Forensic Engineering – Neale (ed.)
© 2005 ICE (Institution of Civil Engineers), London, ISBN 0 415 39523 2

Investigating substandard piles in Hong Kong

S.R. Hencher, J.T. Tyson & P. Hutchinson
Halcrow China Ltd.

ABSTRACT: Since 1999, several cases have been reported in Hong Kong where piles have been installed poorly or fraudulently.

Examples are provided from two cases that were investigated by the Independent Commission against Corruption (ICAC). At Tin Shui Wai, many of the driven piles for two 41-storey apartment blocks were shown to be shorter than reported and numerous other defects were identified. Remedial works cost considerably more than the original piling contract sum. At Shatin, many large diameter bored piles were proved to be too short and founded on poor ground. Two apartment blocks had to be demolished. Investigations of these cases were carried out to a forensic level to satisfy the required burden of proof in criminal trials.

The "short pile" cases caused a scandal with severe criticisms by a Legislative Council committee and criminal convictions. Several senior staff resigned from the Housing Authority. Subsequently supervision requirements at sites have been tightened.

1 INTRODUCTION

Since 1999, several cases have been reported in Hong Kong of buildings where piles – including bored piles, driven "H" piles and pre-cast spun concrete piles – have been installed poorly and, in some cases, fraudulently. While in most cases the substandard piling has been investigated by the owner, some have also been investigated by the Hong Kong Government's Independent Commission Against Corruption (ICAC) and these investigations have led to a number of prosecutions and convictions. By the time the instances of substandard piling in public projects were discovered, suspected piling problems were already being investigated on 15 private projects (Ho, 1998). Subsequently, many additional cases were identified involving major public housing and transportation infrastructure projects.

In the late-nineties, many projects faced extremely demanding programmes and heavy penalties for late completion. In this climate, a number of piling contractors resorted to poor or fraudulent practice.

The first major case to come to light occurred in 1999 on the Mass Transit Railway Corporation (MTRC) Central Station project (see Figure 1), where 82 out of 87 piles were found to be shorter than both specified and reported (Dept of Justice, 2000). Subsequent investigations found that measuring tapes had been doctored to give the impression that the piles were of sufficient length, false concrete delivery dockets were produced to exaggerate the quantity of concrete used in each pile and as-built records had been deliberately falsified.

In 2000, it was discovered that piles for a residential project forming part of the Tung Chung Station Development were also substandard (Dept of Justice, 2000). In this case, it was found that false representations had been made to demonstrate the piles were adequate in a number ways, including:

- using "doctored" measuring tapes to misrepresent the true depth of the piles, as in the Central Station case;
- constructing steel cages for inspection that were sufficient for the approved founding levels, before cutting them short after inspections were completed;

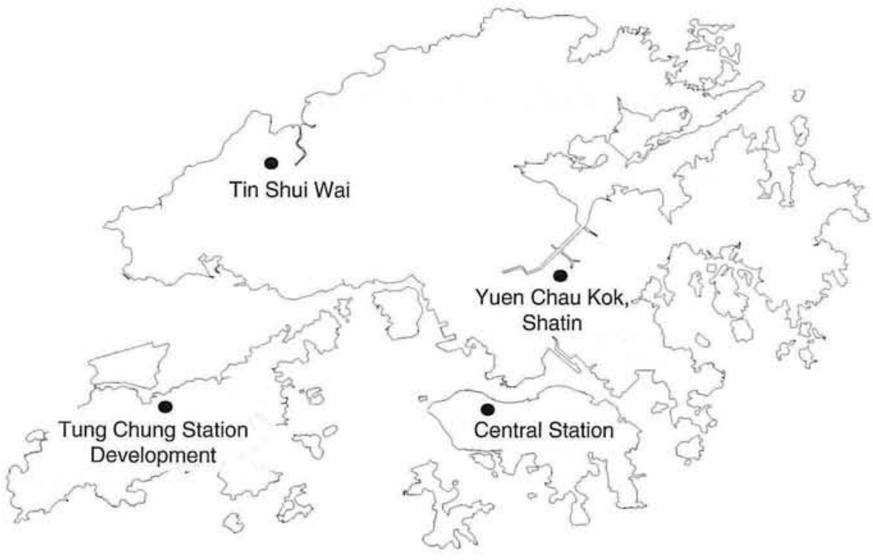

Figure 1. Location plan of sites in Hong Kong referred to in text.

