

This case-study refers a recent multi-use building project of a public sector client. The procurement arrangement for the construction phase in this project is a traditional design-bid-build approach with lump sum contracts. As in the previous 'Case 1', the project delivery mainly included two construction contracts such as (a) foundation contract and (b) superstructure contract. Although this project was procured with traditional approach, the public client employed a team of resident site staff as construction managers who were independent of the design consultants.

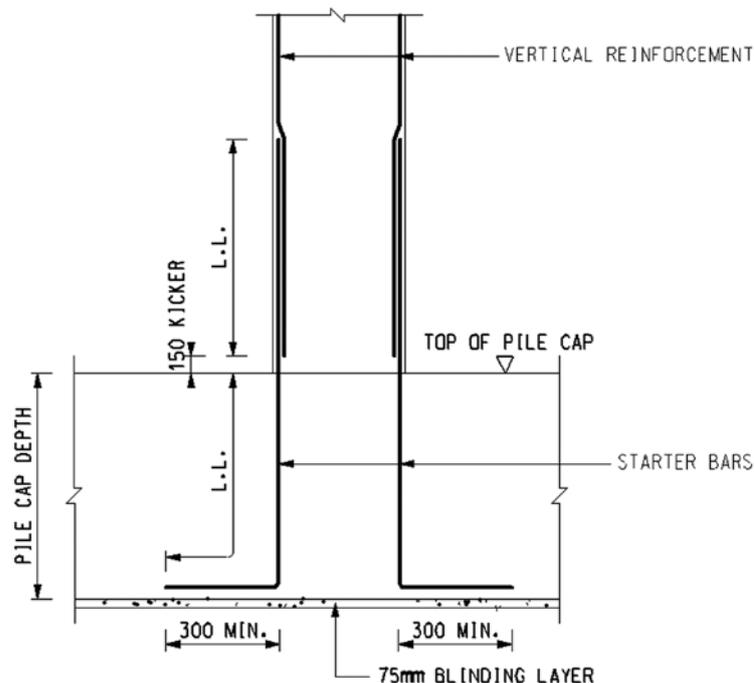
Causes and impacts

Figure 2.1 portrays the standard arrangement for reinforcement details for the column starter bars. According to this standard practice, the reinforcement bars should be taken down to the pile cap bottom level. Besides, the

embedment length of "L.L." (i.e. abbreviation for tension lap length) requirements should be met. According to this arrangement, "L.L." should include a minimum of 300mm L bend, and the minimum lap length (specified elsewhere) shall be 46 times the bar diameter. For example, considering a normal pile cap of 1.5 meter depth and 40mm diameter of column reinforcement with a 50mm cover, corresponding "L.L." is 1840mm (i.e. 46×40), and the available vertical length within the pile cap would be 1370mm (i.e. $1500\text{mm} - 50\text{mm cover} - 80\text{mm for 2 layers of bars each 40mm diameter}$), whereas the remaining 470mm would be provided horizontally as an L bend. In such normal cases, the column bars will reach the pile cap bottom. However, from structural point of view, the column bars need to be embedded into the pile cap only for the required tension anchorage length, and it is not necessary that bars should reach the bottom of pile cap, unless there are some special demanding requirements.

In this multistory building project, pile caps for the main tower were of 4m deep and the contractor intended to embed only "L.L." into the pile cap, which was 1840mm for the 40mm bars. As the pile caps were deeper than usual, the intended anchorage length could not reach the pile cap bottom. Moreover, for the constructability reasons, the contractor had proposed to concrete the cap with three horizontal construction joints (CJ) (with three parts of 0.7m thick and one part of 1.9m thick layer). Thus, CJs were formed at depths of 1.9m, 2.6m and 3.3m from the top of the pile cap. In this case, the starter bars would not pass through any of the CJs. But the structural engineer expected that the starter bars would be taken down beyond the CJs and preferably up to the pile cap bottom level. Conversely, the contractor assumed that according to the contract drawing, only tension anchorage length would be provided into pile cap and the starter bar need not be

Figure 2.1: Typical Detail of Column Starter Bars (Contract Drawing) N.T.S.



