

Field studies of a technique to mitigate ground settlement of operating highways

Key words: Operating highway, Post-construction settlement,
Jet grouted pile, Ground heave

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Principal stages of construction

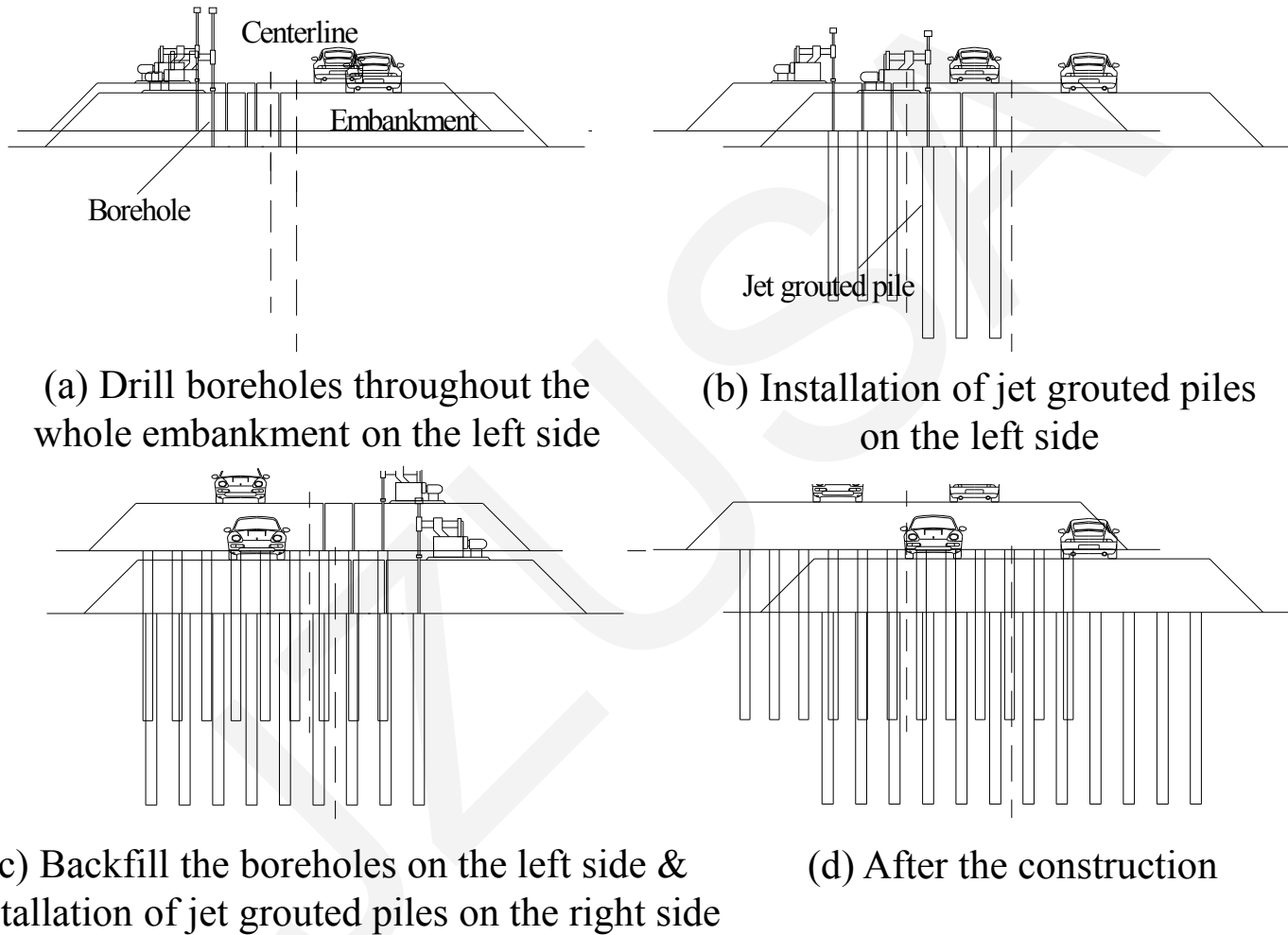


Fig. 1. Illustration of the principal stages in the construction of jet grouted piles

