Dynamic and static horizontal load tests on steel pipe piles and their analyses

P. Kitiyodom & T. Matsumoto
Kanazawa University, Kanazawa, Japan

K. Tomisawa
Civil Engineering Research Institute for Cold Region, Japan

E. Kojima & H. Kumagai
Japan Pile Corporation, Japan

ABSTRACT: In this research, dynamic and static load tests were performed on permanent foundation piles for an abutment of a highway bridge, which had a pile length of 38 m, 800 mm in outer diameter and 9 or 12 mm in wall thickness. The static horizontal load versus horizontal displacement derived from the dynamic load test conformed well to that measured in the conventional static horizontal load test, encouraging the use of dynamic horizontal load testing as an alternative for the conventional static horizontal load testing.

1 INTRODUCTION

For axial compressive pile load test methods, the dynamic load testing or the rapid load testing is widely used in Japan because of the fact that these methods are unsusceptible to reaction piles, and require less time and cost compared with the conventional static load test where reaction piles are employed. Application of the dynamic or rapid pile load test to horizontal pile load test would be very useful in seismic design of the pile foundation.

In Kitiyodom et al. (2006), the possibility of the use of dynamic horizontal pile load test as an alternative method for the conventional static horizontal load testing is presented and discussed. In order to estimate the deformation and load distribution of a single pile subjected to dynamic horizontal load as well as vertical load, a numerical program KWave-Hybrid, has been proposed.

In this paper, the results of static and dynamic horizontal load tests on the actual piles are presented and compared. Static load displacement relation of the pile is estimated using the soil parameters obtained from the wave matching analysis of dynamic horizontal pile load test signals. Both static and dynamic analyses are performed using KWaveHybrid. It is shown that the estimated results match very well with the measured values.

2 TEST DESCRIPTION

A bridge was constructed at the Shinotsu site for the Central Hokkaido Connection Road in 2006. Pile group foundations were employed for abutments of the bridge. In order to assess the performance of the constructed piles, a static alternating cyclic horizontal load test and a dynamic horizontal load test were carried out on the constructed foundation piles. The test piles are located next to each other with pile spacing of 2 m. The specifications of the test piles are summarised in Table 1.

Figure 1 shows the profiles of soil layers and SPT N-values at Shinotsu site. The soil profile at this site is characterised by thick deposits of silt soils. SPT N-values are typically less than 7, except for gravel at depth from 35 m. At this site, soil improvement was carried out prior to the pile load tests. The SPT N-values after soil improvement are also shown in Figure 1.

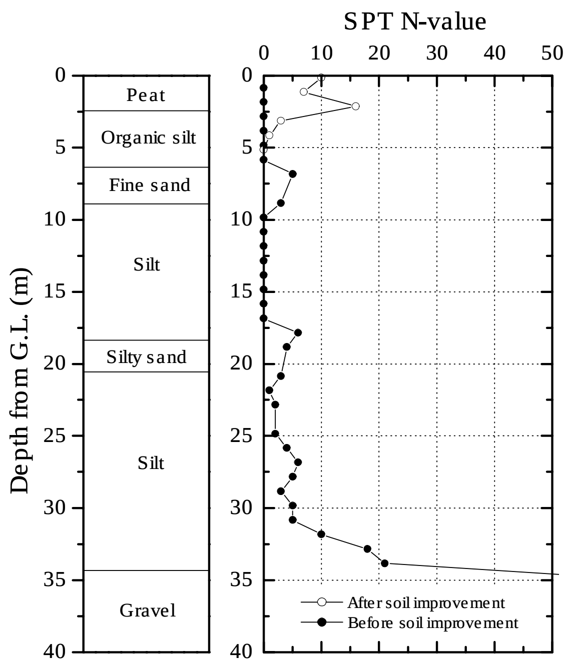


Figure 1. Profiles of soil layers and SPT N-values.

Table 1. Specifications of the test piles.

Property	Value
Length (m)	38.0
Embedment length (m)	37.2
Outer diameter (mm)	800
Inner diameter (mm)	
upper part (z < 7.5 m)	12
lower part (z > 7.5 m)	9
Young's modulus (kPa)	2.06×10^8
Moment of inertia (cm^4)	
upper part (z < 7.5 m)	2.31×10^5
lower part (z > 7.5 m)	1.75×10^5
Shear wave velocity (m/s)	3187
Density (ton/m^3)	7.8
Mass (ton)	7.06

Alternating cyclic horizontal loads shown in Figure 2 were applied to the pile in the static load test. Figure 3 shows the relationships between the horizontal load H and the horizontal displacement u. The residual displacement was measured at full recovery of horizontal load to 0 in each load step, and the elastic displacement was obtained by subtracting the residual displacement from the total displacement measured at the maximum load in each loading step. The residual displacement and the corresponding elastic displacement at the maximum load in each load step are also shown in Figure 3.

