IEM Report

Title: Open Forum on Dynamic Pile Testing
Date: 27th April 2010
Venue: IEM Auditorium, 3rd floor, Wisma IEM
Session Chairman: Ir. Mun Kwai Peng
Reported by : Ir. Liew Shaw Shong (Organising Chairman)

On 27 April 2010, the Geotechnical Engineering Technical Division (GETD) of IEM held a half-day open forum on the much awaited topic of Dynamic Pile Testing, highlighting the concerns on current practice in the pile testing industry. The invited panellists include **Ir. Dr. H. M. Aziz** from the public sector representing project owner for public facilities, **Prof. Samuel G. Paikowsky** from the University of Massachusetts, USA, representing academicians, **Ir. Dr. Toh Cheng Teik** representing the consultancy practice industry and **Ir. Teh Kim Ong** representing pile testing specialists. The invited panellists aim to provide an insight from individual perspectives based on their role and responsibility pertaining to pile testing. The session chairman was Ir. Mun Kwai Peng, who was the past chairman of GETD.

To begin the forum, Ir. Dr. H. M. Aziz started with his presentation on the "**Role of Project Owner, Main Piling Contractor, Test Requesting Party, Tester and 3rd Party Reviewer and also the Contractual Arrangement**". In his presentation, the speaker highlighted the current contractual arrangement of piling subcontractor selecting their own pile tester created a conflict of interest on testing quality control. An independent reviewer on board would be able to improve the quality by specifying the requirement of High Strain Dynamic Pile Test (HSDPT) submission in softcopy, which allowed the review of raw data, rather than the interpreted report in hardcopy. Ir. Dr. Aziz, also highlighted their preference on direct appointment of nominated pile testing specialist by providing a Prime Cost sum for data acquisition, interpretation & reporting and direct payment from project owner. Meanwhile, the main contractor should provide attendance and all necessary equipment during testing.

The speaker suggested that there should be an independent institution providing certification for specialist testers in the local HSDPT industry, such that the quality of testers can be on-par with international standards and practices. Furthermore, the speaker also emphasised on the importance of providing training to engineers and supervisors so that HSDPT would no longer be a black box. The speaker informed that there were checklists available in JKR, developed 5 years ago for supervision of both Maintained Load Test (MLT) & HSDPT. Unfortunately, there were no official guidelines published for the engineering industry.

An audience, Ir. Y. W. Yee, put forward a short question on whether there was any guideline on supervision of HSDPT as he observed that some MLT used to calibrate the HSDPT, in which the MLT itself was not supervised. How could one expect good HSDPT testing quality calibrated with an unsupervised MLT? Dr. Aziz emphasised there was no substitution of supervision to any testing, but the availability of modern instrumentation helps to reduce human errors in MLT. It also provides uninterrupted data recording. Nevertheless, this cannot replace the necessity for checking and supervision by an experienced engineer in ensuring safety of test setup and to obtain good quality test result for subsequent interpretation.

Prof. Samuel Paikowsky was the second panellist who presented the topic entitled "**Common Problem & Myths in Dynamic Pile Testing, Interpretation & Special Site Conditions**". Besides highlighting the fundamental theory of dynamic pile testing, the speaker emphasised that all users of the test should be aware of the basic assumptions made on developing the dynamic wave propagation theory, the

consequences when the assumptions are violated and its limitations in order to attain the fullest benefit offered in dynamic pile test. The theory of dynamic wave theory requires measurement of force and velocity as inputs, but these quantities can only be indirectly derived from direct measurements of strain and acceleration with instrumentation of gauges on the test pile. The evenness of the hammer impact would have serious implication on stress distribution profile within the top three pile diameter below the point of impact. Soft cushion could reduce such irregularity, but at the price of losing resolution of certain important testing features. Prof. Paikowsky also presented the unique behaviour in plugged pile. Among others, the speaker had recommended an area ratio (surface area in contact with soil vs area of pile tip) of at least 350 for better HSDPT interpretation. The conventional CAPWAP analysis could not predict accurately the static resistance of the plugged pile. A new program PWAP (Plugged Wave Analysis Program) was required to take care of the lateral wave movement in the soil plug. The detail of this phenomenon was first presented in the special lecture at the 8th International Conference on the Application of Stresswave Theory to Piles in Portugal in 2008. In addition, capacity gain should also be considered by carrying out restrike test especially at soft clay areas where the dissipation of pore water pressure would take a long time. This was proven via case studies in which restrike tests of up to one month were carried out at a particular site. In fact, long term pile capacity in restriking tests showed good matches with MLT with deviations of up to 16%.