Field Case I : Lianyan highway

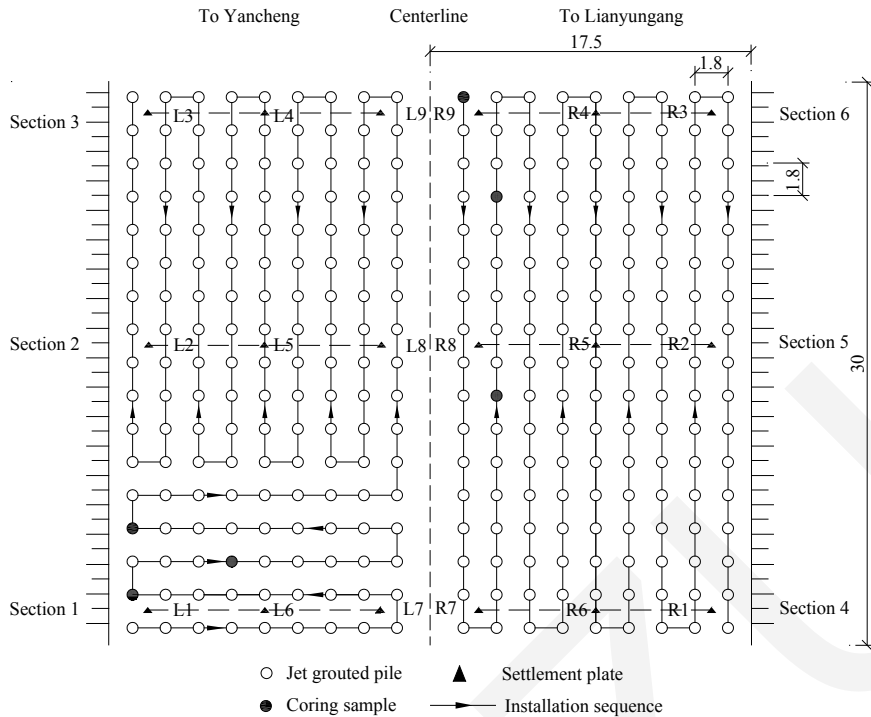


Fig. 2. Plan view of the experimental site on the Lianyan highway (unit: m)

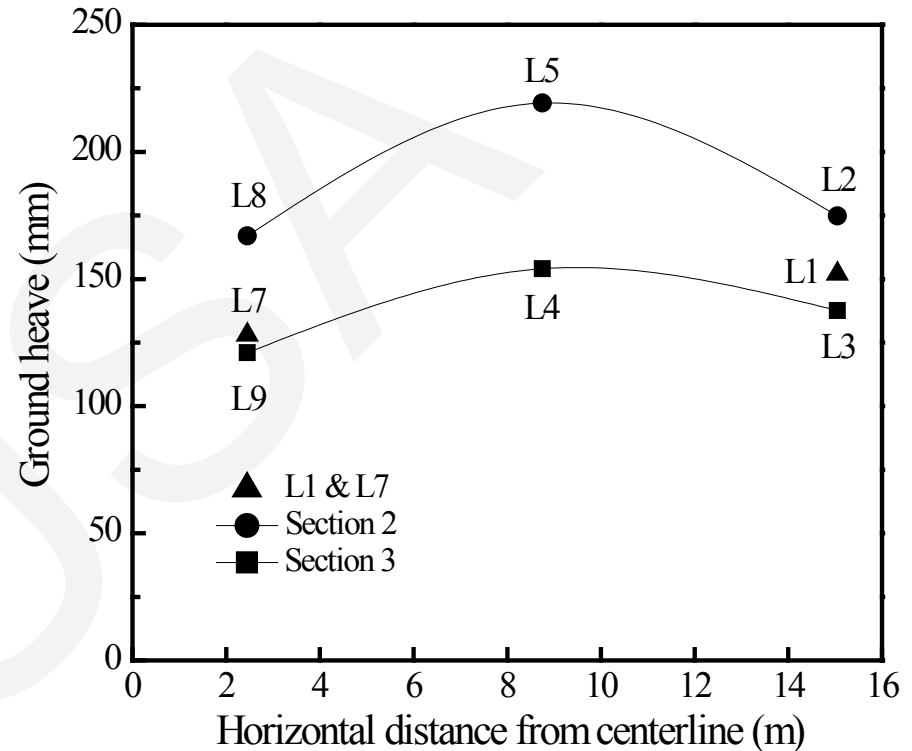


Fig. 3. Ground heave due to jet grouting on the left side of Lianyan highway

- Ground heave with a maximum value of 219 mm was induced over a short construction period on the Lianyan highway. The embankment was uplifted to offset the majority of the previous settlement.