In the dynamic horizontal load test, the pile was hit horizontally by a hammer of mass of 2.14 ton through a coil spring which was attached to the load cell at the point z = 0.3 m below the pile head as shown in Figure 4. Applied force, horizontal displacements and accelerations were measured at the same level of the hit point with a sampling interval of 15 μs. The loading and measuring devices are shown in Figure 4. More details can be found in Kojima et al. (2006).

An example of the dynamic test signals is shown in Figure 5. The measured force increases and decreases smoothly with time, and has a peak of about 330 kN. The loading duration is about 55 ms. The measured displacement also increases and decreases with time having a peak of 20 mm at a time of 40 ms. The peak horizontal displacement delays 18 ms behind the peak horizontal load, showing dynamic effects.

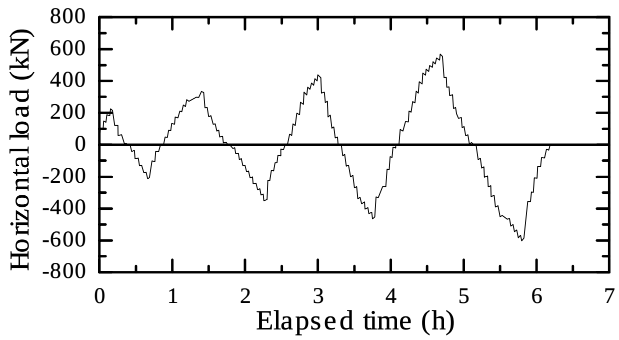


Figure 2. Loading history in static horizontal load test.

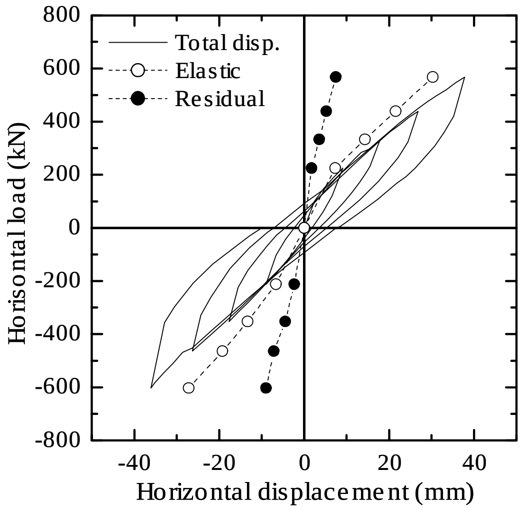


Figure 3. Static horizontal load vs horizontal displacement.

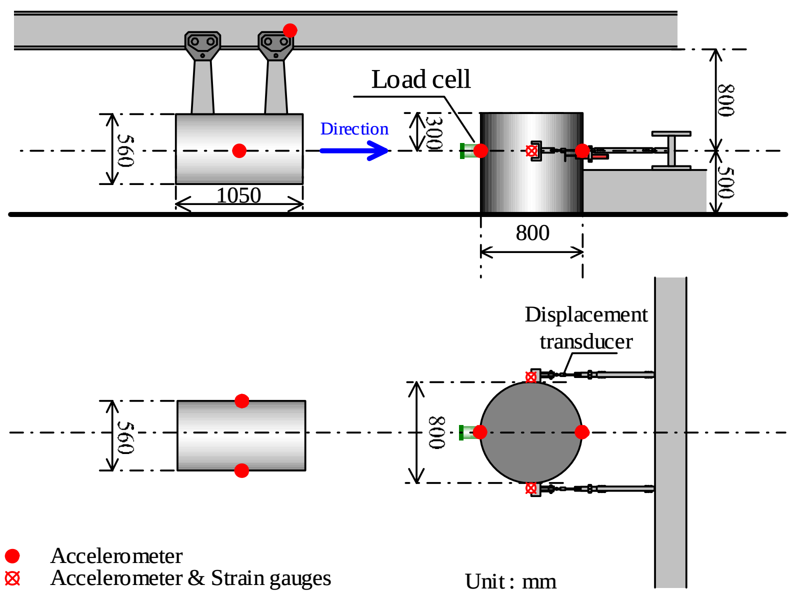
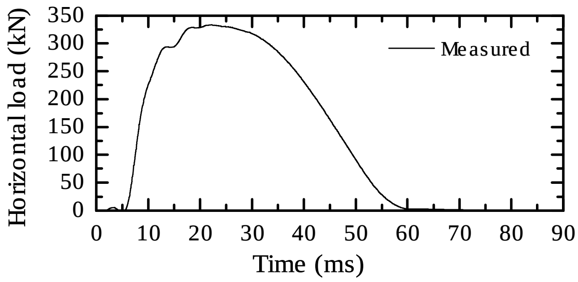
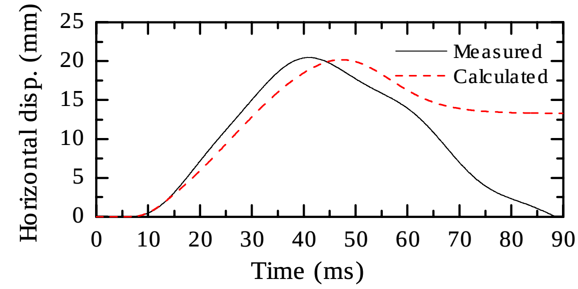