The third panellist, Ir. Dr. Toh Cheng Teik presented a compilation of HSDPT results obtained from local dynamic pile testing results, and his comments from a consultant point of view. The title of his presentation was "**Data Integrity & Content of Reporting i.e. On-Site & Final Reporting**". The speaker presented a database that includes driven to length and driven to set piles, bored piles and jack-in piles. As further clarified by the panellist, no interpretation was done on all test results, and the speaker was merely quoting the actual outcome of the test. The speaker carried out comparisons between MLT and HSDPT on the following parameters:

- Load vs settlement curve
- Load transfer curve
- Ultimate pile capacity
- Pile settlement at working load

Based on the data presented, the speaker concluded that the ability of local dynamic pile testers in predicting the actual pile capacity against MLT was not encouraging. Its inability in predicting the ultimate pile capacity had put engineers in very difficult positions with regards to professional and contractual liability. Furthermore, the ability of HSDPT in predicting pile settlement was also not encouraging. In addition, load transfer curve of HSDPT compared poorly with load transfer curve of instrumented MLT result. In fact, HSDPT generally predicted much lower shaft resistance and much higher toe resistance.

Therefore, the speaker recommended having MLT and HSDPT carried out on preliminary piles to assess the ability of dynamic pile tester in predicting the pile capacity and settlement before allowing the tester to proceed with HSDPT on working piles. He also recommended inviting several specialist pile testers for the testing of preliminary pile on a particular project site and the project should only be awarded to the tester that provides the best estimates of test results.

Prof. Paikowsky clarified that the MLT and HSDPT comparison made by Ir. Dr. Toh was invalid as the interpreted static pile ultimate capacity should be established based on a standardised and systematic approach. Prof. Paikowsky adopted the Davisson's Criterion for the comparison of 527 driven piles on MLT with 210 driven

piles on HSDPT. For the interpretation of shaft and toe resistances, the system would take the interpreted soil resistance at the last element as toe resistance although it includes the contribution of both shaft & toe. As the system was unable to separate the two, one had to make necessary judgement in separating the two components in the last pile element.

Meanwhile, the inaccuracy of settlement recorded may be large in percentage but in terms of magnitude, it was minute. In fact, any other method of prediction was as good as HSDPT in term of settlement prediction as it only involves a few millimetres difference. So the large percentage differences in settlement record were insignificant from an engineering point of view.

However, Ir. Dr. Toh reiterated that the database compiled was on HSDPT done locally and no forward projection of pile capacity was done. He merely presented what he had obtained from the tests. As for the small magnitude differences in pile settlement, the concern was not so much on the pile performance but the contractual liability as our pile specification had called for certain limits in pile settlement under working load.

The last invited panellist was Ir. Teh Kim Ong, a practicing specialist tester himself. Ir. Teh presented the topic "**Quality Assurance/Quality Control in Equipment, Site Testing Procedures, Interpretation & Review on Training & Accreditation of Tester**". As an introduction, the speaker highlighted that every blow of HSDPT equals to an MLT. When plotting the load-settlement curve, all blows must be recorded and plotted on a proper prospective. The load-settlement should be plotted one after another, and not all from the same origin, as the later load cycle experienced the preloading effect of the previous loading-unloading cycles. The speaker also introduced 3-point checks for supervisor prior to the commencement of field test and 6-point checks for interpretation of data at site.

