IPA News Letter

Volume 4, Issue 2 June 2019

Special Contribution

Rapid Load Test of Piles

Tatsunori Matsumoto

Professor, Graduate School of Science and Technology
Kanazawa University, Kanazawa, Japan

Rapid load test of piles (RLT) is an alternative to the conventional static load test (SLT) and is widely used in Japan because of its time and cost effectivenss. In this article, history of the standardization of RLT in Japan, interpretation methods of RLT signals, newly dveloped RLT device, and a case of comprison of th results of RLT and SLT on an open-ended steel pipe pile are introduced.

Keywords: load-displacement relation, falling mass rapid load test method, interpretation method, standards

1. History of Rapid Load Test in Japan

The first rapid load test (RLT) in Japan was carried out by Takenaka Corporation in 1992 on a cast-in-place concrete pile. The Statnamic was employed in the test. The well-known method of rapid load testing, Statnamic, was developed by the collaboration of TNO in the Netherlands and Berminghammer Co. in Canada (Middendorp et al., 1993) [1].

A private research group for RLT was launched in 1993 led by Prof. Osamu Kusakabe (Prof. of Tokyo Institute of Technology at that time, and the president of IPA at present). The research group was composed of general contractors, piling contractors, pile load test companies, pile manufactures and academics. The objectives of the research group were 1) to compile the existing knowledge of RLT, 2) to examine basic characteristics and applicability of RLT to Japanese soils, and 3) to establish interpretation methods of RLT. The outcomes of the activity of the research group were presented in the 1st International Statnamic Seminar (1995) [2] held in Vancouver, Canada.

The research committee for RLT was formed in Japanese Geotechnical Society (JGS) in 1997, based on the activity of the research group, with research targets of 1) definition of rapid load test, 2) interpretation methods, 3) preparation of testing manual and 4) standardization of testing method. The outcomes of the research committee were presented in the 2nd International Statnamic Seminar (1998) [3] held in Tokyo, Japan. The research committee was upgraded to the standardization committee of JGS in 1998. JGS 1815-2002: Method for Rapid Load Test of Single Piles [4] was standardized in 2002. JGS 1815-2002 is the first standard for RLT in the world. After the standardization of RLT, use of RLT has been widened in Japan.

2. Definition of Rapid Load Test in JGS 1815-2002

JGS 1815-2002 clearly defines RLT. Fig. 1 shows an illustration of loading duration and characteristic curves of a stress-wave propagating in a pile having a length, L. Loading duration, t_L, in impact load test (ILT) is 5 to 10 ms, while t_L in RLT ranges typically from 50 to 100 ms. Stress-wave caused at the pile head propagates up and down in the pile with a propagation speed, c. Relative loading duration, R_T, is defined as

$$R_T = t_L/(2L/c) \qquad (1)$$

R_T is the number of return traveling of the stress-wave in the pile during the loading duration, t_L. If R_T is equal or greater 5, the influence of the wave propagation in the pile could be negligible (Nishimura et al., 1998) [5] so that the pile body could be assumed as a rigid, although the inertial force of the pile body needs to be considered. Dynamic load tests with the condition of $R_T \geq 5$ is defined as RLT.

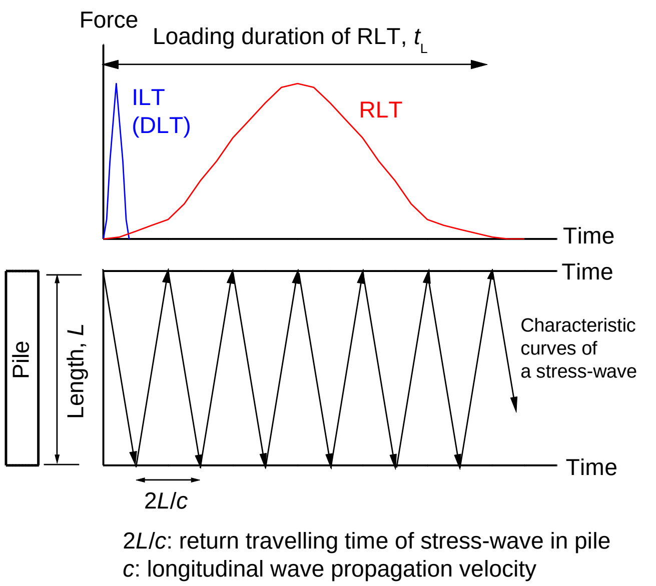

Fig. 1. Comparison of loading duration [4]

