The 2016 World Congress on
The 2016 Structures Congress (Structures16)
Jeju Island, Korea, August 28-September 1, 2016

Design Guideline for Buried Hume Pipe Subject to Coupling Forces

Won Pyo Hong[1)], *Seongwon Hong[2)], and Thomas Kang[3)]

[1)] *Department of Civil, Environmental and Plant Engineering, Chang-Ang University, Seoul 06974, Korea*
[2)] *Engineering Research Institute, Seoul National University, Seoul 08826, Korea*
[3)] *Department of Architecture and Architectural Engineering, Seoul National University, Seoul 08826, Korea,*
[3)] *tkang@snu.ac.kr*

ABSTRACT

A full-scale field test was performed on piled embankment to investigate the resistance effect of movement of soft ground. Embankment load results in both the settlement and lateral deformation of soft ground, inducing severe damage and breakage of the buried Hume pipe in soft ground. It was observed that the vertical and horizontal movement linearly increased under the constant embankment loads. This is called coupling effect. To quantitatively evaluate the coupling effect, the Coupling Area was derived and analyzed with the efficiency of load transfer.

1. INTRODUCTION

The utility pipes for supply of electricity, gas, and water have been buried and installed in reclamation in marine area because of recent growing demand for urban infrastructures in coastal reclaimed land (Tokimatsu et al. 2012; Zhou et al. 2014; Song et al. 2015). In general, the embankment was filled near the buried utility pipes in the coastal zone and the significant loads can cause lateral and vertical movement of soft ground and eventually functional damage to the pipe (Hong 2005; Hong and Lee 2009). Therefore, the detailed design guidelines and estimation method for the lateral and horizontal flow of soft ground are definitely needed to minimize such a damage. In this paper, the innovative evaluation method is proposed and compared with the efficiency of load transfer by soil arching theory.

Figure 1 demonstrates a schematic process of Hume pipe buried in soft soil where the embankment was filled. Lateral movement initially occurs due to the embankment filling and the lateral flow can result in the lateral earth pressure on the buried Hume pipe.

[1)] Emeritus Professor
[2)] Postdoctoral Researcher
[3)] Associate Professor

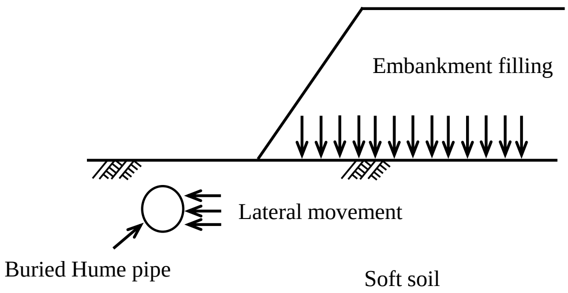


Fig. 1 Buried Hume pipe subject to lateral flow of soft soil caused by embankment filling

2. PILE-SUPPORTED EMBANKMENT AND SOIL ARCHING THOERY

The principle of the piled embankment is to directly support embankment loads by piles (see Figure 2). The significant embankment loads are transferred to a bedrock by the piles through the soil arching mechanism. The lateral movement of soft soil induced by the embankment loads is effectively reduced because the approximately 70% of embankment loads is transferred to a firm layer.

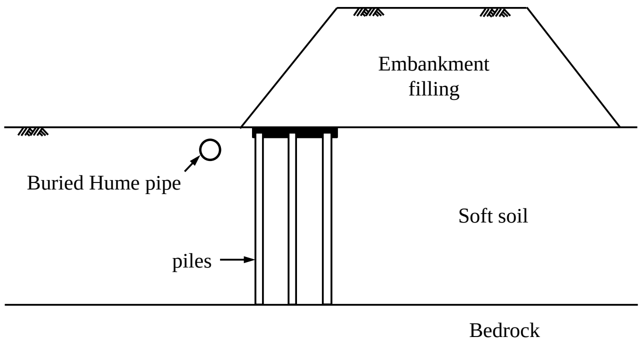


Fig. 2 Pile-supported embankment

Hong et al. (2007) proposed a theoretical equation of the vertical load P_v (kN/m) applied to a beam based on the geometric configuration of the soil arching zone in Fig. 3. The equation is expressed in Eq. (1)