Among others, the speaker emphasised on the importance of checking for signal trail that starts and ends with zero, and Force (F) and Velocity (V) curve to be proportional at the beginning. If these were not observed, the testing system or sensors should be rejected. Furthermore, the difference between measured F and V was the measurement of shaft resistance, while the separation of F & V was the measurement of accumulated shaft resistance up to that point. On the other hand, pile discontinuities or damages were indicated as the reflection of signal in tensile with velocity wave up and force wave down. If these tensile reflections occurred at pile toe it indicated the end of pile for the verification of pile length.

After the field test, the supervising personnel should check the following items:

1. Inputs of wave speed & pile modulus
2. CSX & TSX measurements compared with allowable limits
3. Hammer efficiency, EMX, compared to the common efficiency range of the particular hammer type.
4. Pile integrity in BTA value, where continuous monitoring on the extent of damage was recommended over a few blows to derive the nature of discontinuity.
5. Certification of tester to ensure the competency of field tester and data interpreter.

The speaker once again reiterated the importance of direct engagement of tester by the client rather than by the piling contractor, as this would provide an unhealthy environment for the piling contractor to take advantage of the given contractual

arrangement. Biased test results to favour towards the pay master were bound to occur.

Discussion in Open Forum Session

The discussion session of the open forum was commenced by the chairman on a fundamental but yet crucial question - what exactly was the definition of a "Specialist Tester" in the JKR documents on Pile Testing and what was expected of them? An audience, Mr. Ong, also queried on why dynamic pile testing specialists are not accredited as professional licensed practitioners who can endorse their own report with full professional liability. In responding to these two questions, Ir. Dr. Aziz emphasised that all dynamic pile testing should be carried out by people with adequate skills and knowledge in Geotechnical Engineering. Ir. Dr. Toh also added that although dynamic testers selected by Consultant Engineers are usually from a pool of reputable testers, doubtful test results were still rampant. Therefore, Ir. Dr. Toh was of the opinion that the experience of local dynamic pile testers might not be adequate. Prof. Paikowsky then pointed out that the practice in US was that some of the pile testers were specialist consultants themselves. They will endorse their test reports and bear full professional responsibility. However, he emphasised that MLT and HSDPT must be compared on a common/standard platform of ultimate capacity interpretation, rather than just taking the maximum achieved pile capacity from MLT as the ultimate pile capacity to compare against the achieved test load of HSDPT. On that ground, Ir. Dr. Aziz illustrated the JKR practice of requesting all test reports to be certified by Professional Engineer which was a means of ensuring test and interpretation quality as specified by the project owner.

An audience from the floor, Mr. B.H. Tan, an owner of a specialist testing company himself highlighted that it was very difficult for the industry to retain engineers as the cost of a HSDPT test was only around RM300. Furthermore, expenses on equipment calibration were often very high. The Chairman expressed disagreement to the statement as the tester always had a choice of not taking up the job at unacceptably low price for a proper project deliverable. Meanwhile, Mr. M.F. Chong, who was also a tester, highlighted that far more emphasis had been given to the ability of dynamic pile test in the interpretation of pile capacity, which had its inherent limitation in the interpretation of contribution between the shaft and toe resistances. The merits of dynamic pile testing should not be disregarded due to some unsatisfactory comparison of pile capacity prediction with the MLT results. In fact, more emphasis should be given on its uniqueness in evaluating pile integrity, which was not available in any other tests. On that note, Ir. Dr. Toh highlighted he had frequently used dynamic pile test for driving monitoring in order to control driving stresses induced and to monitor the response of pile joint integrity condition. Despite that, Ir. Dr. Toh stressed that the facts of inaccurate prediction of pile capacity by dynamic pile testing method in his earlier presentation still remains. Prof. Paikowsky disagreed with the approach on pile capacity comparison presented by Ir. Dr. Toh by illustrating the similar comparison on pile capacity of 210 test results performed in developing the Reliability Based Design (RBD) in AASTHO Specification. The full detail of the comparison was given in the internet document NCHRP Report 507. He then emphasised the importance to relate the comparison to the defined failure criterion and serviceability of the test pile as the pile load can continue to increase if the test pile settled with unrealistic movement by force. The MLT test results should be presented in a standardised format and analysed in systematic way. This was to avoid different interpreted static pile capacity from the same MLT results. Prof. Paikowsky suggested adopting the scale where the elastic compression line of the load settlement curves lie approximately 20 degrees with Davisson failure criteria. If there was no significant change of pile capacity over time, the correlation between

