Soil Liquefaction Abatement

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A. Summary

During earthquakes, damage to buildings is caused by large ground displacements due to the liquefaction of the soil underneath. Current methods of avoiding the soil liquefaction are expensive and effective to only a small extent. A new method of avoiding soil liquefaction has been devised and tested. In addition to the earthquake protection, the method is applicable to many other soils (geotechnical) engineering problems.

B. Current solutions

Current solutions focus on keeping the soil particle stationary during earthquakes. This reduces pore pressure buildup, and, hence, liquefaction susceptibility. Table 1 shows some current amelioration schemes, and their disadvantages.

Table 1. Current liquefaction amelioration schemes.

Amelioration scheme	Disadvantages
Grouting	1. usually requires invasion of the building, with concomitant loss of functionality 2. may *displace* soil, causing heave or building/utility damage 3. expense 4. placement of grout is uncertain 5. opportunity to rupture utilities with pressurized grout 6. creation of hard layer, which may result in differential settlement if settlement occurs (esp. if the grout is non-uniform in strength or distribution) 7. *grout is brittle*, and may break during an earthquake, resulting in uneven settlement, and reduced resistance during the next earthquake 8. requires great skill to perform
Soil compaction	1. likely to cause settlement/damage of building, adjacent buildings and underground utilities 2. hard to do under existing buildings 3. may interrupt building service 4. requires skill to perform
Dewatering	causes settlement; expensive to maintain
Drainage	difficult to do under existing structures – installation of gravel or geosynthetic drains, and disturbance of the building are the main problems

C. New solution

Current solutions are based on: strengthening the soil (densification, grouting), or dewatering. A new solution, *fundamentally different*, has been devised. The new solution is a soil additive. Table 2 gives this new method's pros and cons. This solution performed very well in laboratory tests, and is a blend of high technology chemistry, chemical engineering and civil engineering.

Table 2. Pros and cons of proposed amelioration scheme.
ADVANTAGES
1. may be installed without interrupting building service 2. can be placed with very low pressure (no chance of breaking utilities) 3. *flexible* – cannot crack; will survive any number of earthquakes 4. inexpensive material 5. low permeability
DISADVANTAGES
1. new technology 2. slow installation (may take a few months) 3. only installable below the groundwater table (by the proposed methods, anyway) 4. injection drilling may puncture utilities

Proposed installation methods include groundwater flow with diffusion and use of a slurry wall.

D. Current status of the new technology

Laboratory evaluation of the effectiveness in reducing permeability, liquefaction susceptibility and cyclic mobility of Ottawa sand has been performed. Three series of tests were run: permeability, cyclic triaxial testing and flow table (cyclic mobility).

Permeability test program: ASTM D-5084 flexible wall permeability tests were run on Ottawa sand to evaluate the effect of the treatment. Untreated samples had average permeabilities of 2.17×10^{-3} cm/sec. Treated sample permeabilities ranged from 2.06×10^{-3} cm/sec to 4.14×10^{-9} cm/sec, depending on concentration.

Cyclic triaxial tests. Loose Ottawa sand samples were subjected to cyclic triaxial testing. The results of the control (Figure 1) and one treated sample (Figure 2) are shown below. The control sample liquefied in about 5 cycles; the treated sample took about 80.

Flow table (cyclic mobility) tests. ASTM C 230 (Standard Specification for Flow Table for Use in Tests of Hydraulic Cement) was run to evaluate cyclic mobility. The test uses a ten-inch diameter table that is lifted and dropped 0.5 inch. Nearly saturated, untreated Ottawa sand samples liquefied and flowed almost immediately, with the sand and water separating (Figure 3, top row). Saturated samples do not flow at all. These samples break apart in large chunks of viscous gel, and that only because they're unconfined. Water never leaves these samples. No signs of liquefaction or cyclic mobility are present. This reduction in cyclic mobility is vividly illustrated in the pictures in Figure 3 (bottom row). While the untreated sample flowed after 25 drops, the treated samples never flowed and remained largely intact after 25 drops**.**

