Cyclic Stress Ratio Reductions by Stone Columns in Liquefiable Silty Soil

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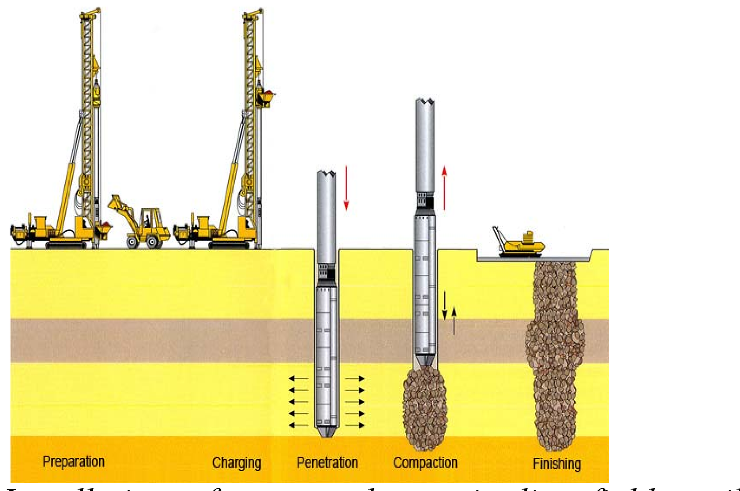
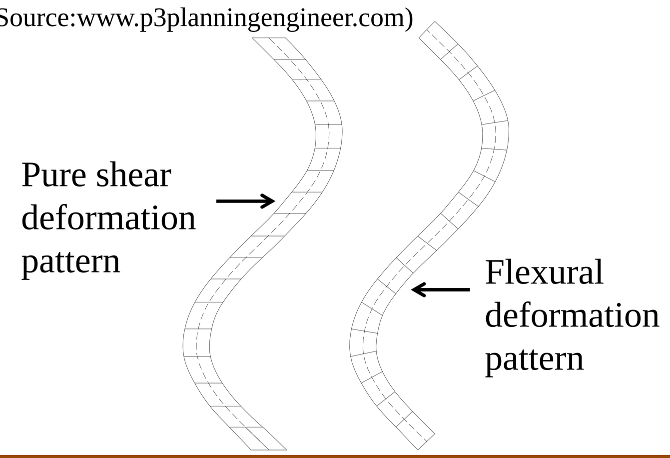
Research Motivation

In silty sand or non plastic silt, the design of stone columns (SC) often assumes that they act as shear reinforcement to reduce shear stresses in surrounding soil (Baez 1995). Shear strain compatibility between SC and surrounding soil is the main assumption in current design practice. However, Goughnour and Pestana (1998), Green et al. (2008) and Olgun and Martin (2008) show that flexural deformations largely negate shear strain compatibility. Limited work has been done to quantify the level of shear stress reduction by SC in liquefiable soil. Therefore, this work aims to ***investigate the shear reinforcing mechanism of stone columns for reducing cyclic stress ratio in loose silty ground*** using 3D nonlinear finite element analyses and compare the results based on linear elastic analyses by Rayamajhi et al. (2014).