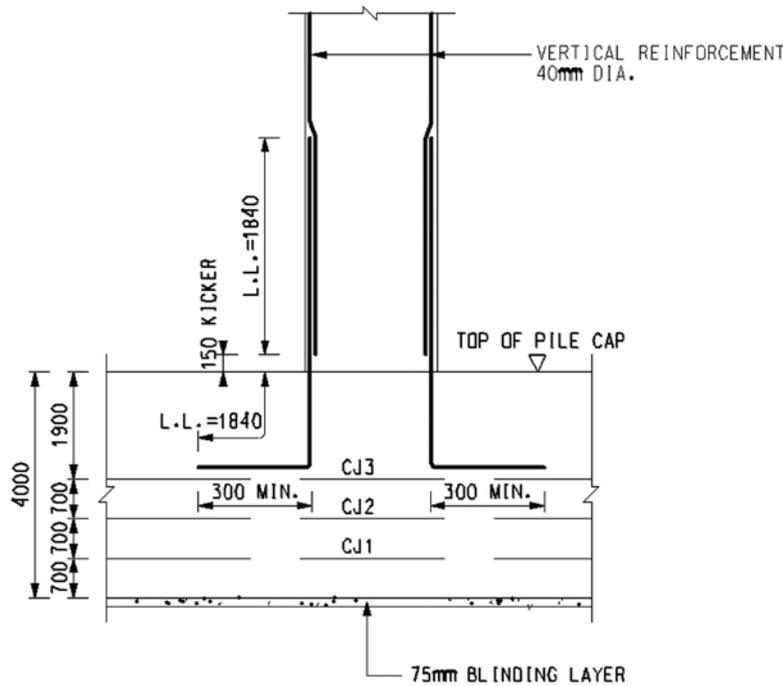
extended down to the cap bottom. The contractor's interpretation is portrayed in Figure 2.2.

The concerned project was of a special situation in which the typical details are not suitable. Given the large size of the pile cap, concreting in several pours was expected. Necessary precautions of such piecemeal concreting had been included in the concrete specifications. But the specifications of typical details were not modified to suit the deep pile cap. However, the experienced contractor anticipated that he would be asked to take the bars down to the pile cap bottom. Hence, he raised the issue ahead of steel bar installation. Thus, the error discussed herein came to light in the initial stages of superstructure contract work and hence serious rework and wastages were avoided.

Management measures

In this project, the pile cap is 4m deep and hence CJs were necessary for constructability. The starter bar detail was ambiguous in the contract drawing and hence the erroneous assumption was made initially, it was subsequently considered as desirable to extend the starter bars passing through the CJs. Consequently, the engineer had to convince the project team on his intended requirements for taking the bars down to pile cap bottom. If the intention of providing the starter bars up to the pile cap bottom had been expressed in an unambiguous way (e.g. with relevant cautionary messages), related claims and variations could have been avoided. Earlier, the project quantity surveyor agreed to the contractor's interpretation. However, the engineer insisted that the bars

Figure 2.2: Contractor's Interpretation
(Contractor's Proposed Construction Joints Inserted) N.T.S.



should be taken down to the bottom of pile cap, as the proposed construction sequence included casting in several pours with three CJs, the starter bars should pass beyond all the CJs. The design team quickly discussed, and the construction manager took stock of the technical requirement, deficiency in the drawing and contract implications and took a decision without any time loss. Subsequently, the construction manager issued formal instructions to the contractor for extending the starter bars up to pile cap bottom and this constituted a necessary variation. Figure 2.3 portrays the 'as-built' details of starter bars.

