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The Effect of Welded Splice with Predetermined Gap of Concrete Spun Pile on The Response of Low Strain Integrity Test

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Abstract: This paper presents the velocity wave of concrete spun piles with welded splice. The stress wave velocity was recorded using Pile Integrity Test. Two specimens were prepared in the experiment. The first sample was prepared visually no gap between the two end-plates of connected piles, while the second specimen was prepared by inserting 5mm thick steel plate into the splice to create a gap in its connection. The results show that a spike of reflecting stress wave still develops at the splice with and without gap, regardless the splice was welded in full circle. The relatively high spikes of reflecting waves at pile toe are noticed for both specimens with and without gaps. It shows that the full welded splice able to transfer stress wave velocity. A good quality of welded splice can be indicated by the reflecting wave at the pile toe, regardless the reflecting wave development at the splice.

Keywords: Low strain; dynamic test; pile integrity test; sonic pulse echo; precast concrete pile; splice.

Introduction

Several methods have been developed to monitor the integrity of pile foundations, as a part of quality assesment. Crosshole Sonic Logging test (ASTM D6760) [1], Themal Integrity Profiler (ASTM D7949) [2], and also Pile Integrity Test (ASTM D5882) [3] in which particularly used to detect the quality of concrete bored pile foundation. Pile Integrity Test (PIT) is a nondestructive method that developed to check the integrity of a shaft, both bored pile and driven pile. The integrity of bored piles includes the homogeneity of concrete and uniformity of its cross section area, while the Pile Integrity Test on driven pile usually used to scan the existence of crack along the pile and the quality of connection joint between two segments of piles. During installation, driven piles may be damaged or broken as a result of high driving stresses (tension or compression). Installed driven piles may also be damaged by large horizontal movements due to impacts, construction equipment, retaining wall failures, etc. [4].

Pile Integrity Test (PIT) is used to determine the integrity of pile foundation by mean of recording the travelling stress wave impacted at the pile head. The velocity of travelling wave will be smooth for a pile with constant cross section area and homogeneous in its quality. On the other hands, spikes of velocity will be developed when the tested pile exhibits change of resistance or impedance, which correlated with cross section area and material homogeneity of pile, due to necking or bulging (in bored pile), pile crack, improper splice, air trapped (gap) in between concrete and steel end plate or in between welded steel plates.

PIT development is based on the theory of wave propagation, which applies on one dimensional wave mechanics to a linear elastic slender structure, such as pile which the length is much longer compared to its diameter. When impacted, a stress wave travels through the pile at a wave speed, c, which is a function of the elastic modulus, E, and mass density, ρ as in Equation (1). The applied load, F, and particle velocity, v, at a point are related as in Equation (2). For a cross-sectional area A, the proportionality constant is called the pile impedance, as in Equation (3), since it is a measure of the pile's resistance to change in velocity.

$$E = \rho c^2 \quad (1)$$

$$F = Zv \quad (2)$$

$$Z = \frac{EA}{c} \quad (3)$$

Change of impedance is related to change in pile cross-sectional area, A, as well as pile material properties, E. Increase of pile impedance or soil resistance results in a decrease measured pile top velocity. Conversely, decrease of pile impedance. results in increased velocity.

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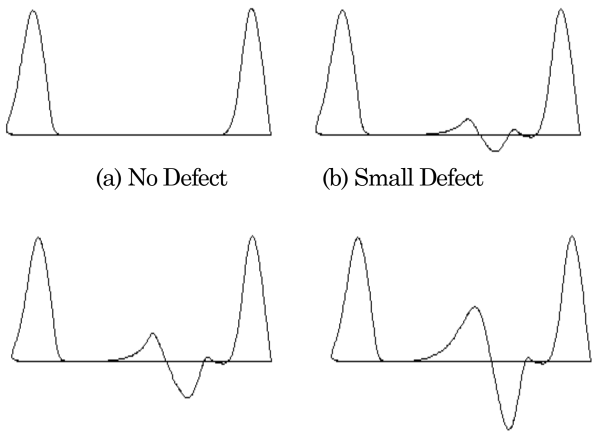
Pile Integrity Test (PIT) is a Non Destructive Test (NDT) technique, where the methods of testing fall into two categories. The first one is Pulse Echo Method (PEM), where pile head motion is measured as a function of time, and time domain record are then evaluated for pile integrity. Secondly, the Transient Response Method (TRM) is where the pile head motion and force are measured as function of time, the data are then evaluated ussually in the frequency domain. Practically, the PIT referred mostly to Sonic Pulse Echo Method, which using an accelerometer and hand held hammer which known as low strain in dynamic testing (ASTM D5882). The schematic diagram of PIT is depicted in Figure 1. Details of the theoretical background and the development of PIT are discussed in various literatures [6-8].