Field Case I : Lianyan highway

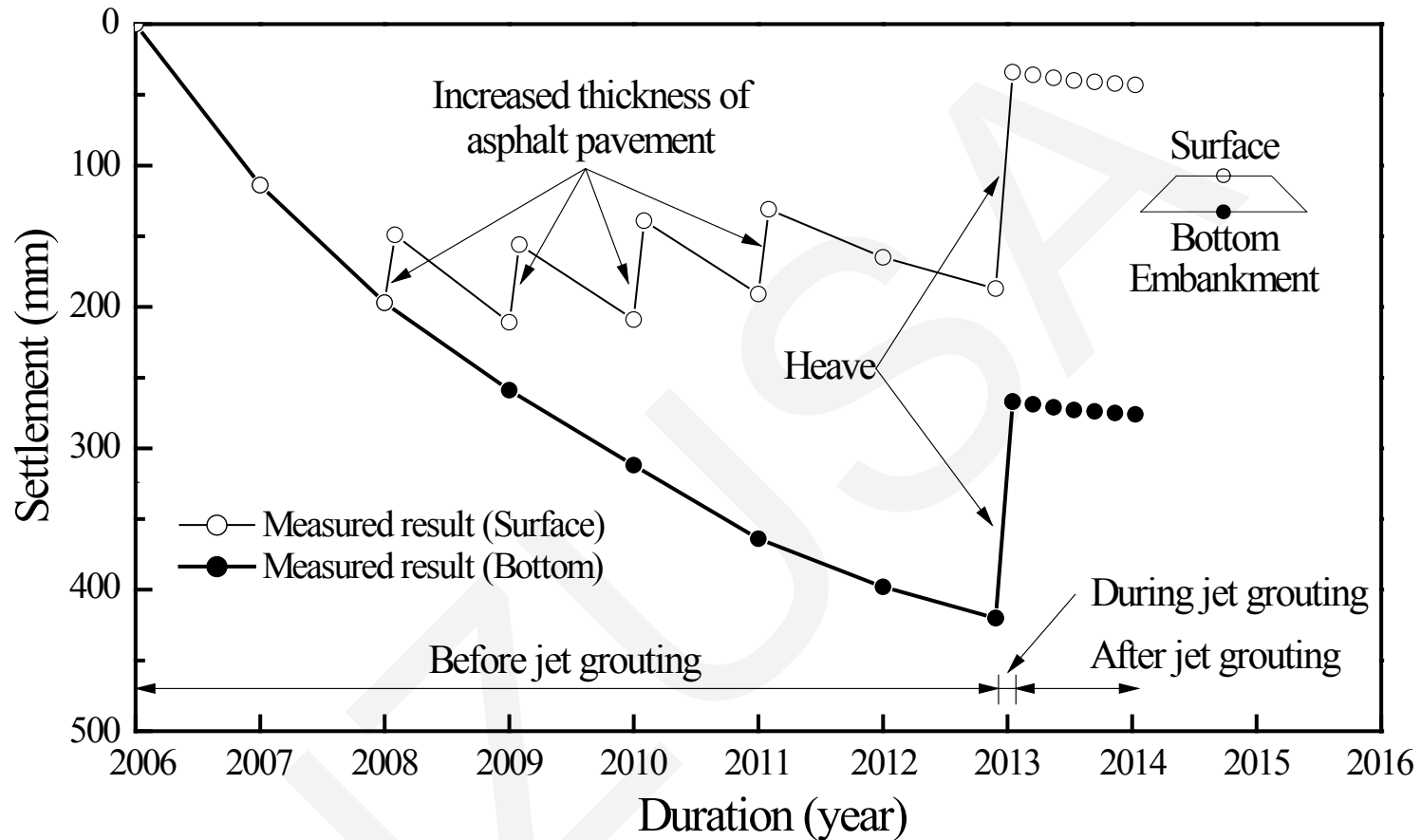


Fig. 4. Variation in ground settlement with time on the Lianyan highway

- Long-term field results show that the average settling rate was reduced significantly, from 60 mm/y before construction to 9 mm/y after construction, suggesting that the technique could be effective in supporting the embankment and mitigating ground settlement of operating highways.