- hiding the excess quantities of waste cut steel to avoid suspicion of the above practice;
- drilling prior sufficient length of core samples from various locations to inspection to give inspectors the impression that piles were of sufficient depth;
- ordering sufficient concrete for the design volume of the piles and then entering into agreement with the concrete supplier to stop delivering once the pile was full; and
- knowingly signing and submitting documentation containing falsified information.

Halcrow China Limited (HCL) was employed to assist in the investigation of two major cases of substandard piling and these will form the subject of this paper. One case involved a public housing project in Tin Shui Wai and the other a public housing project at Yuen Chau Kok, Shatin. This paper sets out in detail the investigations undertaken by HCL to ascertain the actual lengths of pile installed, instances of poor practice and cases of deliberate deception.

2 NATURE OF FOUNDATIONS IN HONG KONG

2.1 *Geotechnical conditions*

Hong Kong is sub-tropical and rocks are often weathered to great depths. The main urban areas are underlain by granite or more rarely volcanic rocks. In one or two areas marble sub crops beneath sediments. The weathered and altered nature of these rocks poses major challenges to foundation designers and contractors. One of the problems is heterogeneity whereby strong rock can occur higher in the ground profile underlain by weaker, more weathered material, often concentrated along joints. The marble can be karstic with caves at depth infilled with soft sediments (Houghton and Wong, 1990; Fletcher, 2000). Whether or not such weaker horizons, particularly bands of weathered rock along joints, pose any particular problem for the integrity of foundations is a matter of some discussion between designers and the Buildings Authorities in Hong Kong who err rather on a conservative side in requiring foundations to be taken to bedrock or otherwise proved by extensive testing (Li et al, 2000).

2.2 *Foundation solutions*

In past years, many buildings in Hong Kong were founded on piles formed by hand dug caissons. These were constructed generally by husband and wife teams and had the advantage of flexibility.

Figure 2. SPT sample from test carried out within rock for recent piling contract.

If they hit rock they would use appropriate methods to advance the hole; if weaker soil-like weathered rock, then excavation would continue accordingly. This practice was banned in 1994 for safety reasons. Consequently, deep foundations are now all mechanically formed, either by driving piles or by boring first. Because of the risks of corestones of strong rock at high levels driven piles are somewhat risky.

In Hong Kong, there is a concept that bored piles must be founded on bedrock and even then only low bearing pressures are allowed. This has been a matter of debate for over 30 years (Lumb, 1972; Thomas, 1984).

Guidance on presumed bearing pressure is given by the Buildings Department (1995). According to that guidance, the founding material is acceptable for a bearing value of 5 MPa if the total core recovery of Grade III rock or better is 85% or more. To quote Li et al (2000):

> *"strictly speaking, it will mean that it is acceptable to have up to 15% of the rock mass occupied by weathered soil seams. Unfortunately, most foundation designers and government authorities who control the acceptance of the bored piles are not at ease with the presence of some soil seams close to the pile toe and would often require some remedial works to be carried out to deal with the 'problem'."*

In practice if there is any material weaker than weathering Grade III recovered below toe level many engineers will insist that piles are taken deeper. This gives rise to some poor engineering practice, driven by the need to avoid delay in approval or because of lack of confidence/experience. For example, Figure 2 shows a core from a pre-drill for a bored pile in excellent quality granite with an SPT test having been carried out (almost zero penetration after 100 blows) in a pegmatite zone. Presumably drilling became slightly easier and so the cautious engineer decided he had better treat this zone as soil with consequences for the design.

Currently all bored piles are not only "pre-drilled" – i.e. the ground is "proved" to be the required quality of rock – but are now also checked by post-construction drilling. That drilling is not only to check pile length but also to check that the concrete/rock interface is acceptable (Buildings Department, PNAP 66, 2004).

With regard to driven piles the common practice is to drive the working piles using a hydraulic hammer "to a set" but then to measure the "final set" at some later stage using a drop hammer. This practice stems from local experience and confidence in using the Hiley formula with drop hammers. Hydraulic hammers are more efficient than drop hammers (can produce more energy per blow) yet, rather than reduce the required set for hydraulic hammers, local practice is to use drop hammers as a calibrated test of set after the pile has already been driven. But as noted by Li et al (2003):

"Hong Kong is perhaps the only place in the world where contractors use modern efficient hydraulic hammers for pitching of piles and medieval drop hammers for final setting of piles."