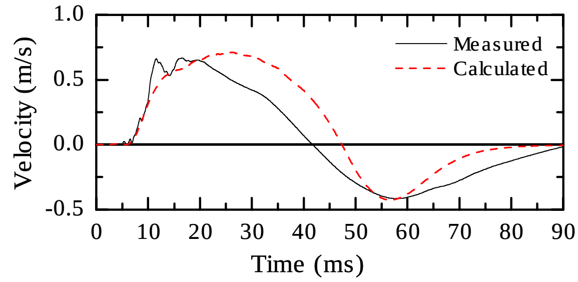
Figure. 4. Loading and measuring devices for dynamic horizontal load test.



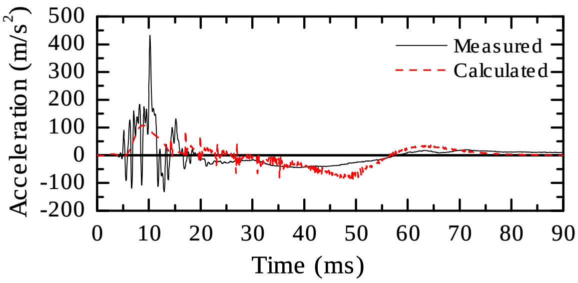
(a) Horizontal load



(b) Horizontal displacement



(c) Horizontal velocity



(d) Horizontal acceleration

Figure 5. Measured and calculated pile load test signals.

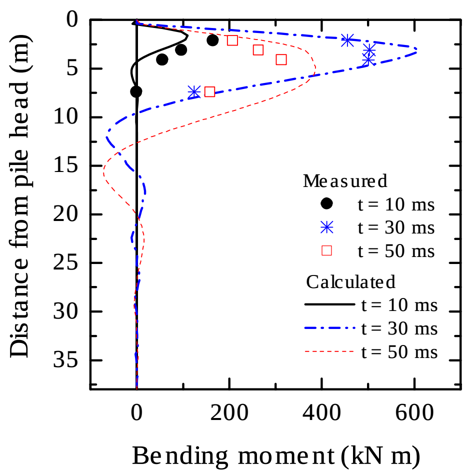


Figure 6. Measured and calculated bending moment.

During the dynamic horizontal load test, the axial strains at both sides of the pile were measured at different levels down the pile shaft. Figure 6 shows the profiles of bending moments along the pile obtained from the measured axial strains.

Figure 7 shows the relationship between the dynamic horizontal load and the horizontal displacement. It can be seen from comparison between Figure 3 and Figure 7 that the measured load displacement relation from the dynamic load test is totally different from the measured static load displacement relation. Therefore, in order to obtain the static load displacement relation of the pile from the measured signals of the dynamic load test, wave matching analysis of the measured signals is needed.

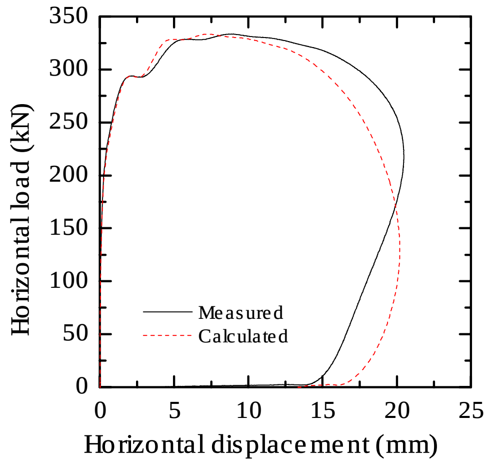


Figure 7. Measured and calculated load vs displacement in dynamic horizontal load test.

3 ANALYSES OF TEST RESULTS

A computer program KWaveHybrid, developed by Kitiyodom et al. (2006), was used for the wave matching analysis of the dynamic horizontal load test. The program was also used to estimate the static load displacement relationship of the pile using the soil parameters obtained from wave matching analysis.

Figure 8 illustrates the hybrid modelling of the pile and the soil used in KWaveHybrid. The pile is modelled as beam elements with masses and the soil is treated as springs and dashpots. More details of the analysis method can be found in Kitiyodom et al. (2006).