Field Case II : Linhai highway

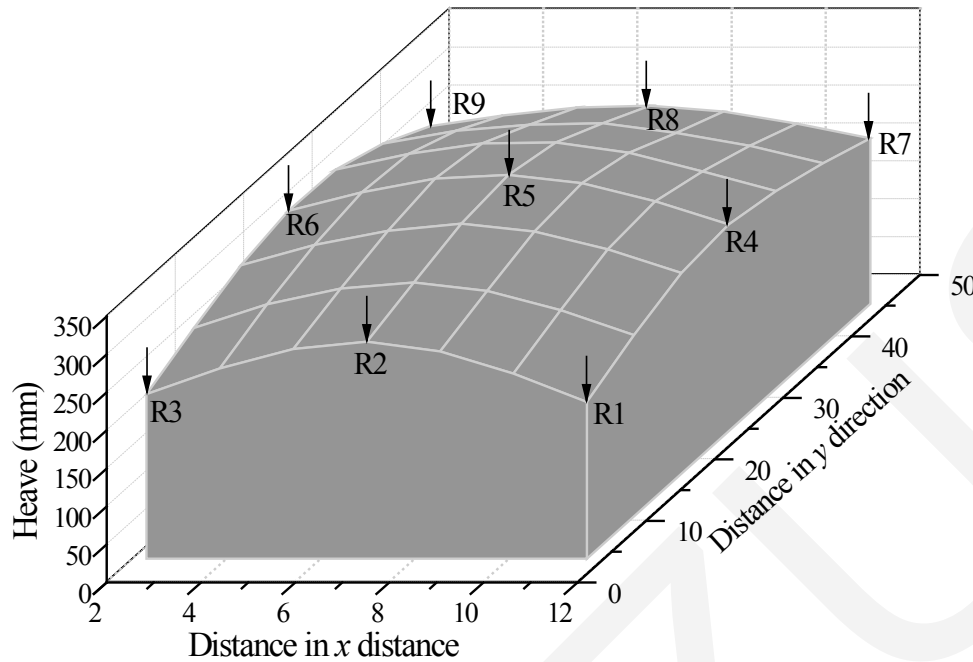


Fig. 5. A 3D view of ground heave measured on the Linhai highway

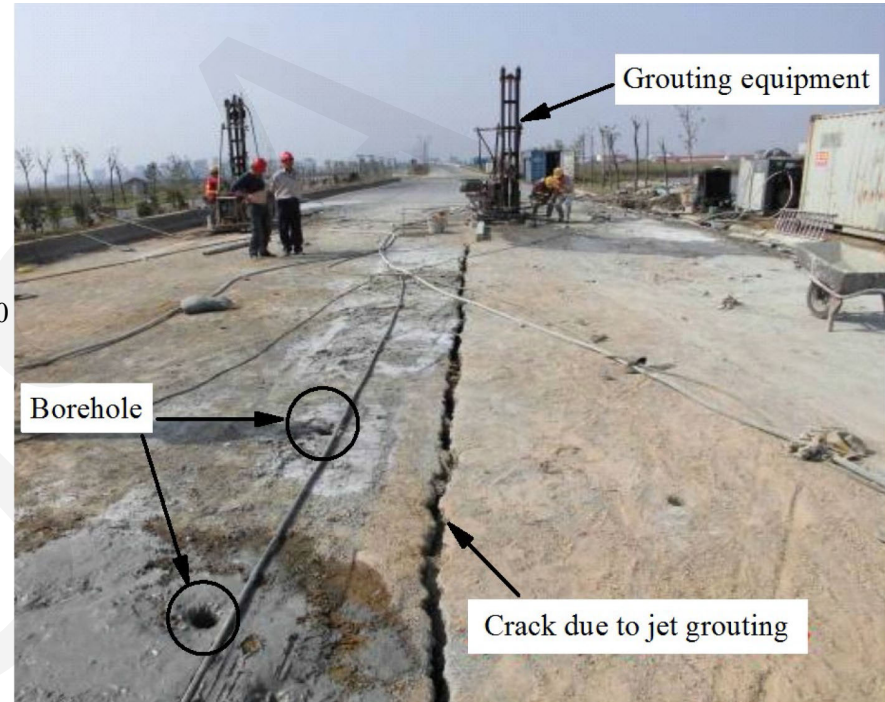


Fig. 6. Crack due to jet grouting on the Linhai highway

- The maximum heave of 337 mm occurred at the central zone during the construction of right side. However, cracking due to the great heave extended along the longitudinal direction.