The recorded PIT Graph is a velocity on time domain function, in which wave propagation mechanics illustrated that the pile integration can be interpreted based on pile impedance, *Z*. The interpretation of PIT result can be bias because of the number of unknown variable that caused a change of impedance, such as pile defect, soil resistance, pile splice, in-homogenous material, etc. However, the location and severity of pile defect can be interpretated simply by observing the impedance spike on the PIT recorded graph. The basic interpretation are illustrated in Figure 2. Figure 2a shows that the integrity of pile is good since there is no reflecting wave between the two spikes at the head and toe of the pile. The development of spikes of reflecting wave in the area between two spikes at the head and toe of the pile is an indication of defect at the pile. The smaller the spike the smaller the defect, and vise versa, as ilustrated in Figure 2b, Figure 2c, and Figure 2d.

Luo et al. [9] conducted experiment to determine the location of accelerometer at the pile head that generate the optimum response wave of PIT.



(a) No Defect (b) Small Defect

(c) Medium Defect (d) Large Defect

Figure 2. Basic Interpretation of PIT

The research carried out using finite element method. It stated that accelerometer of PIT located around 2/3 radius from the source of impact (center) of solid pile or at a distance of ninety-degree (90^o) arc away from the source for hollow/pipe pile producing the optimum wave response.

Promputthangkoon et al. [10] conducted research regarding the interpretation of PIT result of the predetermined flaws of pile. The defect was developed by reducing the cross section area at the certain depth, where the three sides of the periphery of a square pile was grooved continuously (U-shaped groove). Sixty percent (60%) of the cross section area was removed so that the remaining solid area is 40%. The remaining area is compared to the ratio of the spike recorded at the predetermined defect and the initial spike. It is found that the ratio of recorded wave velocity is about 70%, which is much higher than that of the remaining area 40%. In other words, there is no direct correlation between the ratio of reduction area of a pile and the ratio of recorded wave velocity at the defect location.

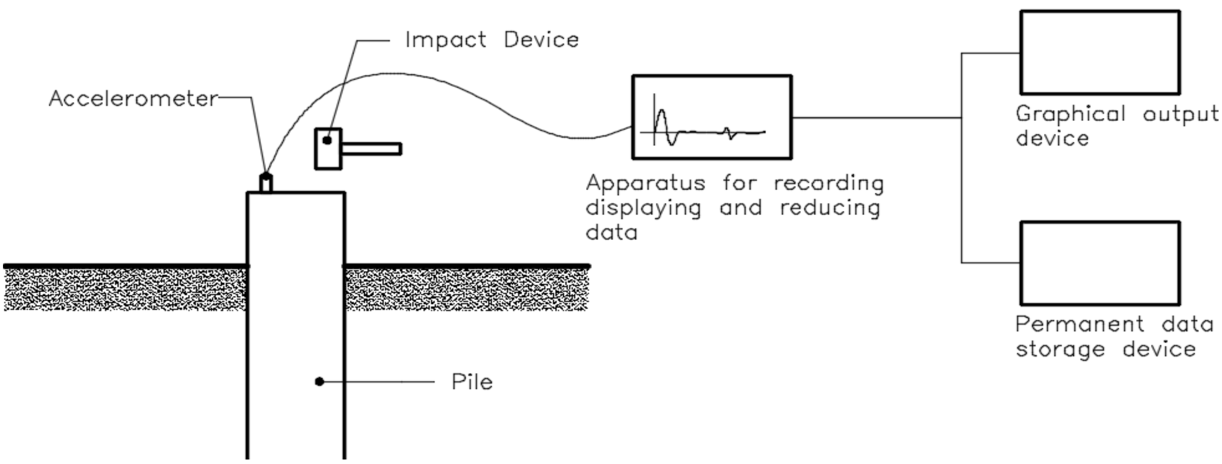


Figure 1. Schematic Diagram of PIT (ASTM D 5882)

Webster et al. [11] propose seven (7) classifications of the quality of PIT results. Class AA for a good integrity piles; AB for piles with minor defect, ABx for piles with no major defect until certain depth; PFx for flaw piles at a certain depth; PDx for piles with major defect at certain depth; IVx for piles with inconclusive results below a certain depth; and IR for inconclusive record. Liang & Rausche [12] provided examples for each category proposed by Webster et al.