One argument put forward to justify this practice is that the pile might take up strength with time as sometimes happens in sands and clay (Hencher & Mallard, 1989) and has also been observed in Hong Kong conditions (Siu & Kwan, 1982). Whether or not that makes it good practice is a debatable point.

It is against this background of often rather difficult ground conditions with heterogeneous mixtures of weathered rocks of different weathering grades at rock head, very demanding and generally over conservative requirements by the Authorities and very competitive tendering, that the short pile scandals occurred. It might be added that at that time, the Authorities were generally trying to reduce the costs of supervision which meant that many sites were supervised by inexperienced people who often worked hours which were rather shorter that the Contractor's hours, leading to works being carried out without supervision. Buildings Department (2000) has since issued further notes on supervision requirements for foundation works.

3 TIN SHUI WAI

3.1 *Background*

Tin Chung Court is a Hong Kong Housing Authority (HKHA) development comprising 6, 41-storey buildings and two schools. The type and density of building is illustrated in Figure 3.

3.2 *Ground conditions*

A ground investigation carried out in the early 1990's showed the geology to comprise fill and superficial deposits down to a depth of about 10 metres, overlying decomposed volcaniclastic sediments

Figure 3. Housing blocks at Tin Shui Wai.

with SPT "N" value increasing gradually to more than 50 at a depth typically of 30 to 40 metres (Figure 4). A foundation advice report in 1996 estimated that piles should be a minimum of 30 metres in length and that, if driven piles were to be used, pre-boring might be required in many cases to get through "hard pans" (stronger layers) at higher levels.

3.3 *Pile type*

The contract was awarded in September 1996 to a contractor proposing to use driven pre-cast, pre-stressed concrete piles (PPC), otherwise known as Daido piles. These piles are cast generally in 8 or 12 metre segments. The pile section is circular with a hollow centre. Each concrete segment has a metal cap which allows segments to be welded together to form longer piles as each segment is driven into the ground. At the pile tip, a metal conical shoe (0.3 m long) protects the pile while driving. All piles were to be trimmed off to cut-off level. In order to save cost and materials, steel "followers" were often used to drive the tops of piles below ground surface awaiting exhumation and the construction of pile caps.

3.4 *Design requirements*

Each pile had a designated working load of 2.7 MN. The piles were to be driven to set (using the Hiley formula) but also had to be driven to a depth calculated according to a "Static Load Formula". The way that was to be determined was by driving a "Preliminary Pile" (PP) for each housing block close to an existing borehole indicating the worst conditions in that area. Each PP was to be instrumented with strain gauges along its length and then tested to more than twice the working pile load (5.4 MN) which was the required Factor of Safety for the working piles. Shaft

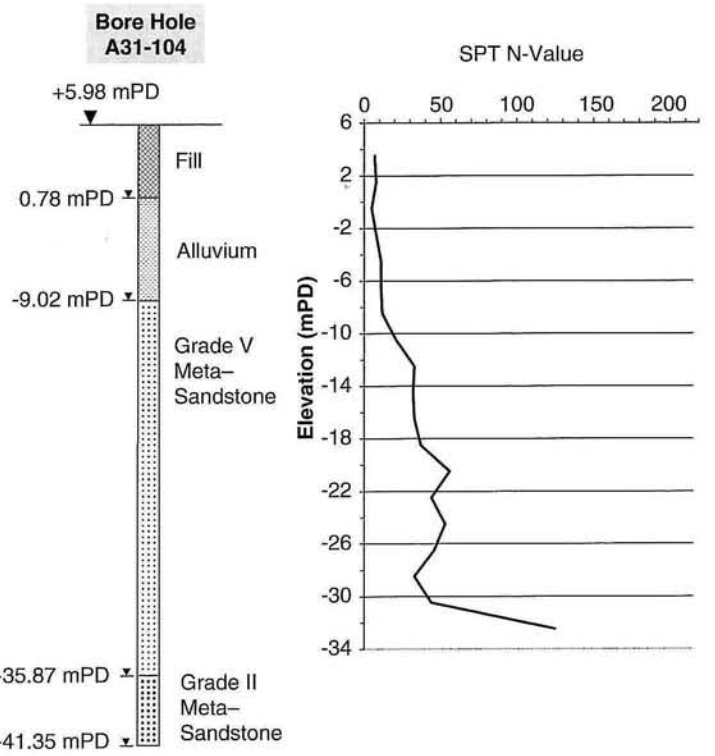

Figure 4. Example of ground conditions at Tin Shui Wai.

friction values were to be determined for each of the strata from these tests that could then be used in ensuring that the working piles were driven to an adequate depth.

