Discussion: Ground response and grout distribution by field soil grouting

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The authors have presented their findings on a field grouting trial (Chang and Huang, 2016). The discussion contributor proposes a slightly different interpretation of their field observations.

The trial involved the top-down (GCB and CB) and bottom-up (SA40) injection of three types of grout at different depths through a single tube à manchette (TaM), as summarised in Table 5. The values for injection time per step are inexact, as the data in the paper are not sufficient to provide the exact values; these estimated values are given for comparison with the gel or setting time of the relevant grout.

The trial involved the injection of three types of grout, identified by the authors as GCB, CB and SA40. The acronyms are not defined by the authors, but the mix proportions given show that the grouts were: Cement/Bentonite/Silicate (GCB), Cement/Bentonite (CB) and Silicate/Reagent (SA40). The three types of grout injected have significantly different uses in common practice. The GCB grout is commonly used for compensation grouting, or to recompact disturbed or loosened soil, or for the initial sealing of leaks. CB grout is commonly used as a pre-treatment for silicate grouts, and for rock fissure grouting (although not with this formulation). Silicate grout, like the SA40 grout used in the trial, is commonly used to permeate fine sand, in order to reduce permeability and provide a small increase in strength.

The GCB and CB grouts, as shown in Table 5, had a high water-to-cement ratio (w/c). The added bentonite will minimise bleeding in trial mixes prepared at the surface and not pressurised. However, when injected under pressure and forming fractures ('fracs') in the ground, these types of grout are subject to severe pressure filtration. A large proportion of the mix water will be expelled, particularly when injecting into sand or silty sand strata. For a similar CB grout injected into silty sand in Hong Kong, the discussion contributor estimated that over 80% of the mix water was expelled. This was calculated by comparing the unit weight of the mixed grout with the unit weight of samples from fracs excavated during tunnelling through the grouted zone. The effects of the pressure filtration can also be seen in the colour of the grout, with sleeve

grout (placed under gravity) being a light grey whereas fracs of the same grout injected into silty sand are typically a very dark grey. Komiya *et al.* (2003) record tests of a grout similar to the GCB grout, which showed significant bleeding under pressure, even after initial gelation.

The SA40 grout mix used had a short gel time (3 to 5 min) in comparison with the duration of injection. This would not have been optimum for permeation, owing to the viscosity evolution of the grout between mixing and gelling.

The expelled mix water from the GCB and CB grouts would, initially, still have added volume to the ground, raising pore pressures and contributing to the heave and lateral movement measured. Positive excess pore pressures would also be generated by shearing of the normally consolidated soils at the site during the fracture grouting process. However, as the positive excess pore pressures dissipated, there would have been loss of heave. This is confirmed in the 33% loss of the maximum heave measured during steps 12A and B, after the completion of the injections. However, the loss of heave evidently accelerated between step 12A and step 12B, as shown in Figure 5 of the paper, so the process appears to have been ongoing when the monitoring ceased, and it is not known how much of the remaining heave would finally have been lost. The authors refer in their conclusions to the 'final' heave volume of 22% of the injected volume, and 'final' lateral expansion of 12% of the injected volume. However, these do not appear to represent final values in terms of achieving a steady state, merely the values when the monitoring was discontinued.

In Figure 6 of the authors' paper, the injection of the GCB grout (parts (a) and (b)) caused outward displacement. During the subsequent steps 7 to 12 (parts (c) and (d)), there was outward movement at the active grouting zone, but inward movement above the active grouting zone. The overall horizontal net volume change for steps 1 to 6 was positive, but for steps 10 to 12 was negative. The authors suggest that this was due to a change from fracturing to permeation behaviour. The discussion contributor would suggest that the overall negative horizontal volume change during steps 10 to 12 was attributable to the partial dissipation of excess pore pressures that would have resulted from the prior injection of CB and GCB

Table 5. Summary of the grouts used (from data presented in Chang and Huang (2016))

Grout type	Depth injected: m	Soil injected	w/c	Gel or setting time	Injection rate: l/min	Estimated injection time/step: min
GCB	4.2–6.2	CL and SM	4.2:1	50–60 s	1.8–7	45 to 136
CB	6.2–7.2	SM and ML	2.5:1	16–24 h	2.3–6	87 to 102
SA40	7.2–8.2	SM and ML	NA	3 to 5 min	2.8–5.4	51 to 78

CL, silty clay; ML, sandy silt; SM, silty sand

grouts, rather than a change in grout behaviour. There was still significant heave during steps 10 to 12, during the SA40 grouting, which would not be consistent with purely permeation behaviour. The inward ground movements measured above the active grouting zone even in steps 7 to 9 would indicate that partial dissipation of positive excess pore pressures (caused by the earlier GCB grouting) was occurring during the CB grouting. The dissipation would also have caused partial loss of the heave that had been generated by the GCB grouting, but this would have been masked by the heave from the CB grouting.

The authors suggest that the CB grout both fractured and permeated (from the fractures) the soil, a behaviour also known as ‘claquage–permeation’. This behaviour has been previously documented for silicate grouts in silty fine sand, as it is in this paper for the SA40 grout. However, this is unlikely behaviour for CB grout in silty sand, owing to the size of the suspended particles in the grout. If the authors observed a reaction to phenolphthalein adjacent to the frags of CB grout, it is possible that this reaction was from the expelled mix water, which

would be highly alkaline. Unless the ground around the frags was obviously cemented by permeating grout, this would not represent ‘claquage–permeation’ by the CB grout, but the effects of pressure filtration.

The authors’ conclusion, also reported in the editorial, that heave increases with depth of grouting is questioned: depth was not the sole variable in the trial. The type, sequence and behaviour of the grout used in the trial altered with depth. The increase in the percentage of the grout volume measured as heave with successively deeper grouting, may have been due to variables other than simply depth.

REFERENCES

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