Field Case II : Linhai highway

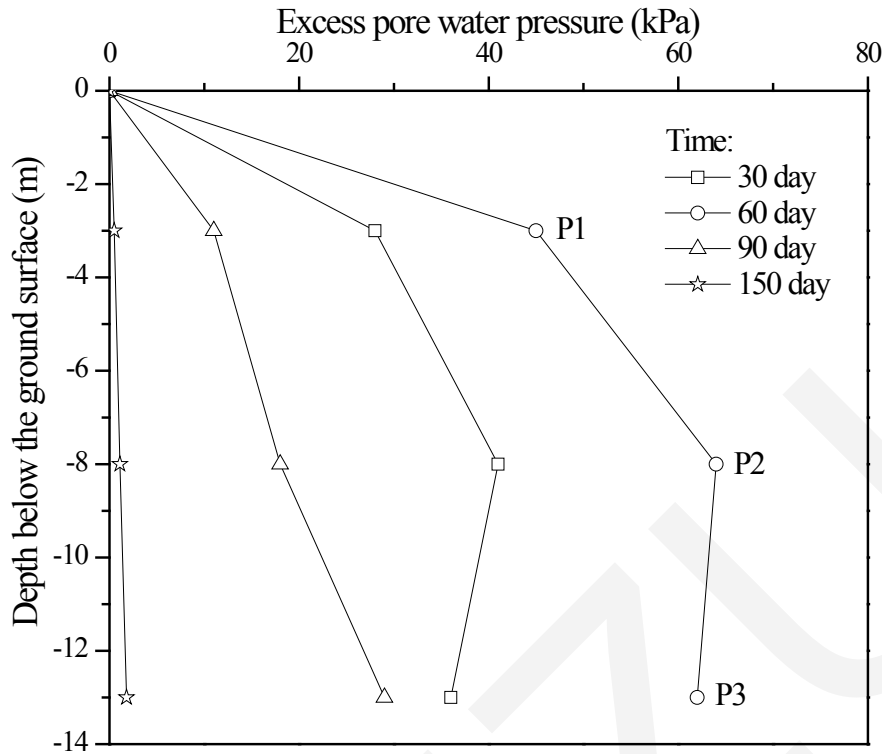


Fig. 7. Variation in excess pore water pressure with time on the Linhai highway

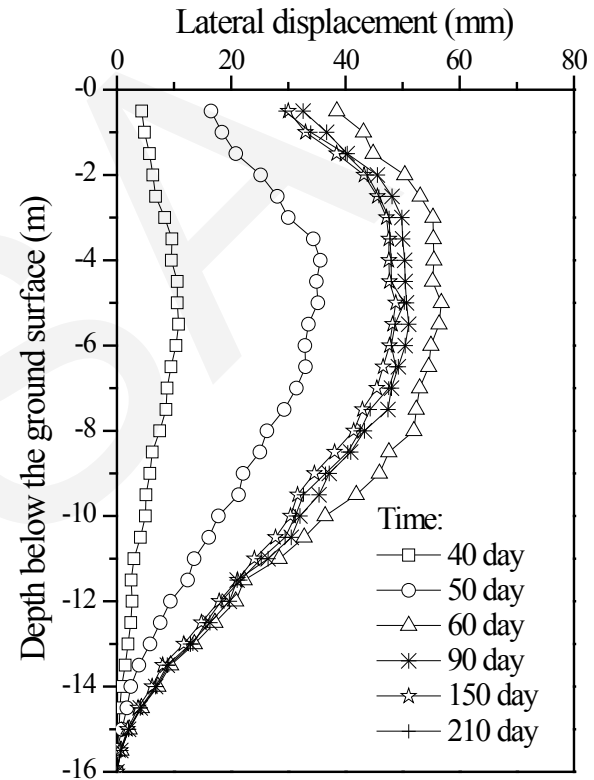


Fig. 8. Lateral ground displacement profiles on the Linhai highway

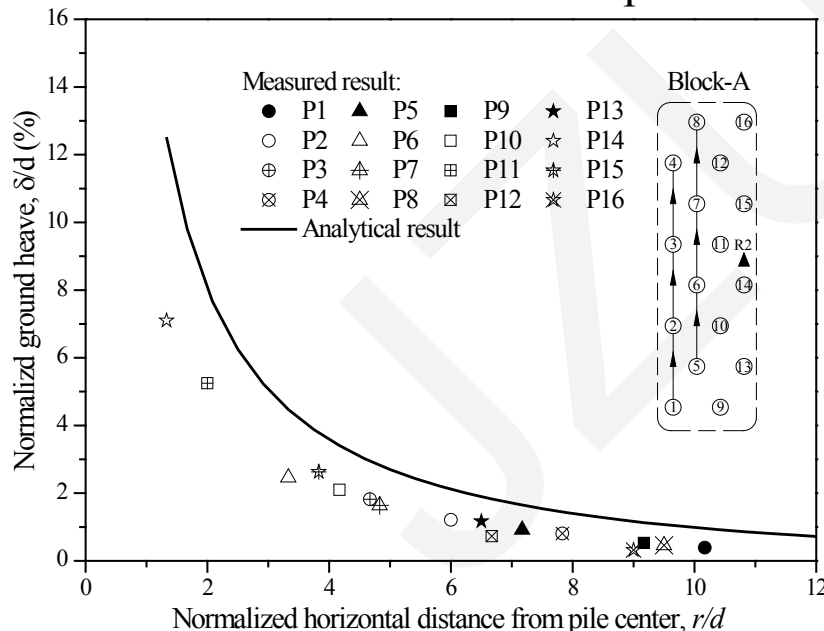
- Excess pore water pressure observed was 64 kPa at most, near the mid-depth of the pile shaft at the end of construction (i.e. at day 60).
- The lateral displacement increased to as much as 56.8 mm during construction, but appeared to reduce after construction, in association with the dissipation of excess pore water pressure.

Relationship between ground heave and distance from the pile center

- Ground surface heave due to a single jet grouted pile (Wu *et al.* 2016):

$$\delta = \frac{3(1-\nu^2)d^2}{4E} \left[\frac{Y + (\alpha - 1)p}{3\alpha} \right]^{\frac{3\alpha}{2(\alpha-1)}} \left[\frac{2 + \alpha}{Y + (\alpha - 1)p_0} \right]^{\frac{\alpha+2}{2(\alpha-1)}} \left| \frac{1}{\sqrt{l^2 + r^2}} - \frac{1}{r} \right|$$

where δ =ground surface heave; ν =Poisson's ratio of soil; E =Young's modulus of soil; d =pile diameter; $Y=2cc\cos\varphi/(1-\sin\varphi)$; $\alpha=(1+\sin\varphi)/(1-\sin\varphi)$; c =soil cohesion; φ =soil friction angle; p =grout pump pressure; p_0 =embankment load; l =pile length; and r =horizontal distance from the pile center.



- Ground surface heave decreases with a lower grout pump pressure p , a larger embankment load p_0 and increasing horizontal distance from pile center r .
- Both measured and analytical results reveal that the induced ground heave decreased with increasing distance from the pile center, indicating the predictability of the analytical solution.

Fig. 9. Relationship between normalized ground heave and horizontal distance from the pile center

Conclusions

- ❑ A technique using jet grouted piles by drilling boreholes throughout the embankment is developed to mitigate post-construction settlement of operating highways in China. Two field studies show that the embankment was uplifted to offset most of the previous settlement over a short construction period and the average settling rate was reduced significantly after construction, suggesting that the technique could support the embankment and mitigate ground settlement well.
- ❑ Based on the adopted analytical method (Wu *et al.* 2016), ground heave due to a single jet grouted pile was found to depend mainly on grout pump pressure, embankment load and horizontal distance from the pile center. Moreover, both the measured and analytical results reveal that the ground heave decreased with increasing distance from the pile center.
- ❑ A larger maximum ground heave of 337 mm was measured on the Linhai highway than that (219 mm) on the Lianyan highway. This is because the increase in grout pump pressure had a significant effect on the induced heave, as indicated by the analytical method. Owing to the great heave, cracking occurred along the longitudinal direction of the embankment during construction. In addition, the maximum excess pore water pressure observed was 64 kPa, near the mid-depth of the pile shaft at the end of construction. The lateral displacement increased to as much as 56.8 mm during construction, but appeared to reduce after construction, in association with the dissipation of excess pore water pressure.