3.5 *Construction practice*

In the event, many of the working piles were installed for Blocks 1 and 2 before the first "Preliminary Pile" was installed and tested (as was permitted under the contract). These piles had been installed to various *reported* depths of between 22.8 m and 33.9 m. Subsequently data supposedly from the PP tests were presented by the Contractor that purported to justify the reported installed lengths of the working piles as discussed later.

3.6 *Settlement*

In 1999 it was found that lifts could not be installed into Blocks 1 and 2, apparently due to tilting of the superstructure. Various consultants were employed to advise different parties regarding remedying the situation and to advise on legal aspects.

HCL, with the lead author named as Expert Witness, was employed by the ICAC to assist in investigations with respect to possible criminal action. As such HCL worked in parallel to others advising on remedial works but with particular concern regarding the collection of evidence to a forensic level.

3.7 *Pile lengths*

An immediate question concerned the integrity of the working piles. Most of these could not be accessed because of the superstructure but several of those on the periphery could be. The hollow section of the pile allowed investigators, once the top had been located and broken out, to lower a video camera down the hollow part of the pile and visually inspect the condition and measure the toe depths of the piles. Thirty-two piles below Blocks 1 & 2 were inspected in this manner as illustrated in Figure 5.

Significant discrepancies were found between observed and recorded pile lengths for some piles. Indeed, 27 of the 32 surveyed piles were shorter than reported, with 15 more than 1 metre and 5 more than 5 metres too short. It was evident the blow count records recording the driving histories of these piles must have been falsified together with the reported installation depths.

3.8 *Other faults*

Other instances of bad practice (associated with fraudulent reporting) were discovered on excavation below some pile caps.

Figure 6 shows two exhumed pile segments that had not been welded together. The lower section is clearly an off-cut concrete section without a steel cap onto which has been balanced another length of pile (with metal cap) to bring it up to pile cap level. Figure 7 shows another "stub" pile hanging below the pile cap without any apparent pile beneath.

3.9 *Forensic studies*

Many of those individuals and organizations involved in investigating these matters were concerned either with structural integrity and the need for remedial measures to stabilize the building or contractual responsibilities and possible civil action. HCL's brief was different in that it was supporting ICAC in their investigations of fraud and the potential for criminal prosecution. The objectives are different.

For example, clearly from the point of view of those responsible for making the structures safe, the pile shown in Figure 7 has no bearing capacity and is to be ignored. However, in assessing this pile HCL was conscious that there were various site records available (regarding delivery and driving

Figure 5. Video inspection underway for one of the working piles.

Figure 6. Working pile segments without weld.

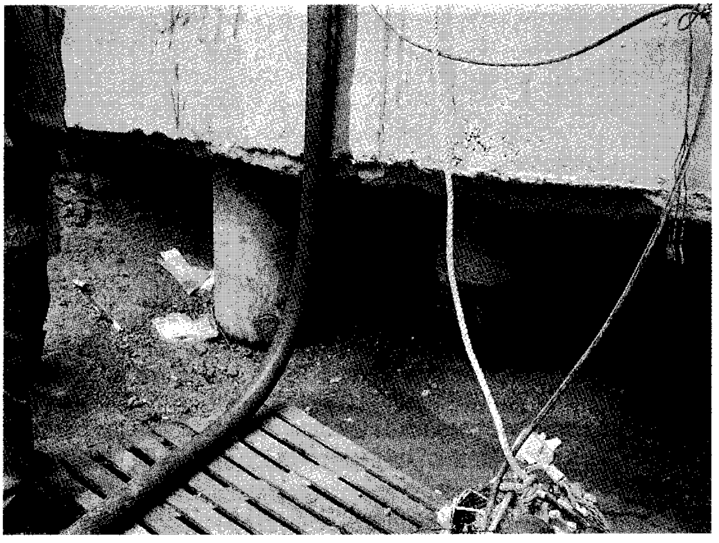

Figure 7. "Stub" pile below pile cap.

of pile segments, welding records, set records and so on) that might or might not all be fraudulent (with implications for individuals culpability). Therefore, HCL considered it important to investigate and understand the history of installation of individual piles. This involved a detailed investigation and analysis of all records.