Santosa and Leonardo [13] conducted experiment to study the correlation between the high of recorded spike of PIT and the depth of predetermined groove (cut) of square pile to simulate the defect of square concrete prestressed pile of 25cm x 25cm. The groove was made in one side of the cross section of the pile. The result shows that the ratio between the spike at the groove and that recorded at the impact point is about 10% lower than the ratio between the depth of the groove and its original dimension of the pile.

In practice, it is very often encountered a spike of velocity (or change of impedance) at the splice of a precast driven pile. It is very unlikely to interpret the integrity of the connection since the spike can be caused by the quality of its welding, the gap between two connected endplates (to keep upper pile vertical), or the existing gap between concrete and endplate due to trapped air during concreting of the pile.

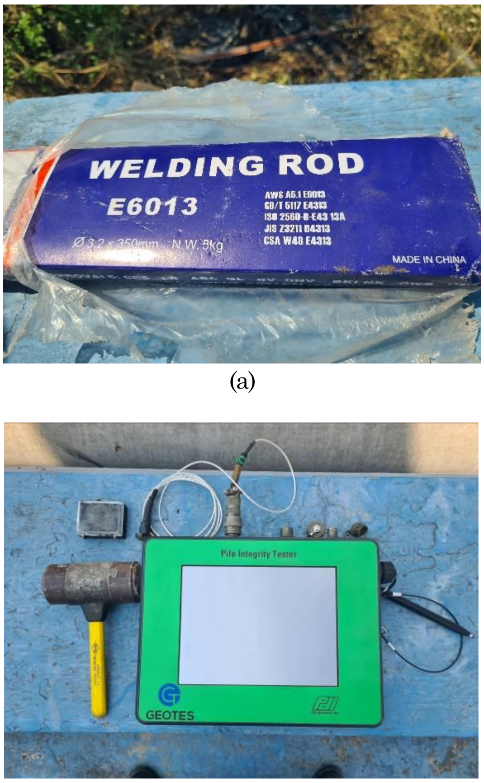
The aim of this experiment is to investigate the effect of gap between fully welded endplates of precast prestressed spun pile to the response of stress wave velocity recorded using PIT.

Research Methodology

The research was performed to investigate the response of recorded stress wave velocity at the welded splice of precast prestressed spun pile diameter of 350 mm using PIT. There were two (2) sets of spun piles connected by welding at its endplates. The splice of the first specimen of pile was welded without any gaps (observed visually) between the two endplates, while the second specimen was prepared with predetermined gap between the two endplates. The gap was generated by inserting a 5 mm thick steel plate. The total length of the specimen was 7000 mm, which was connected in the middle of its length (Figure 3). The pile specimen exhibits concrete strength (fc') of 42 MPa, 6 PC-bars with diameter of 6 mm, and 6 mm thick steel endplate.

The specimen was connected using welding rod type E6013, which has diameter of 3.2 mm (Figure 4a) then tested using low strain integrity apparatus (PIT) as depicted in Figure 4b.

Figure 3. Precast Pile Specimens

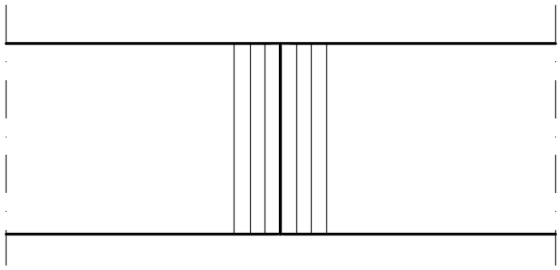


(a)

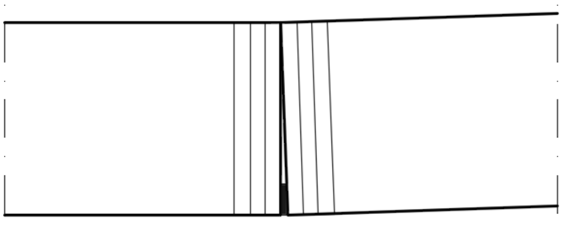
(b)

Figure 4. (a) Welding Rod; (b) PIT and its Accessories

The first specimen was prepared in such a way that visually there was no gap. There was no special effort to push the two parts of the pile to close the gap. The connection was performed by welding the two end-plates without gap (Figure 5a). Figure 5b shows the second specimen that was prepared with predetermined gap by inserting a 5 mm thick steel plate at one side of the area into the space between endplates. The two endplates of the piles were then welded at four points to tie the end-plates (Figure 5)