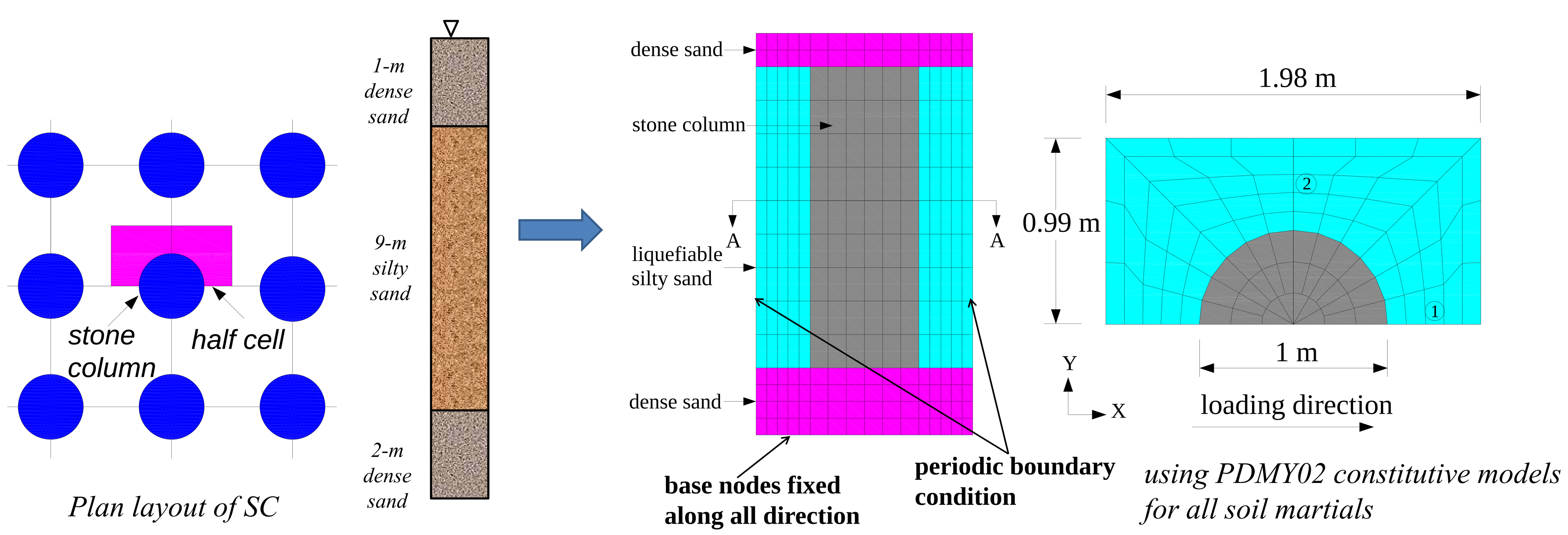


Installation of stone columns in liquefiable soil
(Source:www.p3planningengineer.com)



FE Modeling

Numerical analyses of unimproved and improved ground were carried out using OpenSees. Cases with and without excess pore pressure generation were developed. In order to isolate the drainage effects of stone columns from the shear reinforcement mechanism, the hydraulic conductivity of the stone columns was set equal to that of hydraulic conductivity of the surrounding soil.



Plan layout of SC

Soil profile

using PDMY02 constitutive models for all soil martials

Shear stress and shear strain ratios:

$$R_{CSR}=\frac{CSR_I}{CSR_U}=\frac{(a_{\max}r_d)_I}{(a_{\max}r_d)_U}=R_{a\max}R_{rd}\quad and\quad \gamma_r=\frac{\gamma_{stone-column}}{\gamma_{soil}}$$

CSR_I and CSR_U are the cyclic stress ratios for improved and unimproved cases, respectively.
R_{amax} is the ratio PGA for improved soil /PGA unimproved soil
R_{rd} shear stress distribution ratio
γ_r shear strain ratio

Baez (1995)