In the case of the pile shown in Figure 7, probing with steel rods had suggested that there was no pile below the ground (within a metre or so). Nevertheless, in order to investigate more fully, HCL prepared a specification for several holes with pre-defined geometries that should intersect a pile if one actually existed below the location of the stub. Figure 8 shows the investigation underway and Figure 9 shows core recovered from a "buried" pile segment. This indicated that some

Figure 8. Inclined drilling to search for installed pile below stub pile in Figure 7.

Figure 9. Curved outer surface retrieved from hidden pile by coring.

pile segments had been installed as the records suggested, albeit with some questions unanswered. It was also clear that no attempt had been made to connect the "stub" to the buried pile below. The "stub" appears to have been placed to fool inspectors into the belief that a competent pile existed at that location.

Another example of the forensic investigation was the review of the strain gauge data from one of the "preliminary" test piles. As discussed earlier these were not carried out in advance of the working piles although the Contractor needed to use these test data to demonstrate that the piles already installed met the static load requirements by calculation of available skin friction and end bearing. The working piles in the vicinity had *reported* depths (a high proportion probably falsified) of installment between about 23 and 34 metres. From the CCTV surveys it seems that many of these had apparently been driven essentially to a target depth of about 20 m (using one 12 metre and one 8 metre segment) with a hydraulic hammer and were awaiting confirmation of final set using a drop hammer in the Hong Kong way. In many cases pile heads had already been driven a long way below ground level using a "follower". In the event of already installed piles being shown to be inadequate they would have had to be extended with additional pile segments before continuing driving, a process that would have been very difficult. In fact it appears that the strain gauge data from Preliminary Pile PP2 were manipulated in an attempt to prove the adequacy of the reported lengths of the installed piles.

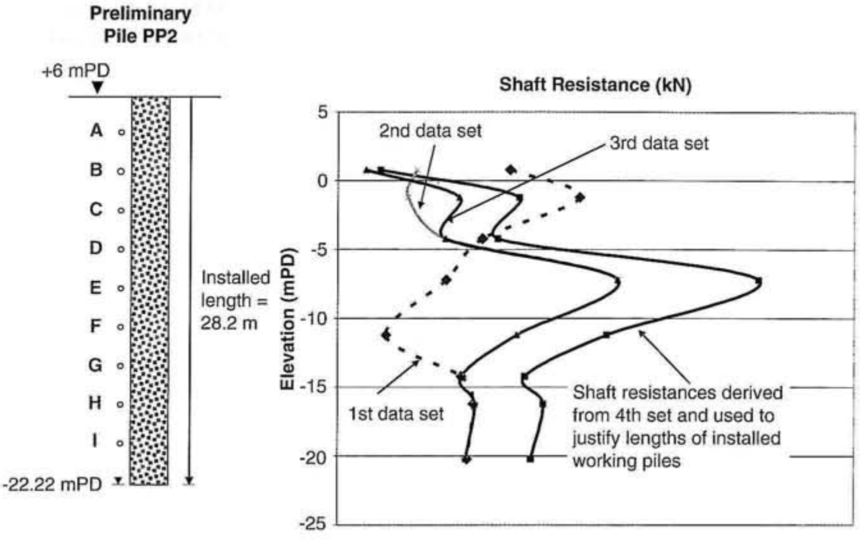

Figure 10. Shaft resistance inferred from strain gauge data (4 sets).

Nine sets of strain gauges were embedded in PP2 at positions A to I as illustrated schematically in Figure 10. Post test, data from each strain gauge were to be analysed to determine the amount of load carried in each stratum. A review of these data revealed numerous inconsistencies both in the test data itself and in the use of the data in pile load capacity and differential settlement calculations. Not least of these was the discovery, by the ICAC, of four different sets of data for the single test. One of the documents issued by the Contractor actually contained three of the four data sets in the same report, with the data presented in such a manner as to appear to present a single set of data.

The four data sets, which comprise what appears to be the original (un-doctored) data and three spurious data sets are shown in Figure 10. It appears that the data were revised (several times) in an attempt to indicate skin friction values higher than actually measured to justify shorter pile lengths than would be possible if the lowest (and probably "real") set of test data had been used. Using what is believed to be the real set of data for the test indicates the need for piles at least 24.5 m long, whereas some of the reported installation lengths were shorter than this, according to the site records.