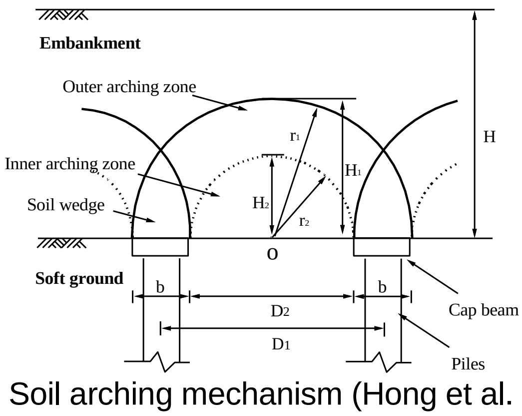


Fig. 3 Soil arching mechanism (Hong et al. 2007)

$$P_v = \gamma H D_1 - \left[\gamma \left\{ H - H_1 - \frac{r_1}{N_\phi - 2} \right\} \left(\frac{r_2}{r_1} \right)^{N_\phi - 1} + \gamma \frac{r_2}{N_\phi - 2} - \left\{ 1 - \left(\frac{r_2}{r_1} \right)^{N_\phi - 1} \right\} \frac{2cN_\phi^{1/2}}{N_\phi - 1} + \gamma H_2 \right] D_2 \qquad (1)$$

where N_ϕ = tan^2 (π/4+ϕ/2), H is the height of embankment fills (m), H_1 (= r_1) is the height (m) at the crown of the outer soil arch, H_2 ($= r_2$) is the height (m) at the crown of the inner soil arch, D_1 and D_2 are the center-to-center distance (m) and clear distance between the beams, respectively, c is the cohesion (kN/m^2), ϕ is the internal friction angle, and γ is the unit weight (kN/m^3) of the embankment fills.

The efficiency of load transfer E_f is defined as a ratio of the vertical load P_v to the total embankment load in Eq. (2)

$$E_f = \frac{P_v}{\gamma \cdot D_1 \cdot H} \times 100(\%) \qquad (2)$$

3. FULL-SCALE TEST ON EMBANKMENT

A full-scale experiment was conducted on piled embankment to investigate the resistance effect of movement of soft ground in Shiwha region of Ansan City. The period of the experiments was 70 days and the experimental measurements in the embankment without reinforcement were employed as a reference. Fig. 4 exhibits plane view of the full-scale experiment on embankment.

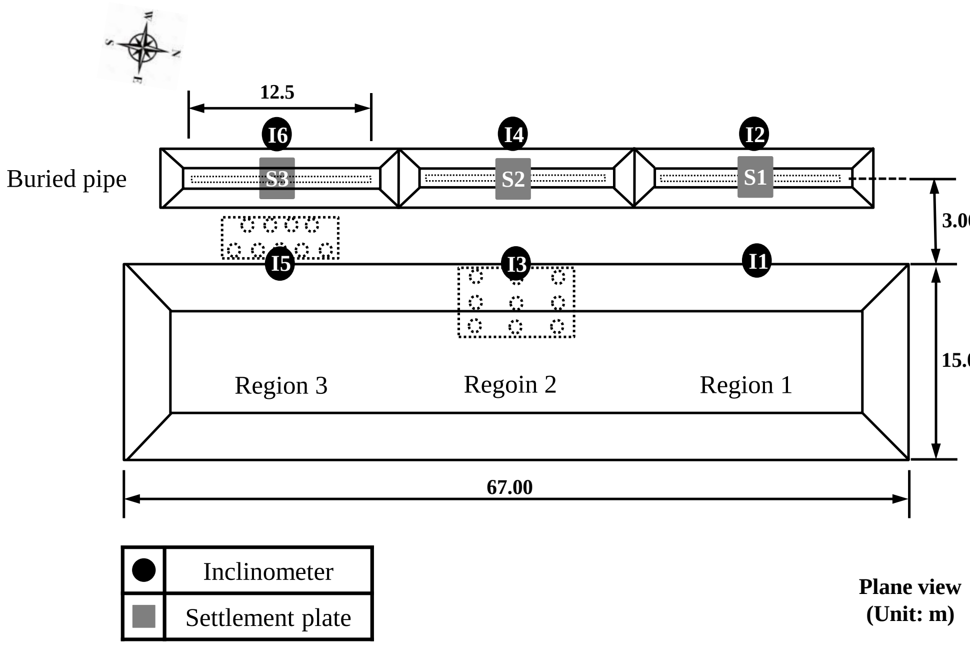


Fig. 4 Plane view of full-scale test on embankment

4. RESULTS AND DISCUSSSIONS

The embankment filling results in the horizontal and vertical movement of the soft soil, and the piled embankment can effectively restrain such a settlement and lateral displacement of soft ground. In order to quantitatively determine the restraining effect of both movements, the Coupling Area (CA or A_δ) (cm^2) was derived and expressed in Eq.(3).