Lessons learnt

This case illustrates that implementation of standard practices without adequate checking of suitability aspects can lead to errors. Before inserting standard details into the tender set of drawings, corresponding suitability for the particular project should be carefully checked. In

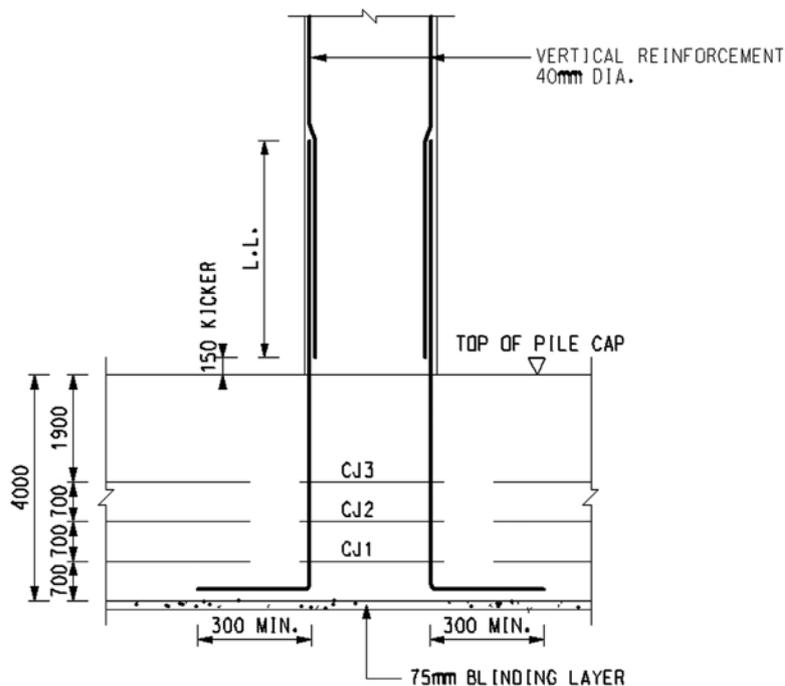
this case-study, not inserting additional warning notices and not exercising adequate care (e.g. verifying on applicability of standard particulars and constructability) had caused additional costs to the project stakeholders and the ripple effects included embarrassment to a design consultant. Adequate care and appropriate systems can prevent such errors. Early discovery will reduce the damaging impacts on costs and schedules, and ripple effects can also be avoided.

CASE – 3: LATE DISCOVERY OF A DRAFTING ERROR

Description of the error

All construction projects are multi-disciplinary, and however small it is, engagement of several design consultants is necessary. For ensuring performance and project success, relevant project leadership roles (e.g. by lead consultants) and appropriate interface coordination arrangements (e.g.

Figure 2.3: Starter Bars as Constructed N.T.S.



between foundation and superstructure works) are necessary. Depending upon the project type (such as building works and infrastructure projects) such lead roles may vary. In addition, design managers may be employed in some projects. Inadequacies in such arrangements including lack of clarity and poor interface coordination can result in dysfunctions such as rework and wastages. In this section, a design related rework occurrence due to late discovery of a drafting error is presented. This error led to the demolition and rebuilding of a portion of the work, the cost of which was borne by the design consultant.

Project details

This case-study refers to a recent private project that mainly included the design and construction of a plant and a 40-meter tall steel chimney. The private client is a manufacturing company. The plant and chimney were part of a research study jointly conducted by the client and an educational institution. The purpose of the plant was to enable the recycling of some wastes by thermal treatment. The steel chimney was designed by a specialist mainland firm, which also fabricated and erected it. The client employed a consulting engineer to design the foundation of the chimney. In addition to the foundation design, the consultant was also nominated as the RSE (under the Building Ordinance) and he was required to manage the submission of the aforementioned specialist's drawings and calculations (as per local codes and regulations). The engineer designed the raft foundation based on the chimney loadings, with a RC ring beam on the top together with threaded bolts embedded into it for fixing the steel chimney.