A final point about the static load tests (preliminary and working piles): many results showed little residual (i.e. permanent) settlement and some actually show piles ending up at higher levels than they started (heaved). Such results, at the very least, indicate questionable test set up and recording techniques but went apparently without comment by the supervisory staff.

All final set records for the two housing blocks were reviewed. Sometimes, more than one final set record was available for a single pile, usually, although not always, following the failure of the 1st final set test to meet the required criteria. Close inspection of the final set records indicated that there may have been manipulation of the recording pen during some of the tests to give an artificially low penetration value.

3.10 *Conclusions regarding Tin Shui Wai*

In conclusion, the excessive settlement of the two housing blocks at Tin Shui Wai was probably the result partly of piles being fraudulently installed to shorter lengths than either reported or required by the original design or other poor practice in piling. The design itself was subsequently modified, at least in part, by what was apparently fraudulent data obtained from load tests to justify the recorded pile lengths. The actions of the Contractor were exacerbated by poor contract requirements, allowing piling to commence prior to obtaining proper field test data from load tests and the employment of inexperienced, supervisory staff who were incapable and/or unwilling to enforce good working practices on the contractor or were simple unable to recognise what was going on. In many ways this may be viewed as a salutary lesson what can happen when the risk of design and construction of foundation works is pushed onto the contractor by using a design and construct contract, without adequately providing protection in the form of good contract documentation and an appropriate level of experienced site supervision.

Following the discovery of these defects, remedial works costing of the order of HK$250 million were carried out to the foundations, which is more than three times the original piling contract value. Two of the site staff were convicted and given custodial sentences of seven years.

4 SHATIN

4.1 *Introduction*

The second case concerns two 41-storey housing blocks in the housing development at Yuen Chau Kok, Shatin, that were identified to be suffering excessive settlement in late 1999 to 2000. Investigations suggested that this was the result of the piles being materially shorter than the designed pile length by between 2 m and 15 m (Hong Kong iMail, 2001). Detailed investigation of the installed piles subsequently revealed that only four out of 36 large diameter bored piles installed below these two buildings met the specified founding requirements. Some of the piles were reportedly founded on "soft mud", rather than rock as designed.

4.2 *Halcrow's brief*

An investigation was carried out by other consultants into the causes of the settlement. This investigation involved drilling vertical coreholes through each of the piles to prove the length and nature of the pile material and the ground beneath each pile. The coring was by triple tube core barrel with foam flush from about 10 m above the reported toe levels. Where soft material was encountered, SPT testing was carried out. HCL's brief was to review the adequacy of the methodology of the main investigator, to provide an opinion on the verticality of the investigation drillholes and to provide a review of the investigation report. The first author was to act as an Expert Witness in the trial.

4.3 *Investigation*

Key aspects were the nature of rock or other material encountered in drill core "below" concrete and whether or not the drilled holes were vertical. There was concern and indeed it was argued in court that the drillholes might deviate from vertical and exit out of the side of the pile rather than the toe. It was also argued that some "sludge" might be forced up the side of the piles during tremying the concrete and that drills might deviate into that material, giving a false indication of the founding conditions.

HCL carried out independent inspections of all cores and identified many cases where logging was questionable. In several cases it was judged that the material below concrete was reconstituted (probably collapsed) completely weathered rock rather than "fill", "sediments" or "ingressed soil" as sometimes the original logs had it.

During drilling of two piles there was a significant tilting of one of the blocks in the direction of the piles and consequently the drilling was halted. Several other holes had to be terminated when they encountered steel. Surveys were carried out on each drillhole using a gyroscopic verticality probe. Three dimensional (birds eye) plots were prepared of all data by HCL. It was concluded that the coreholes had penetrated the full length of compliant piles and that similarly, for the many non-compliant piles, that the coring had remained within the circumference of the pile albeit with some anomalies. That being so it was concluded that the Contractor had installed piles that were too short. In several cases, holes had collapsed during construction and concrete has been poured on top of the collapsed material. In other cases, piles had been formed in and on saprolite rather than rock as the design required.