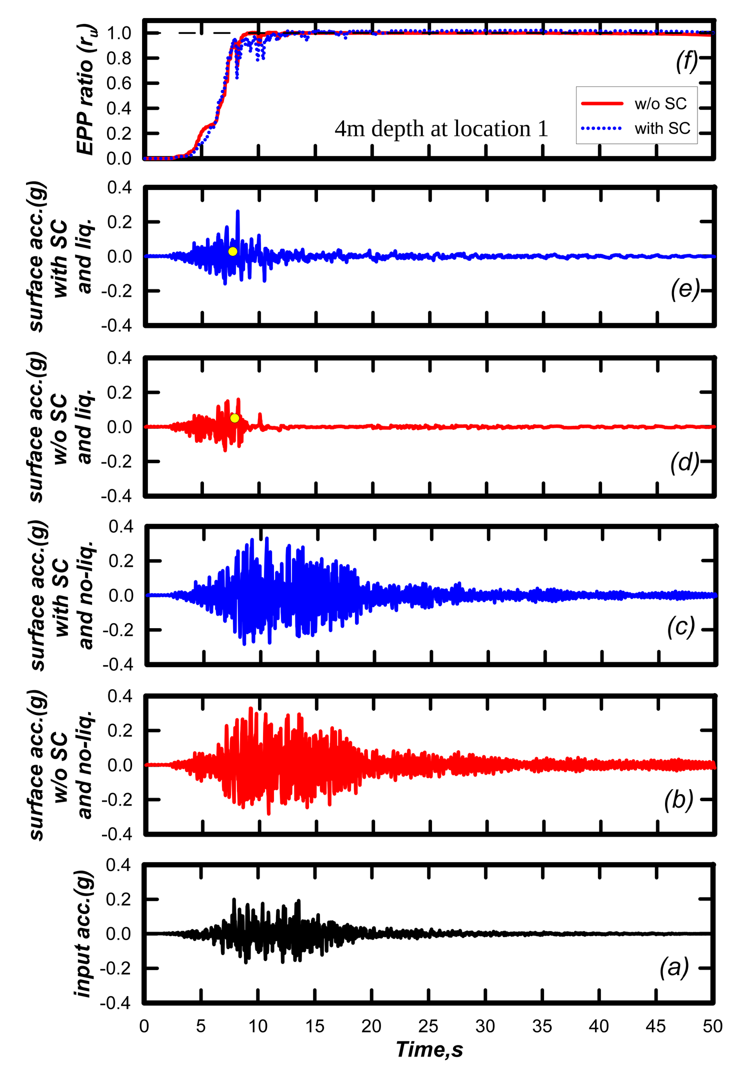
$$R_{rd}=\frac{\tau_s}{\tau_{avg}}=\frac{1}{G_r\left[A_r+\frac{1}{G_r}(1-A_r)\right]}$$

Rayamajhi et al. (2014)

$$R_{rd}=\frac{\tau_s}{\tau_{avg}}=\frac{1}{G_r\left[A_r\gamma_r C_G+\frac{1}{G_r}(1-A_r)\right]}$$

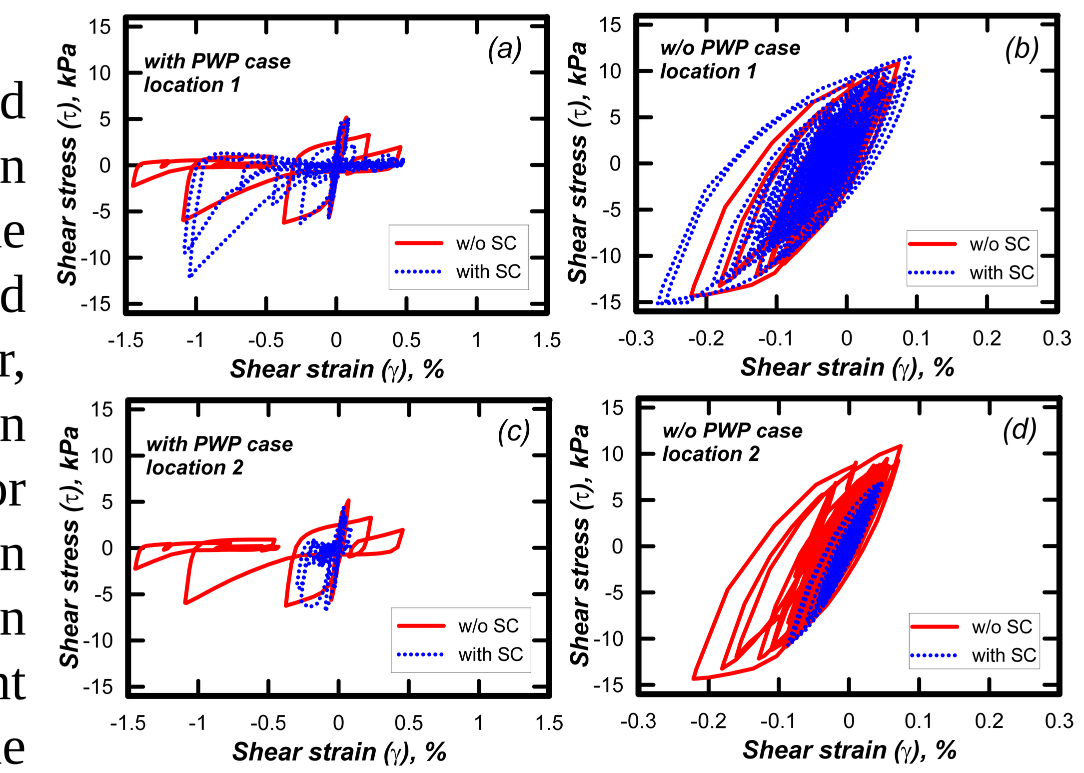
$$\gamma_r=1.04(G_r)^{-0.65}-0.04\ \le 1.0$$