3. **Rapid Load Test Devices**

Loading mechanism of the well-known Statnamic device is launching a reaction mass placed on the pile head by the gas explosion pressure. At the same time, the gas explosion force pushes the pile gently downward. The maximum acceleration of the reaction mass caused during loading is about 5g. Hence, weight of the reaction mass is about 20% of the planned maximum load. An advantage of the Statnamic is high loading capacity up to 60 MN. However, repeated loading is difficult in the Statnamic.

Another type of RLT device is a falling-mass type device. Fig. 2 is an example of falling-mass type device, called Hybridnamic, developed by Jibanshikenjo Co. Ltd. In the falling-mass type device, a hammer mass is free-dropped from a certain height onto the pile head through a soft cushion on it. Relatively wide ranges of the loading duration and the maximum force can be realised by adjusting combination of the stiffness of the cushion and the hammer mass. A great advantage of the Hybridnamic is that repeated loading is conducted very easily. It is possible to conduct 10 blows (tests) on a pile in a day. It is a common practice in the Hybridnamic to apply several blows on a pile with increasing the drop height of the falling hammer.

Fig. 2. Falling-mass device with soft cushion (provided by Jibanshikenjo Co., Ltd.)

4. Interpretation method of RLT signals

Generally, force applied to the pile head, F_{rapid}, is measured via a load cell, and acceleration at the pile head, α, is measured via accelerometers. The velocity of the pile, v, is obtained from time integration of the measured α. An optical displacement meter is employed to measure the pile head displacement, w.

If $T_r = t_L/(2L/c) \geq 5$, the pile body could be treated as a rigid body having a mass of M. Fig. 3 shows a modelling of pile and soil during RLT. F_{rapid} is the sum of inertia of the pile, R_a, and the soil resistance, R_{soil} (Eq. 1). It is assumed that soil resistance, R_{soil}, is the sum of the static soil resistance, R_w, and the dynamic soil resistance, R_v (Eq. 2). R_d is assumed to be proportional to the pile velocity, v, with a constant value of damping factor, C. Hence, R_{soil} is readily obtained from the measured F_{rapid} and α (Eq. 2).

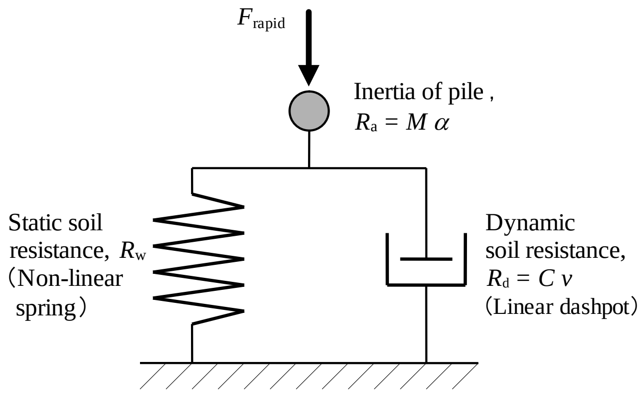

Fig. 3. Modelling of pile and soil during RLT [1, 6]

$$F_{rapid} = R_a + R_{soil} = M\alpha + R_{soil} \quad (1)$$

$$R_{soil} = R_w + R_v = R_w + Cv = F_{rapid} - M\alpha \quad (2)$$

$$C = (R_{soil\,max} - R_{w\,ULP})/v^* \quad (3)$$

$$R_w = R_{soil} - Cv \quad (4)$$

Fig. 4 is an example of thus obtained R_{soil} vs w. The point at the maximum displacement, w_{max}, is call Unloading Point (ULP). The velocity of the pile, v, is zero at ULP. Hence, R_{soil} at ULP is regarded as the maximum of the static soil resistance, $R_{w\,ULT}$. The damping factor, C, is estimated from the difference of $R_{soil\,max}$ and $R_{w\,ULT}$ (Eq. 3). Finally, R_w vs w is obtained using C and v (Eq. 4). R_w vs w is called "derived static load-displacement curve".