Causes and impacts

After completion of design and submission requirements, a foundation contractor completed the foundation works as per the engineer's drawings and specifications. But, before installing the tank, the superstructure contractor found that bolts installed in the foundation were not in correct position to build

the steel chimney. It was subsequently discovered that the bolt locations shown in the engineer's drawings were incorrect, and did not match those in the chimney drawings. This resulted in significant wastages and unwarranted rework. Moreover, the project was also delayed. The root causes include poor communication, lack of coordination and absence of well-defined design leadership for effective design management.

Management measures

Due to the late discovery of this design error, subsequent construction works were affected. Since the error of misplaced bolts was discovered after considerable advancement in the construction phase, easily implementable options were not available for rectification. Consequently, the ring beam was demolished, the bolts were re-fixed at correct locations and the beam was re-cast. Although design leadership in this project was not well-defined, the client felt that the consulting engineer should be held responsible for this rework and wastages as he should have avoided this drafting error or at least should have discovered it much earlier. Hence the client decided to recover some costs from the consulting engineer, such as the direct costs of demolishing and re-constructing the ring beam. Due to this recovery, the engineer had to forego most of his consultancy fee and his reputation was also affected.

Lessons learnt

The error referred to in this case is a drafting error (or 'draftsman error'), but the engineer had to pay a price in this project. This case illustrates the importance of interface-coordination and necessary verifications. Normally the design coordination roles of electrical and mechanical services in building projects will remain with the main civil contractors, who should also coordinate with his own sub-contractors and other nominated specialist contractors. A main contractor should prepare 'combined builders work drawings' or 'structural electrical and mechanical drawings',

showing relevant details including all openings and fixtures. In order to prevent errors, such drawings should be vetted by the design consultants. From the case-study observations (including respective interviewed perceptions), it is apparent that the managerial measures and quality management systems were not rigorous in the supply chain because this project was relatively small. More importantly, the interviewed perceptions revealed that due care might have been missing, with respect to coordination amongst contractors and consultants. In order to avoid such errors and carry-forward rework effects, the consultant should provide all relevant superstructure drawings to the respective civil contractor and the latter should be asked to check the bolt locations and alike before carrying out the subsequent works. In addition, the superstructure contractor should be asked to comment on the engineer's foundation drawing. Such good practice measures would have relieved the consulting engineer from bearing the entire burden in the aforementioned case. Nevertheless, adequate care should be exercised in drafting and checking the details involving multi-interface works.

SUMMARY AND CONCLUSIONS

Three interesting cases of design and construction errors which occurred in recent project are presented in this paper. The case-study illustrations provide useful dissemination of those error examples with highlights on causes and impacts, management measures and lessons learned knowledge-sets. For example, the first case cites a late discovery instance of one non-typical construction error which necessitated a series of design and construction rework. Although some recovery was made from the erring contractor, some impacts were experienced by other project participants as well. In the next example, a wrong assumption of a standard practice led to a design error which might have caused some serious problems including defects. However, this error was detected subsequently before actual

construction. However, as the tendering phase was already over and the contractor had already commenced some works, this error led to some formal variations and additional costs. The other case referred to another late discovery of a design error caused by multiple dysfunctional reasons such as unclear project leadership role, lack of design verifications and interface coordination. In this case, the default designer had to pay for the error consequences and some tangible/intangible ripple effects might have been felt by other stakeholders.

Thus, design and construction errors in projects can lead to serious concerns as the resulting rework and wastages will affect project performance and productivity aspects. In general, the errors are avoidable. Necessary mechanisms for prevention/reduction of errors should be in place. Moreover, timely discovery of error occurrences will minimize the extent of impacts. But, several inadequacies in project systems (e.g. lack of knowledge, poor coordination, and mediocre quality management) add to difficulties for such timely discoveries and/or prevention measures. Since time pressures and resource limitations are common in the construction industry, many of the error-related dysfunctions and lessons are not properly documented in all cases. Hence, developing a knowledgebase of error-related case-studies is considered as useful, e.g. finding ways to avoid errors, formalizing recording of error occurrences and constructing systematic knowledge systems. Moreover, such measures and knowledge systems should be suitably integrated with project-based operational systems and other learning frameworks.

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