(a)



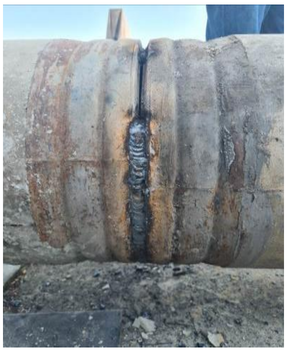
(b)

Figure 5. Pile Connection (a) No Gap; (b) With Gap

Pile Connection without Gap

First of all, the endplates were welded in four points (Figure 6a), then three layers of welding were applied in a half circle of the splice (Figure 6b). Finally, the splice was welded in full circle in three layers (Figure 6c). The three conditions of the specimen were tested using PIT to observe effect of those change of impedance.

(a)



(b)

(c)

Figure 6. Spun Pile Connection with Gap (a) Welding at Four Points; (b) Welding at Half Circle; (c) Full Welding

Pile Connection with Gap

Similar to the preparation steps for specimen with splice without gap, a 5_mm thick steel plate was inserted into the edge of the two endplates as shown in Figure 7a, then three layers of welding were applied in a half circle of the splice (Figure 7b). Finally, the splice was welded fully in three layers (Figure 7c). The three (3) conditions of specimen were tested using PIT.

The specimens were positioned horizontally on the ground during testing, and the sensor (accelerometer) of PIT was attached at the very same location (point) throughout the testing process.

(a)

(b)

(c)

Figure 7. (a) Welding at Four Points; (b) Welding at Half Circle; (c) Welding Full Circle

Testing Results

The results of PIT on the specimen without gap is depicted in Figure 8. It shows that when the splice of the pile is welded at four points (point welded), the stress wave unable to propagate through the splice; the wave is reflected back. In other words, the pile is assumed exhibits the length of 3500mm. When splice was welded half circle of its periphery, a relatively high spike of response wave (reflecting wave) at the distance of 7000mm (pile toe) was observed. The spike of wave velocity is as high as that of the initial one. When the splice was welded in full circle, the spike of recorded reflection wave velocity at the distance of 7000mm is higher than that at the impact location. Figure 8 shows that the spike of wave velocity at the distance of 7000mm increases with the welded area at the splice. The spike of reflecting wave velocity at the splice that was welded in full circle might be caused by a gap that still exist between the endplates regardless visually there was no gap noticed. The gap can not be entirely closed since there was no special efforts to push the two segments of the specimen to contact each other, to replicate the welding process of a splice in the field, where to upper pile that will be connected is laid down in fully contact on the pile head of the lower pile previously installed.

The response of recorded travelling wave velocity of the specimen which was connected with a gap at its splice is presented in Figure 9.