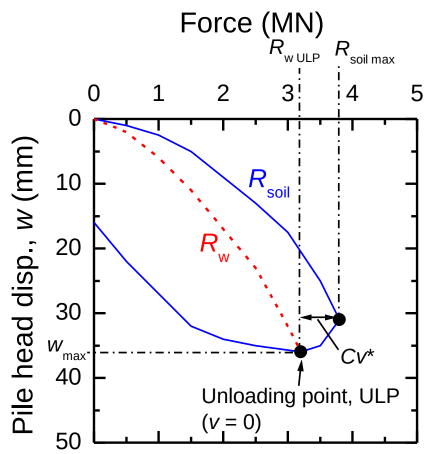

Fig. 4. Unloading Point Method (ULPM) for obtaining static load-displacement curve

If multiple blows with increasing the drop height of hammer are carried, interpretation of RLT signals becomes easier, as shown in the next section.

5. Comparative SLT and RLT on an Open-ended Steel Pipe Pile

Results of comparative SLT and RLT on an open-ended steel pipe pile (Hoshino et al., 2012) [7] are briefly introduced in this section.

The pile having a length of 15.5 m, an outer diameter of 1.0 m and a wall thickness of 14 mm was installed in the sandy ground by a water jet vibratory installation method (Fig. 5). The bottom 4.5 m section of the pile was embedded into the sand rock layer having SPT *N*-values greater than 50.

The conventional SLT was carried out for the pile with a loading sequence shown in Fig. 6. It took 6 hours to complete five loading cycles of the SLT. Each load step was maintained for one hour, and finally the maximum load of 9000 kN was applied.

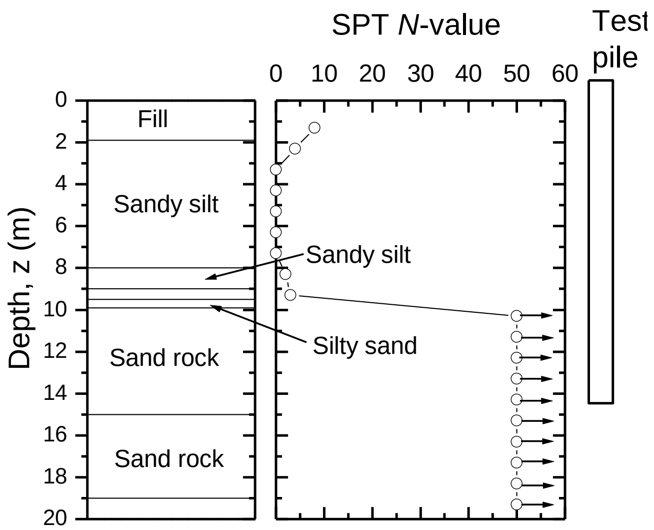

Fig. 5. Soil profile at the test site

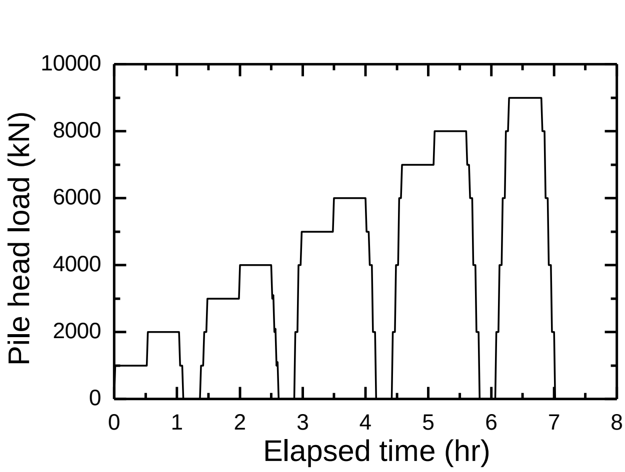

Fig. 6. Loading sequence in SLT

RLT of the pile was carried out subsequently to the SLT. A total of 8 blows were applied to the pile using a hammer mass of 22 tonnes. Fig. 7 shows F_{rapid} vs time in the last blow. The loading duration, t_L, was 60 ms that resulted in the relative loading duration $T_r = t_L/(2L/c) = 9.7$ ($c = 5000$ m/s). As mentioned above, $T_r = 9.7 \geq 5$ satisfies the criterion for RLT.