FE Modeling Results



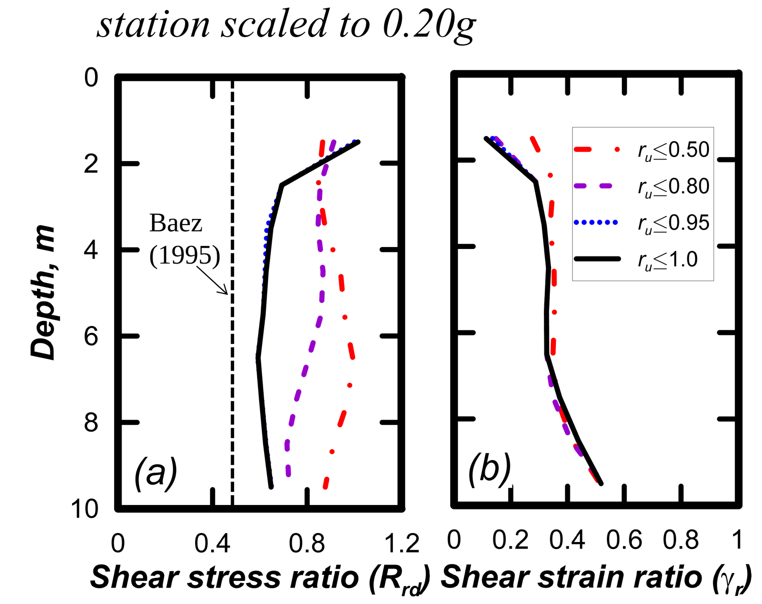
Typical responses for Loma Prieta (1989) earthquake at San-Jose Hills station scaled to 0.20g

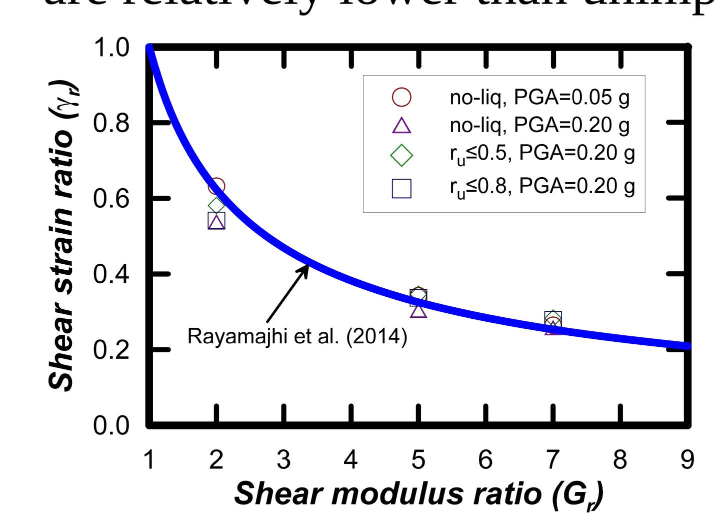
Both unimproved and improved soil liquefied. The liquefaction triggering occurred almost at the same time for both unimproved and improved cases. Moreover, no significant difference in acceleration responses for unimproved and improved soil in without pore pressure generation case suggesting no significant stiffening effects by stone columns.