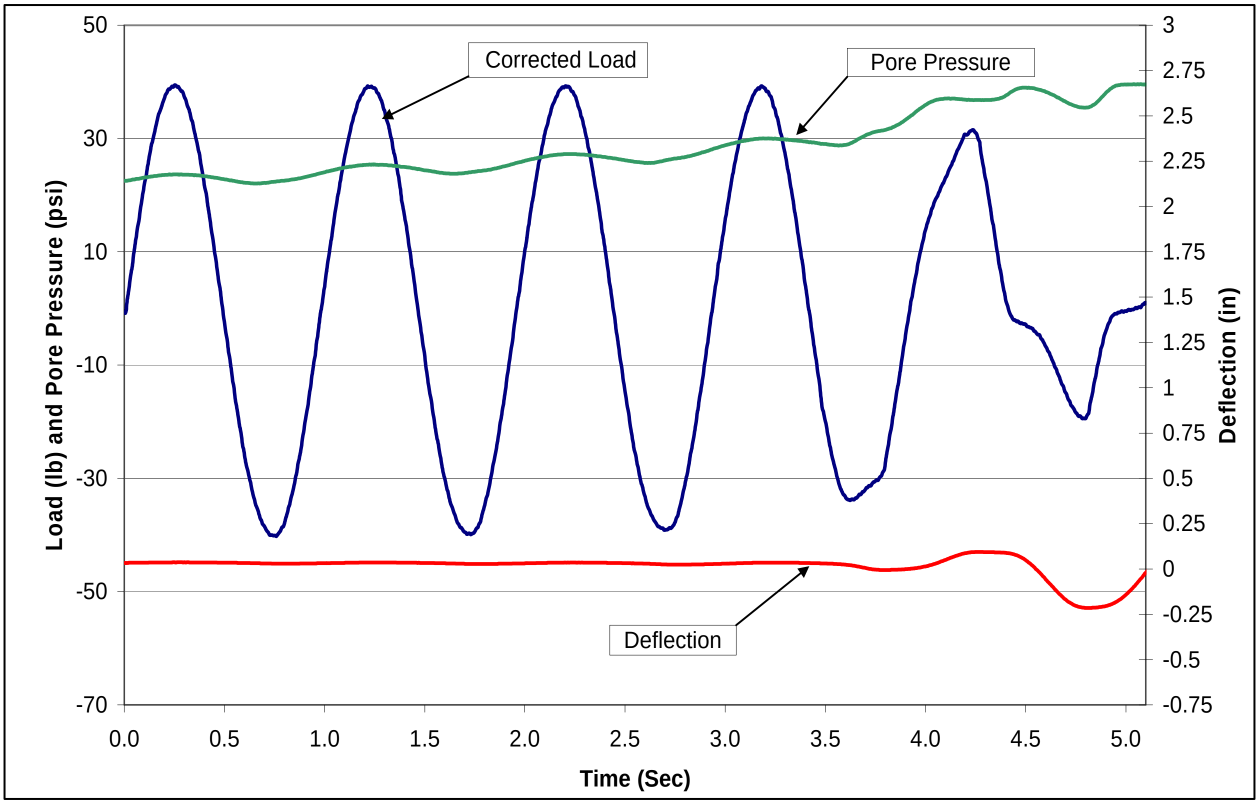

Figure 1. Cyclic Triaxial Test 0% (Control)