Fig. 8 shows F_{soil} vs w in all the 8 blows. The red line is the connection of ULPs which can be regarded as the static load-displacement curve.

Static load-displacement curves from the SLT and the RLTs are compared in Fig. 9. Note here again that the RLTs were conducted after the 5th loading cycle in the SLT.

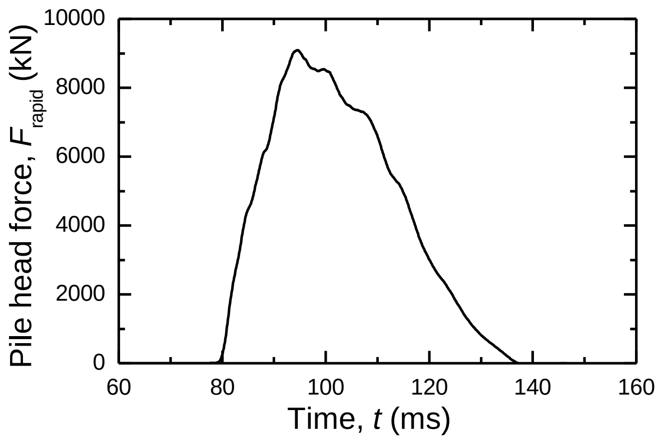

Fig. 7. An example of RLT load

Load-displacement curve in the 5th loading cycle of the SLT and F_{soil} vs w from the RLTs are shown in Fig. 10, in which the pile head displacement at the start of loading was zeroed for comparison purpose. It is seen that the curve derived from the RLT is almost equal to that obtained from the SLT.

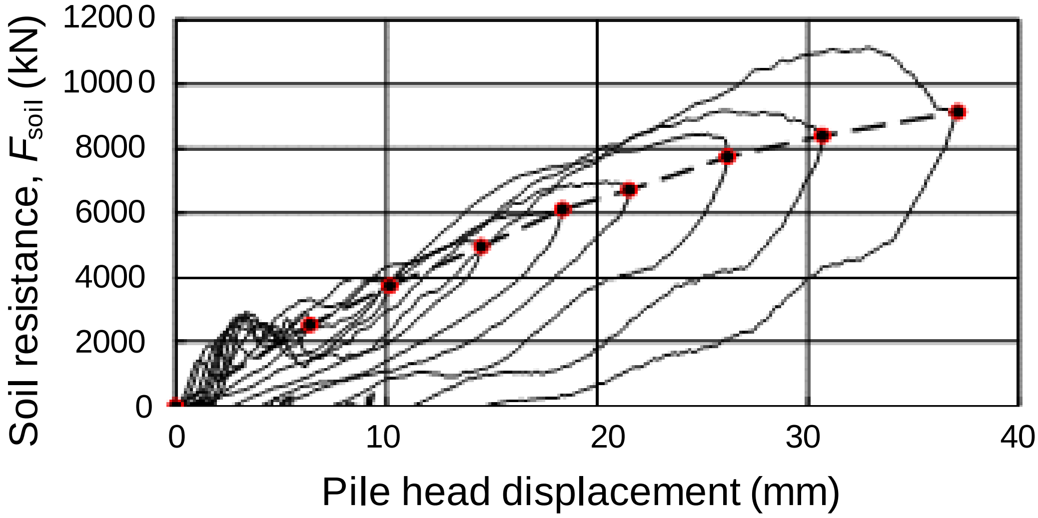

Fig. 8. F_{soil} vs w from RLTs with different falling height of hammer, and ULPs