the dynamic pile test and MLT results showed that dynamic pile test under-estimated the pile capacity by about 15%. The panellist, Ir. Teh Kim Ong, also presented similar cases that the mobilised pile capacity could be under-estimated.

An audience from the floor enquired on the possible limitation of pile diameter to be tested by HSDPT. Ir. Teh highlighted that theoretically there was no limitation in pile size as long as the maximum compression and tension stresses (CSX & TSX) of pile had been checked. In fact, Mr. M. F. Chong of Dynamic Pile Test added that he had carried out test with test load of 10,000-ton before without much problem. The chairman shared that the typical requirement of the gauge measurement level should be two times the pile diameter for even impact stress profile would render the HSDPT not practical unless the pile head was extended for the testing. In the case of 4m diameter pile ,gauge attachment level at 8m below the pile head would be required. This is practically not feasible. In addition, Prof. Paikowsky highlighted that additional tensile reinforcement may be required for testing if significant tensile stress was detected. However, based on Ir. Dr. Toh's experience in Kenny Hill & Granite Formation, reinforcement of bored pile extending up to 12m length had also undergone HSDPT without much problem. As for JKR practice, Ir. Dr. Aziz mentioned that all piles at MRR2 were fully reinforced for HSDPT test and hammer drop height had been controlled.

On that ground, Ir. S. S. Liew highlighted a few reasons of why HSDPT became arguable in local practice. Among others were the "fast food" culture adopted by local Engineers in which quality time was not spent on proper evaluation and interpretation of HSDPT. Meanwhile, CAPWAP software was also too costly for consultant to own and to run through the entire process of dynamic pile testing interpretation. Furthermore, current practice of contractual arrangement had led to increasing biasness in test results which tends to invite exploitation. Finally, Ir. Liew invited comments on testing for pile capacity of rock socket pile as it requires certain magnitude of pile movement to mobilise its rock socket capacity. On that note, Prof. Paikowsky highlighted that he had carried out HSDPT on 6 cases of rock socketted pile, but were all done on sacrificial piles for design optimisation purposes rather than as verification test on working piles.

The last question of the forum was raised by the chairman. Based on his experience the same magnitude of velocity reflection may show very different BTA value depending on the location of such velocity reflection along the length of the pile. In fact, based on his experience, velocity reflection detected near the top of pile tends to give larger BTA value compared to those detected near the lower end of pile. The panellist, Ir. Teh clarified that the BTA value was a function of the wave reflection magnitude, the impact energy and the magnitude of resistance, and it should not be affected by the position of detected impedance along the pile. Prof. Paikowsky added that for velocity reflection detected near pile joint, pile driving monitoring was essential to check whether the BTA value reduces at the end of drive which indicates the closing up of gaps at pile joint. Meanwhile, it was a useful tool to limit hammer drop height.

The chairman also raised the question that some testers stressed the importance of soil damping in predicting the CASE method of computing static resistance. The tester in most cases used a high damping value especially for soft clay and short pile. Ir. Mun was of the opinion that that was not true. For long piles where the toe velocity measured was low, whatever value of soil damping selected was not important. For short pile where the toe velocity was high, a big portion of the static resistance would be removed if high soil damping was introduced. It was not realistic to measure a hammer force of said 1000 tons and only predicted a static resistance of pile of only,

said 200 tons. The static resistance was signal and resistance dependent. Prof Paikowsky agreed to the opinion and explained briefly on it.

The forum ended at noon with great appreciation to all four panellists, the chairman and all participants on their willingness to share knowledge and experience making the forum a truly fruitful event.