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Hybridnamic rapid load testing with an extended interpretation method of dynamic signals

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ABSTRACT: The Hybridnamic testing is a kind of falling-mass type rapid load test (RLT), by which several blows on a pile can be conducted easily and quickly. Hence, static load-displacement curve is constructed by connecting UnLoading Point (ULP) loads. This procedure is called UnLoading Point Connection (ULPC) method. ULP method or ULPC method is employed for cases of the relative loading duration $T_r = t_L/(2L/c)$ greater than 5, where t_L is loading duration, L is pile length and c is bar wave velocity. Segmental ULPC (SULPC) is proposed so that RLT can be employed even in cases of T_r less than 5. A case study was carried out to demonstrate the applicability of SULPC. Load-displacement curve from RLT with the SULPC method was comparable to that from the conventional static load tests.

1 INTRODUCTION

Twenty years have passed since the rapid loading test (RLT) of piles were newly added to the Japan Geotechnical Society (JGS) standard (JGS1815-2002). Until 2002, most of RLTs were conducted using the mass-launching method such as the Statnamic test developed by Middendorp et al. (1992). After 2002, most of RLTs in Japan are conducted using the falling-mass method with a soft-cushion placed on the pile head. The Hybridnamic device (Figure 1) developed by Jibanshikenjo Co. is a typical falling-mass method. In line with this, the number of loading cycles has also changed from one loading of the maximum planned load to multiple loading

Figure 1. Hybridnamic test device.

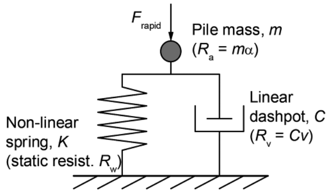

Figure 2. Modeling of pile and soil during RLT (after Middendorp et al, 1992, and Kusakabe and Matsumoto, 1995).

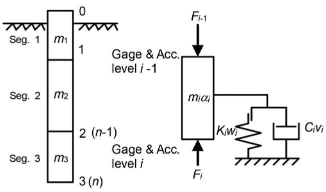

Figure 3. Segmental Unloading Point Connection (SULPC) method.

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with the hammer drop height being raised in stages. Therefore, the interpretation method has shifted from the UnLoading Point (ULP) method to the UnLoading Point Connection (ULPC) method (Kamei et al. 2022), which provides a static load-displacement relationship simply by connecting ULPs without the need to obtain the damping constant C required in the ULP method.

As a result of the widespread use of the ULPC method as an interpretation method for RLT signals, some cases have emerged that pose challenges for the analysis of single mass model method in which the entire pile length is considered as a rigid body.

In this paper, as a new interpretation method to address these issues, the Segmental UnLoading Point Connection method (SULPC method) which is an extension of the Segmental UnLoading Point (SULP) method is proposed. The load-displacement relation of a pile from RLT is compared with the result of static load test (SLT).

2 SEGMENTAL UNLOADING POINT CONNECTION METHOD (SULPC METHOD)

Middendorp et al. (1992) treated the pile as a rigid mass during RLT assuming that the effects of wave propagation phenomena in the pile body are negligible. When a dynamic load F_{rapid} is applied to the pile, the static soil resistance R_{w} and dynamic soil resistance R_{v} act on the pile. These relationships are expressed in Equations 1 and 2, and Figure 2.

$$F_{\text{rapid}} = R_{\text{a}} + R_{\text{v}} + R_{\text{w}} = m\,\alpha + C\,v + R_{\text{w}} \tag{1}$$

$$R_{\text{soil}} = F_{\text{rapid}} - m\alpha \tag{2}$$

$$R_{\text{w}} = R_{\text{soil}} - \;C\,v \tag{3}$$

$$R_{\text{soil at ULP}} = R_{\text{ULP}} = R_{\text{w}} \tag{4}$$

where, F_{rapid} = Rapid load, R_{a} = Inertial force of pile, R_{v} = Dynamic soil resistance, R_{w} = Static soil resistance, m = Pile mass, α = Pile acceleration, C = Damping constant, v = Pile velocity, R_{ULP} = ULP resistance (static soil resistance).

Since the ULP method supposes that F_{rapid} equivalent to the ultimate pile bearing capacity is applied once, the damping constant C must be determined to estimate R_{w} (Eq. 3). However, the value of C may vary depending on the displacement and velocity of the pile.

At the maximum displacement w_{max} (called UnLoading Point, ULP) the pile velocity v is 0, hence R_{soil} is equal to R_{w} (R_{ULP}) as Equation 4.