$$\mathrm{A}_\delta = \frac{1}{2}\delta_v \cdot \delta_h \tag{3}$$

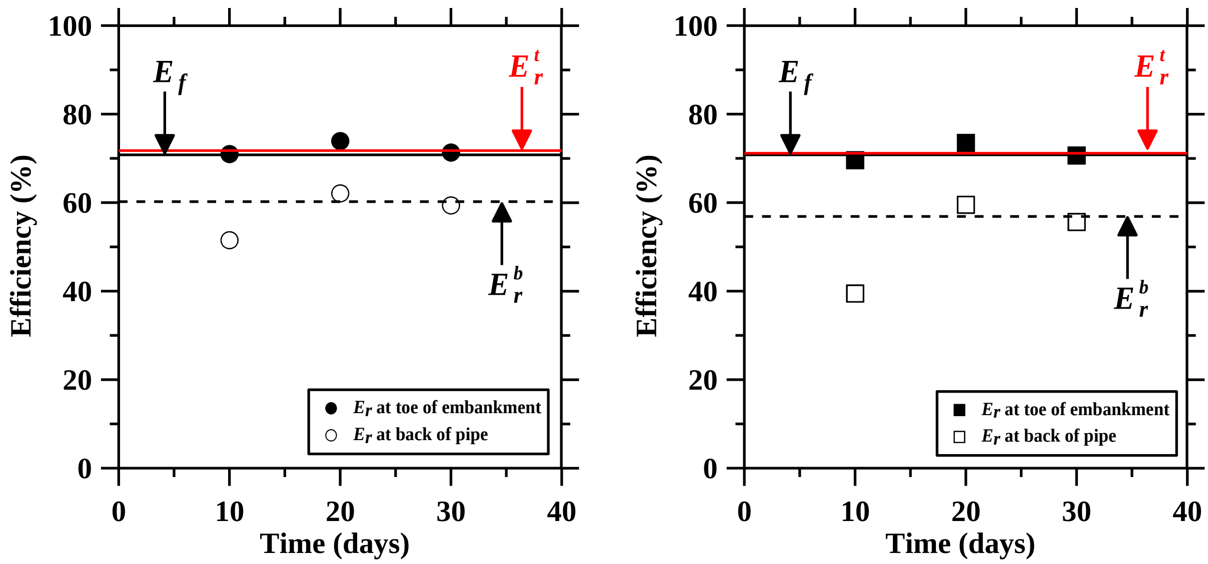
where δ_v is the settlement of buried pipe (cm) and δ_h is the lateral displacement of soft ground at surface (cm).

The efficiency of reinforcement determined by the CA is written as

$$E_r^{t \text{ or } b} = \frac{\left(A_\delta\right)_E - \left(A_\delta\right)_{PE}}{\left(A_\delta\right)_E} \times 100(\%) \tag{4}$$

where $\left(A_\delta\right)_E$ is the CA in the area of the embankment without reinforcement and $\left(A_\delta\right)_{PE}$ is the CA in the region of the piled embankment. Here, superscript *t* or *b* represents location (e.g., *t* stands for the toe of embankment and *b* signifies the back of pipe).

The efficiency E_r^t of reinforcement at the toe of embankment was 71.8% (solid red line), while the efficiency E_r^b of piled embankment at the back of the pipe was determined to be about 60.2% (dashed line), as shown in Fig. 5(a). In Fig. 5(b), the efficiency E_r^t of the CA at the toe of embankment at a depth of 1.5 m was calculated to be approximately 71.2 % (solid red line), whereas the efficiency E_r^b at the back of the pipe was 56.9% (dashed line). These experimental results indicate that 1) about 30% of the embankment load was transferred to the soft ground, 2) the efficiency of reinforcement based on the CA does not depend on the depth since the difference between the efficiencies at surface and a depth of 1.5 m are approximately 0.6% at toe and 3.3% at back, and 3) the CA at surface can have be used to determine the restraining effect and will be a very useful value for developing design guidelines that may mitigate the damage to the buried pipe.



(a) At surface

(b) At a depth of 1.5m

Fig. 5 Efficiency analysis by the Coupling Area: (a) at surface; and (b) at a depth of 1.5 m

5. CONCLUSIONS

In this paper, the novel term, called the CA, to evaluate the coupling effect of soft ground induced by significant embankment loads was proposed and employed to compare it with the efficiency of load transfer. The efficiency determined by the CA showed good agreement with the efficiency calculated by soil arching theory. Therefore, the CA will be a very useful value for developing design guidelines of buried pipe.

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