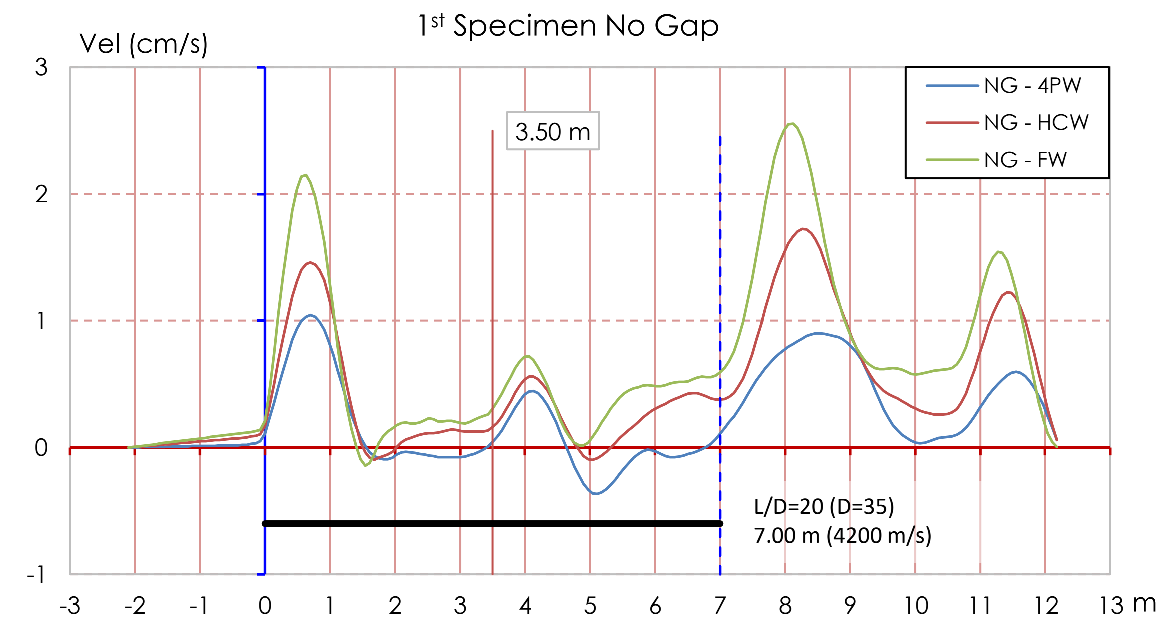


Figure 8. Response of Stress Wave at the Splice with no Gap, which were Welded Together at Four Points (NG – 4PW), Half Circle (NG – HCW), and Full Circle (NG – FW)

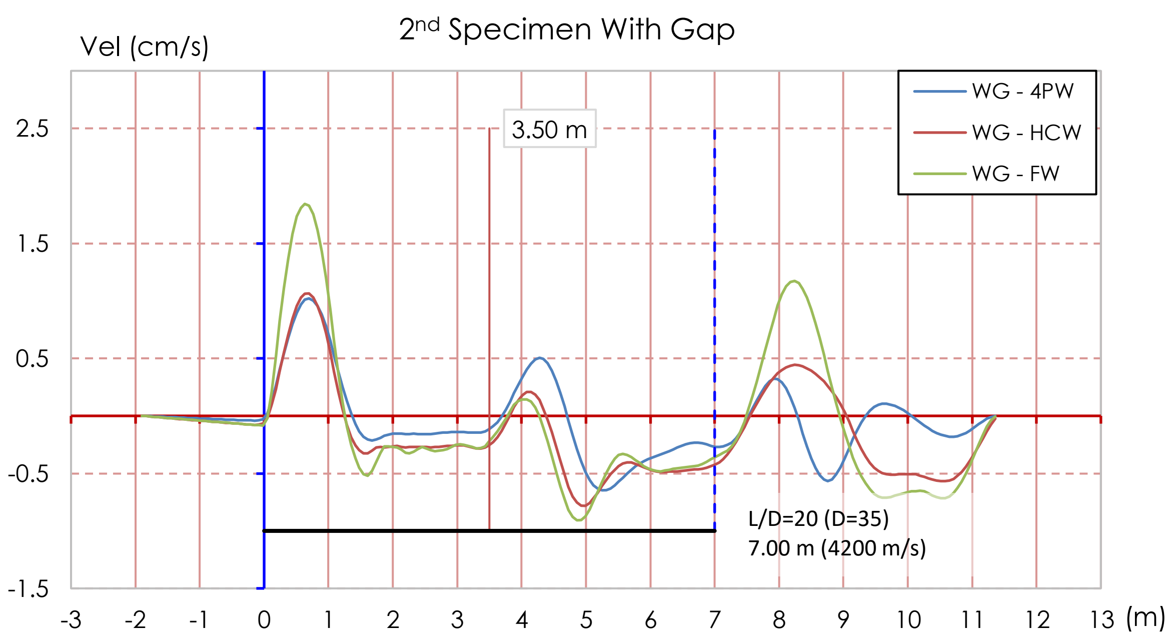


Figure 9. Responses of Stress Wave at the Splice with Gap, which were Welded Together at Four Points (WG - 4PW), Half Circle (WG – HCW), and Full Circle (WG – FC)

Conclusion

A spike of reflecting stress wave velocity still develops at the splice with and without gap of spun piles regardless the steel endplates was welded in full circle.

The splice that was prepared visually without gap still exhibits gap, which changes the impedance of the specimen so that generates reflecting wave that recorded as spike of wave velocity

The spike of reflecting wave velocity at 7000 mm (pile toe) for splice welded at four points relatively lower than that of initial impact. It is very likely the repetition of reflecting wave (spike) at 3500 mm (at the splice) rather than the wave response at the distance of 7000 mm (pile toe) since the stress wave can not propagate through the splice

The relatively high spikes of velocity of reflecting waves at the distance of 7000 mm (pile toe) are noticed for splice that welded in full circle for both specimen with and without gaps. It shows that the full welded splice able to transfer stress wave velocity

A good quality of welded splice can be indicated by comparing the peak at the splice to that at the impact. The reflecting wave at the pile toe was apparently clear regardless the reflecting wave development recorded at the splice.

The welding connection on precast concrete pile shows a change of impendace (spike), regardless the welding quality.

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