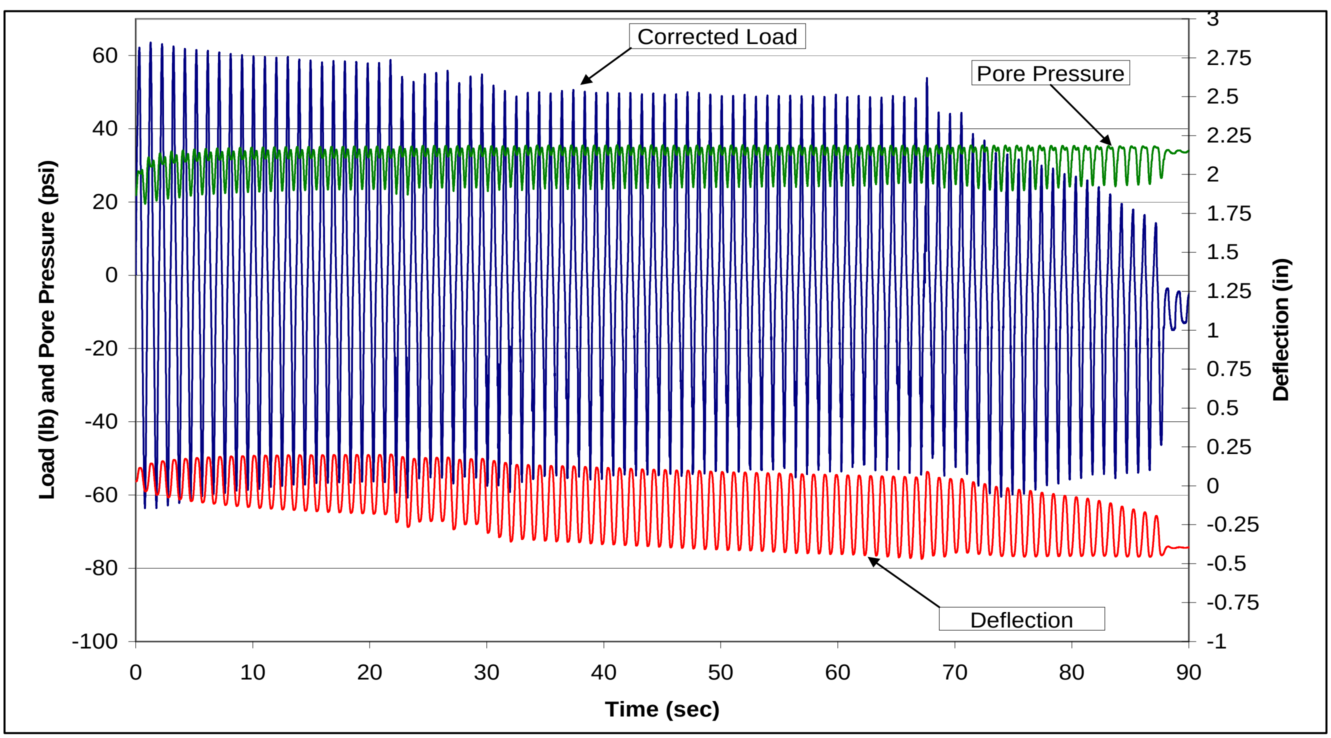

Figure 2. Cyclic Triaxial Test (treated at 0.33%)

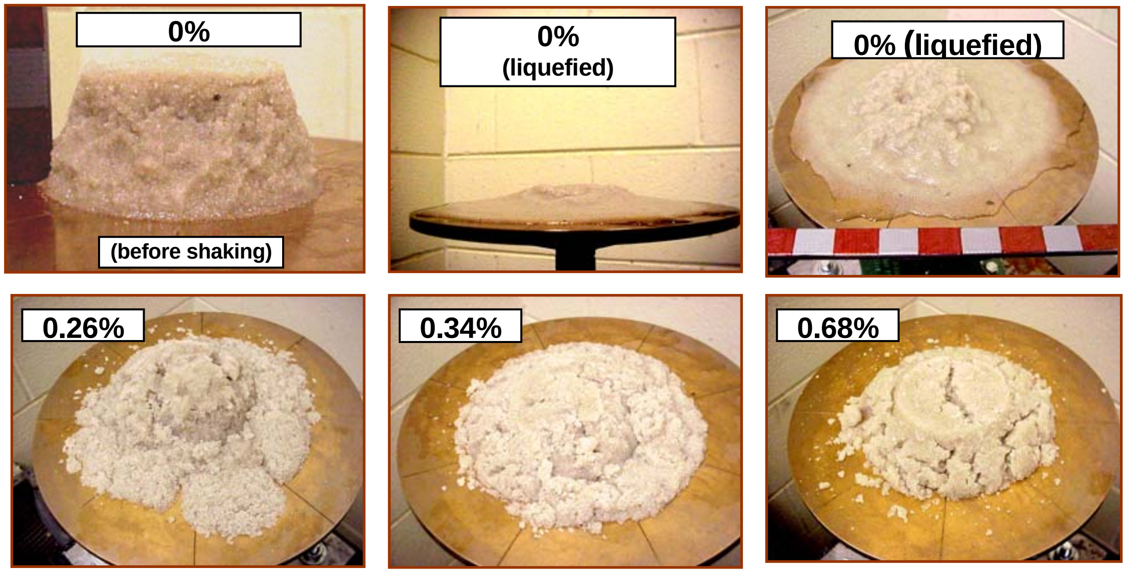

Figure 1. Top row: untreated sample before and after shaking (note water separation)
Bottom row: treated samples after shaking. Scale: one-inch marks on stick.

E. Uses of this technology

1. The project results can immensely and immediately *reduce liquefaction danger* for existing buildings under extreme events. Currently, it's expensive and risky to ameliorate soils for liquefaction abatement under existing buildings. The proposed procedure makes it possible, effective, and, most likely, inexpensive.

The *impact on infrastructure* will be huge. A large market exists for treating liquefiable soils under existing buildings, pipes, dams, and roads. The application can pay for itself as the insurance costs will significantly reduce. Liquefaction-prone sites, formerly undevelopable, will become available. The new method is much easier to use, and less risky than the existing methods.

2. Can be used to reduce the cost of construction excavation.

3. Can be used in groundwater remediation.

4. Can be used in dam rehabilitation, to reduce leakage through dams.

5. Can be used in canal rehabilitation, to reduce leakage through canals. This is especially important in arid areas.

6. Can be used in foundation remediation – to reduce moisture inside buildings (and consequent mold / mildew development).

7. Can be used in landfill isolation, to contain fugitive leachate.

A PCT patent application has been filed.

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