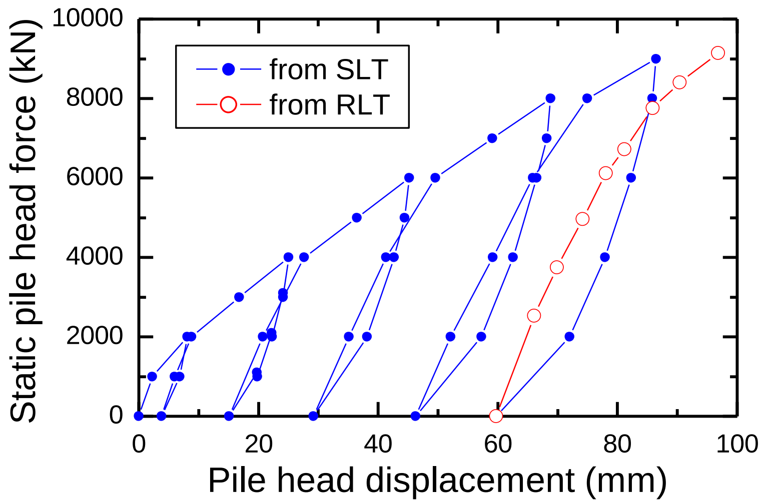

Fig. 9. Load-displacement curve in SLT and F_{soil} vs w from RLTs

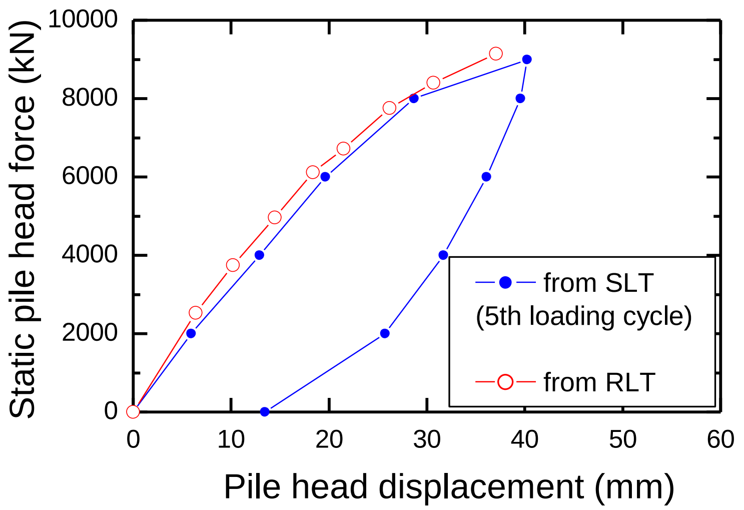

Fig. 10. Comparison of static load-displacement curves from SLT and RLT

Fig. 11 shows the axial forces in the pile measured in the SLT and the RLTs at the maximum pile head load of 9000 kN, and the distributions of the shaft resistance estimated from the axial forces in the pile. The results from the SLT and the RLT are comparable, showing that RLT is an alternative to the conventional SLT.