4.4 *Conclusions regarding Yuen Chau Kok, Shatin*

A formal investigation into the incident identified deliberate deception, poor contract management and a failure to carry out site inspection properly as the primary causes (LegCo Panel on Housing, 2003). Specifically, tapes were again doctored and also sonic test results were manipulated to misrepresent pile lengths (Legislative Council Proceedings, 13 February 2003). Ultimately, demolition of the two blocks, which were near completion when the problems first came to light, was considered the only viable option, at a cost of HK$542 million (Skyline News Update, 2002). Two directors and a site agent of a piling company were charged with conspiracy to defraud the Hong Kong Government. The directors were each sentenced to 12 years imprisonment. The site agent, who pleaded guilty and testified against his co-accused was imprisoned for 3 years 3 months. The same subcontractor was involved in another case of short piling, where piles below a pumping station on Hong Kong Island were found to be between 3 m and 14 m short. The former director of the subcontractor is serving concurrent jail sentences for the Shatin and this incident (ICAC, 2003b).

5 CONCLUSIONS

As a result of these and other piling scandals, all occurring over a relatively short period of time, major government reviews of piling contract supervision and administration were launched. The Construction Industry Review Committee made over 100 recommendations for improved practice and these are being implemented through the industry. In recent years, only one new suspected case of substandard piling on a major public project has come to light and is still under criminal investigation.

ACKNOWLEDGEMENTS

The important role and inputs by the ICAC in investigating these cases of fraud are acknowledged. This paper is based on information in the public domain.

REFERENCES

Buildings Department 1995. Practice Notes for Authorized Persons and Registered Structural Engineers No. 141 (PNAP No. 141): *Foundation Design.*

Buildings Department 2000. Practice Notes for Authorized Persons and Registered Structural Engineers No. 242 (PNAP No. 242): *Quality Supervision Requirements for Foundation Works.*

Buildings Department 2004. Practice Notes for Authorized Persons and Registered Structural Engineers No. 66 (PNAP No. 66): *Pile Foundations.*

Department of Justice 2000. *Criminal Appeals Bulletin Part 2, 2000*, Prosecutions Division, Department of Justice, Hong Kong.

Fletcher, C.J.N., Wightman, N.R. & Goodwin, C.R. 2000. Karst related deposits beneath Tung Chung New Town: Implications for deep foundations: *Engineering Geology HK 2000*, Institution of Mining and Metallurgy – Hong Kong Branch: 139–150.

Hencher, S.R. & Mallard, D.J. 1989. On the effects of sand grading on driven pile performance. *Proceedings of the International Conference on Piling and Deep Foundations*, London: 255–264.

Ho, Chung-tai Raymond 1998. *Question to LegCo by Raymond Ho Chung Tai*, 22 July 1998.

Houghton, D.A. & Wong, C.M. 1990. *Implications of the Karst marble at Yuen Long for foundation investigation and design*. Hong Kong Engineer, 6: 19–27.
ICAC (2003a). *ICAC Press Release*, 31 Oct 2003.
ICAC (2003b). *ICAC Press Release*, 23 July 2003.
LegCo Panel on Housing 2003. *Recommendations of Investigation Panel on Staff Discipline in Tin Chung Court and Yuen Chau Kok Incidents*.
Legislative Council 2003. Proceedings of Debate, 13 February 2003.
Li, K.S., Lo, S.C.R. & Lam, J. 2000. Design of deep foundations in Hong Kong – time for change? *HKIE Geotechnical Division 2000 Seminar*: 79–86.
Li, K.S., Lam, J. & Ho, N.C.L. 2003. *Design and Construction of Driven and Jacked Piles – Chapter 3: Driven Piles*, Centre for Research & Professional Development: 51–72.
Lumb, P. 1972. Asian Building & Construction. *Soil Engineering in Hong Kong*: November: 23–26.
Lumb, P. 1979. Building foundations in Hong Kong, *Proc. 6th Asian Regional Conference on Soil Mechanics and Foundation Engineering*, Singapore, 2: 211–214.
Hong Kong iMail 2001. extract from 12 October 2001.
Siu, K.L. & Kwan, S.H. 1982. Case history of a pile foundation in unusual ground in Hong Kong. *Proceedings of the Seventh Southeast Asian Geotechnical Conference*, Hong Kong, vol. 1: 423–438.
Skyline News Update 2002. Article issued on 29 October 2002.
Thomas, R.L. 1984. *Acceptance criteria for large diameter piles*. Hong Kong Engineer, 12, 12: 29–39.