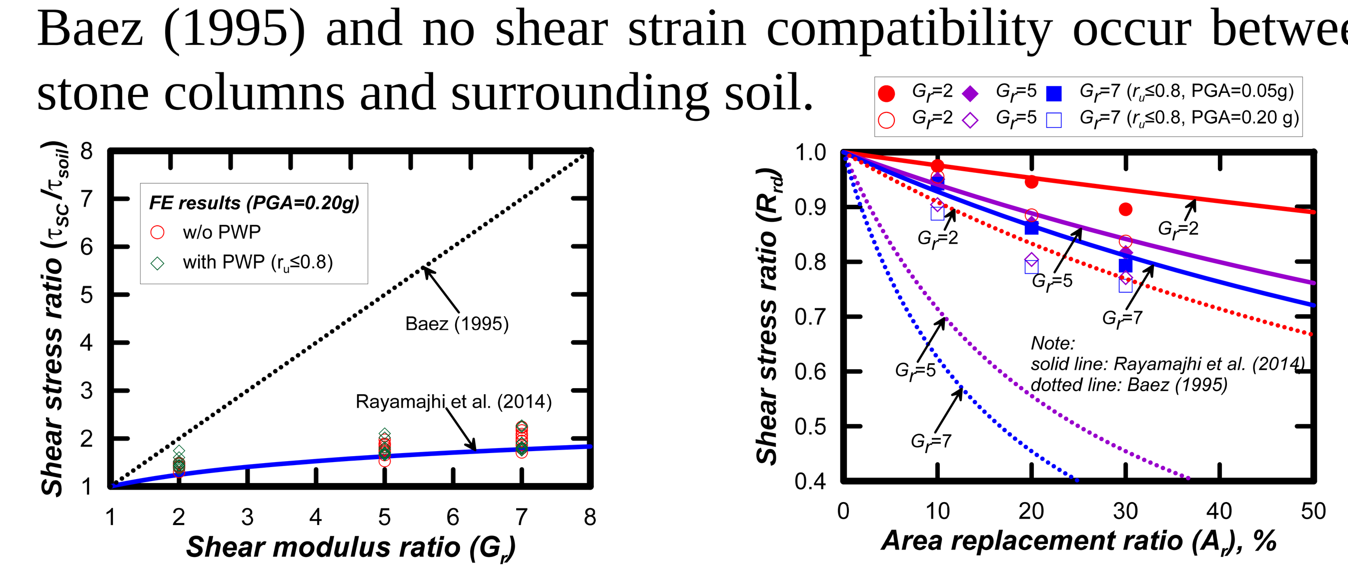
Stress-strain responses in soil for both unimproved and improved cases at 4m depth

For no pore pressure generation case, the maximum shear stress and strain for improved soil is slightly higher than unimproved soils at location 1 (along the direction of shaking). However, at location 2 (located normal to the direction of shaking), the shear stress and strain for improved soils are significantly lower than unimproved soil. On other hand for pore pressure generation case, shear stresses in improved soils are higher in both location 1 and 2, though shear strains are relatively lower than unimproved soil.





Shear stress and strain distribution in the soil at different stage of r_u show no significant reduction in shear stress compared to Baez (1995) and no shear strain compatibility occur between stone columns and surrounding soil.



The shear stress in the stone columns is not in proportional to their relative stiffness such that the cyclic shear stress reduction due to stone columns are not significant as predicted by Baez (1995) work. The new design equation proposed by Rayamajhi et al.(2014) gives better estimate for cyclic shear stress reduction in liquefiable soil.

Summary

- Shear strain compatibility between SC and surrounding soil does not occur and SC does not attract stresses in proportional to their relative stiffness such that SC marginally reduces shear stress in surrounding soil as compared to Baez (1995).
- The use of shear strain compatibility assumption should be discarded and the new proposed design method should be used to estimate the CSR reduction in improved soil due to SC.

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