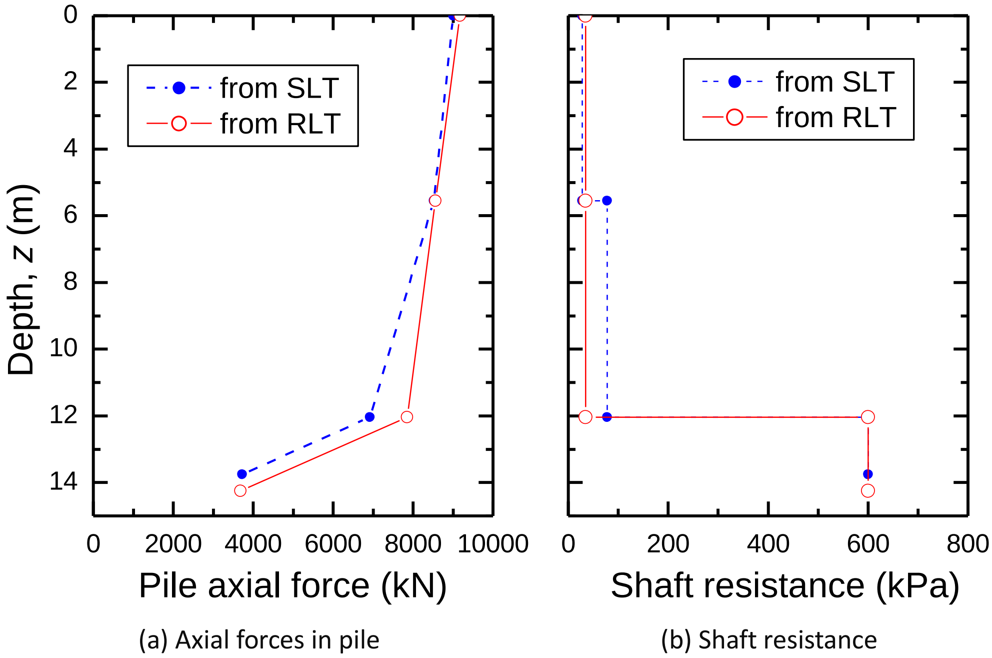

Fig. 11. Axial forces in pile and shaft resistance

The above case study was carried out for the sandy ground. Brown (2009) [8] pointed out that the static load-displacement curve derived using UPM (Unloading Point Method) is still influenced by the strain rate effects of the surround soils, especially in clay ground. The initial parts of the static curves (working load range) from SLT and RLT are comparable, while the ultimate load derived from ULM is overestimated by 50% in maximum. This information is useful when RLT is used for design purpose of piles in clayey grounds.

6. Concluding Remark

The author's belief is that the performance of a pile installed using Press-in Method is higher than that of the same pile installed using the other installation methods. This belief, however, needs to be verified through load testing on constructed piles. A handy load test may be possible using the Press-in machines, although the maximum load is limited to 3 MN. The rapid pile load testing is one of useful tools to conduct load tests on many piles, because of its time and cost effectiveness as well as a reasonable reliability.

References

[1] Middendorp, P., Bermingham, P. and Kuiper B.: Statnamic testing of foundation pile, Proc. 4th Int. Conf. on Application of Stress-Wave Theory to Piles, The Hague, pp.585-588, 1993.

[2] Proc. 1st Int. Statnamic Seminar, Vancouver, Canada, 1995.

[3] STATNAMIC Loading Test (Kusakabe, Kuwabara & Matsumoto Ed.), Proc. 2nd Int. Statnamic Seminar, Tokyo, Japan, 1998.

[4] Standards of Japanese Geotechnical Society for Vertical Load Tests of Piles, JGS 1815-2002: Method for Rapid Load Test of Single Piles, 2002.

[5] Nishimura, S., Shibata, A., Yamashita, K., Kita, N. Ogita, N. and Ishida, M.: One dimensional stress wave simulation analysis of Statnamic load test, evaluation of boundary between Statnamic and dynamic loading tests, Proceedings the 2nd Statnamic Seminar, Tokyo, pp.337-344, 1998.

[6] Kusakabe, O. and Matsumoto, T.: Statnamic tests of Shonan test program with review of signal interpretation, Proc. 1st Int. Statnamic Seminar, Vancouver, Canada, pp.113-122, 1995.

[7] Hoshino, M., Sato, K., Takano, K., Kamei, S. and Nishimura, S.: A comparison between static load test and rapid load test for a steel pipe pile installed by water jet vibratory technique, Proceedings of the 9th International Conference on Testing and Design Methods for Deep Foundations (IS-Kanazawa 2012), Kanazawa, pp.581-585, 2012.

[8] Brown, M.: Chapter 2 Recommendations for Statnamic use and interpretation of piles installed in clay, Rapid Load Testing on Piles, pp.26 - 36, Taylor & Francis Group, London, UK, 2009.

◆ A brief CV of Prof. Tatsunori Matsumoto

Professor Tatsunori Matsumoto obtained his Bachelor of Engineering and Master of Science from Kanazawa University, Japan. He joined the Department of Civil Engineering of Kanazawa University in 1981 as research associate. He became an Associate Professor in 1991 and promoted to a Professor from August in 1999.

He retains an active involvement in research into pile dynamics and deformation of pile foundations including piled rafts subjected to load combinations. He has published more than 200 technical papers including more than 45 Journal papers.

He was the Chairman of IS-Kanazawa 2012: The 9th International Conference on Testing and Design Methods for Deep Foundations held in Kanazawa, Japan, from 18 to 20 September, 2012.