It should be noted here that the unloading and reloading curves measured in the static alternating cyclic load test (Figure 3) indicate that gapping between the pile and the surround soil occurs during unloading and reloading stages. Such gapping has not been incorporated in KWaveHybrid at present. Hence, monotonic horizontal loading of the pile is considered in the analysis. Note also that the interior of the pipe pile was almost filled with soil at the end of driving. It was assumed that the pipe pile was fulfilled by the soil with the density of 1.8 ton/m^3, and the masses of the soil inside the pipe pile was taken into account in the analysis.

Matching analysis was repeated with assumed values for the maximum shaft horizontal pressure, q_h, and the soil shear modulus, G_s, using the measured dynamic load (Figure 5(a)) as the force boundary condition at the loading point, until a good matching between the calculated and the measured pile displacements was obtained. Soil parameters used in the final matching of the pile are listed in Table 2.

Figure 5 and Figure 7 show the displacement, velocity, and acceleration versus time and load versus displacement of the test pile calculated in the final matching analysis, compared with the measured values. It can be seen that the calculated dynamic pile displacement overestimated the measured values after the peak displacement. This is thought to be due to the soil spring in KWaveHybrid. At the present, the values of the soil spring in KWaveHybrid during the loading and unloading states are the same. The values of the soil spring during the loading and unloading states should be different due to gapping between the pile and the surrounding soil as mentioned earlier. However, the calculated displacement matches well with the measured displacement until the peak displacement.

Figure 6 shows the comparison of the calculated profiles of bending moments along pile with the measured value. There are good agreements between two solutions. It can be seen from the figure that only the upper part of the pile deforms during the dynamic horizontal load test.

Using the same soil parameters as shown in Table 2, the static load displacement relation of the pile was estimated using KWaveHybrid. Figure 9 shows the comparison of the calculated static load displacement relation with the measured value. It can be seen that the calculated result matches well with the measured one.

4 CONCLUSIONS

In this paper, the results of alternating cyclic horizontal load tests and dynamic horizontal pile load tests on driven open-ended steel pipe piles constructed for foundations of a bridge abutment at Shinotsu site have been presented and discussed

A good matching between the calculated and measured behaviours of the piles during dynamic loading as well as during static loading was obtained.

The possibility of the use of dynamic horizontal pile load test as an alternative method for the conventional static horizontal load testing was demonstrated.

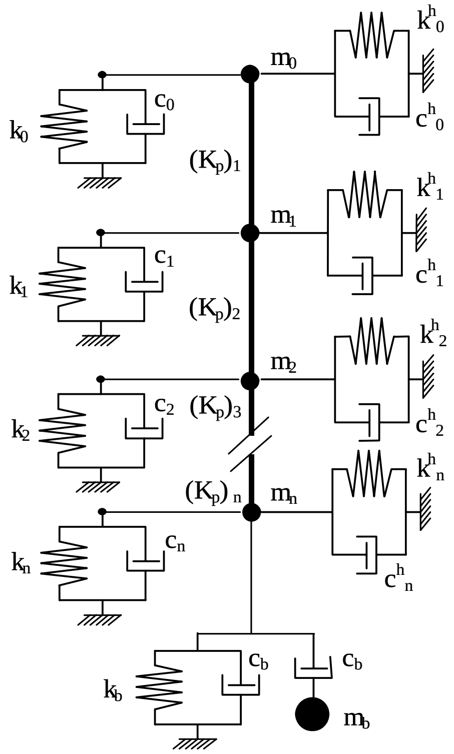


Figure 8. Hybrid modelling of the pile and the soil.

Table 2. Soil parameters identified in final matching.

Depth (m)	G_s (kPa)	q_h (kPa)
0 to 2.7	9615	116.0
2.7 to 18.4	836	Elastic range
18.4 to 31.8	1607	Elastic range
31.8 to 37.0	11587	Elastic range

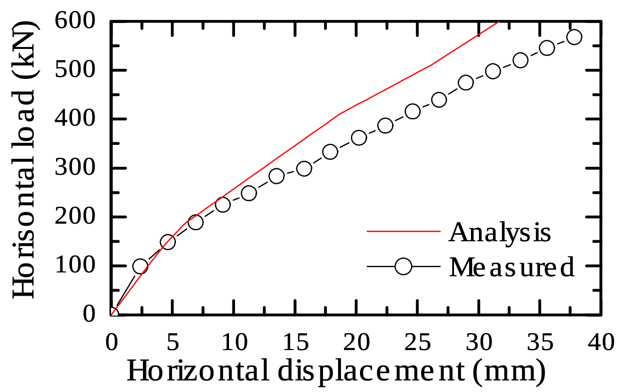


Figure 9. Measured and calculated static load vs displacement.

REFERENCES

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