In the Hybridnamic RLT, the hammer drop height h is increased in stages, and several blows are applied to the pile. In each blow, ULP load and the corresponding displacement are obtained. Therefore, by simply connecting the ULPs, the $R_{\text{w}} - w$ relationship can be easily obtained without the estimation of C. This interpretation is called UnLoading Point Connection (ULPC) method (Kamei et al. 2022).

Mullins et al. (2002) proposed the Segmental UnLoading Point (SULP) method for a pile instrumented at several pile sections. In the SULP method, force and acceleration are measured at the pile head whereas only force is measured at other pile sections. The velocity and acceleration at a particular measurement point other than the pile head are estimated using the measured force at that point, and the force and displacement at the pile head. Note that only the total static soil resistance is estimated in the SULP method by summing up the static soil resistance of each segment.

In the proposed Segmental UnLoading Point Connection (SULPC) method, forces and accelerations are measured at several sections of the pile (Figure 3). Soil resistance $R_{\text{soil}i}$ vs displacement w_i of segment i is estimated using the relation of Equation 5 (Step 2 in Table 1).

Table 1. Flow of SULPC.

Step 1 : Multi cycle rapid load test
Step 2 : Calculate relationship of soil resistance R_{soil} - displacement w and ULP load for each segment
Step 3 : Constuct static resistance R_w - displacement w relationship for each pile segment by connecting ULPs (SULPC)
Step 4 : Analize responses of elastic pile subjected to static loading using a load transfer method

Table 2. Specifications of test pile.

Item	Value
Length, L (m)	24.8
Outer diameter, D_o (mm)	800
Inner diameter, D_i (mm)	772
Wall thickness, t_w (mm)	14
Cross-sectional area, A (m^2)	0.0346
Cross-sectional area, A (m^2)†	0.0376
Young's modulus, E (kPa)	2.00×10^8
Density, ρ (ton/m^3)	7.85
Mass, m (ton)	7.032
Bar wave velocity, c (m/s)	5048

† : including steel protection cover for strain gages.

$$R_{soil_i}(t) = F_{rapid_i}(t) - m_i \cdot \alpha_i(t) = F_{i-1}(t) - F_i(t) - m_i \cdot \alpha_i(t) \tag{5}$$

As several blows are applied to the pile in the Hybridnamic test as mentioned earlier (Step 1), static soil resistance R_{wi} vs w_i of segment i is constructed by connecting ULPs (Step 3).

The responses of the whole pile subjected to static pile head load are then calculated using a load transfer method (Step 4). In this calculation stage, the pile is treated as elastic, and non-linear soil resistance behavior estimated in Step 3 is considered at each pile node.

3 CASE STUDY

3.1 *Test description*

The test site was in Okayama Prefecture, Japan. The profiles of soil layers and SPT-N values are shown in Figure 4, together with pile embedment. The test pile was a steel pipe pile (SPP) having the specifications listed in Table 2. The pile was constructed using the down-the-hole hammer method. To increase plugging effect, concrete was filled inside the pile along a section of 1 D_o from the pile tip.

Two strain gages and two accelerometers were attached near the pile head (L1), and strain gages were instrumented at L2, L3 and L4. Furthermore, accelerometers were instrumented at L3 and L4. The acceleration α at L2 was obtained as the weighted mean value of α measured at L1 and L3. The outer surface of the pile section in the weathered rock between L3 and L4 was coated by a friction reduction material to ensure that the load on the pile head was sufficiently transferred to the pile tip.

Static load test (SLT) was carried out 29 days after the pile construction. In the SLT, 6-step load maintenance test was conducted followed by a continuous load test. RLTs using the Hybridnamic test device with a hammer mass of 44 ton was carried out 90 days after the SLT.

3.2 *Test results*

A total of 7 blows were conducted in the RLTs, increasing the hammer falling height h from 0.25 m to 3.0 m.

Figure 5 shows the measured dynamic signals in the RLT with h = 3.0 m. The relative loading duration T_r was 7.1, which satisfied the criterion of RLT ($T_r \geq 5$) specified in the JGS standard. Nevertheless, α at different levels were largely different showing that rigid body modeling of the pile was not adequate. It can be seen from the local pile displacements w that

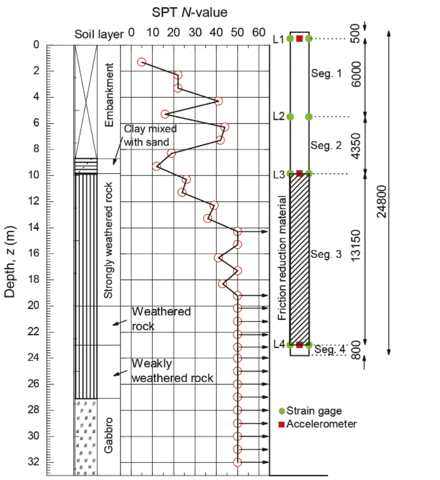

Figure 4. Profiles of soil layers and SPT-N values, together with pile embedment.

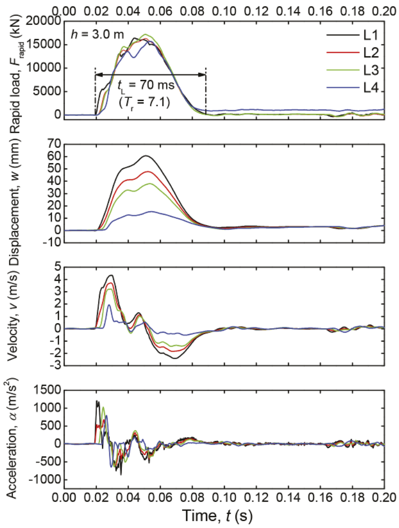

Figure 5. Measured dynamic signals (h = 3.0 m).

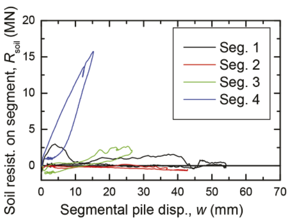

Figure 6. R_{soil} vs w of each pile segment (h = 3.0 m).

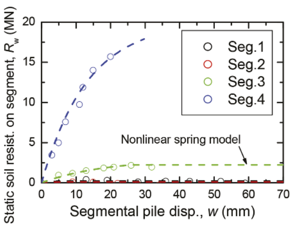

Figure 7. R_w vs w of each pile segment from multiple blows.

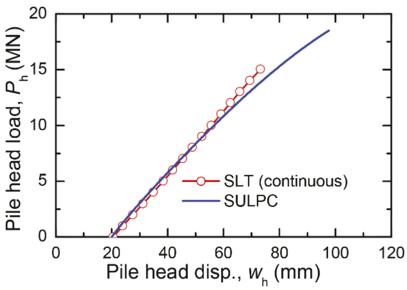

Figure 8. Static load-displacement curves from SULPC and SLT.

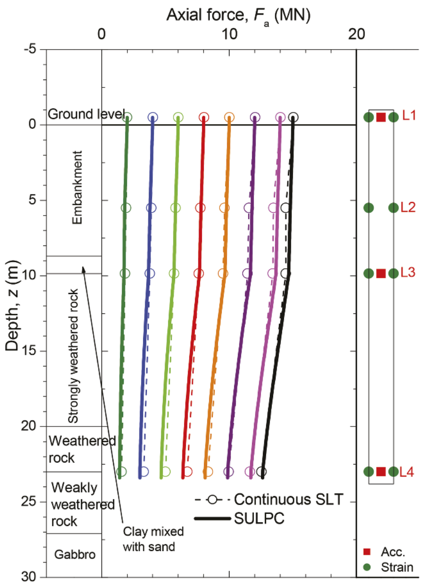

Figure 9. Axial pile force distributions from SULPC and SLT.

relatively large deformation of the pile was caused. Hence, the proposed SULPC interpretation was adopted.

Figure 6 shows the R_{soil} vs w in each segment estimated from the RLT with h = 3.0 m.

By connecting ULPs of each segment from all the 7 blows, the static soil resistance R_w vs w of each segment was obtained as shown in Figure 7. For the load transfer calculation, thus obtained R_w vs w was modeled by the dashed line for each segment.

Figure 8 shows the pile head load P_h vs pile head displacement w_h from the SULPC and the continuous SLT. The result from the SULPC is comparable with the SLT result.

Figure 9 shows the axial pile force F_a distributions from the SULPC interpretation and the continuous SLT. The results from the SULPC are again comparable with the SLT results.

4 CONCLUSIONS

A new interpretation method, SULPC, of RLT signals was proposed in this paper. The behaviors of a steel pipe pile from RLTs with the SULPC interpretation were comparable with those from SLT. The loading in this test was within the range of reloading. In future, similar comparison until ultimate load will be needed.

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