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Soil liquefaction mitigation using crosslinked Xanthan gum treatment on coarse sand using a dynamic centrifuge test

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ABSTRACT: Soil liquefaction during earthquakes remains one of the most pervasive threats to geotechnical infrastructure, demanding mitigation strategies that balance effectiveness, constructability and environmental responsibility. Among bio-geotechnical approaches, biopolymer treatment is distinguished by its ability to reduce cyclic degradation and permanent strain through viscoelastic energy dissipation. It presents a viable solution that integrates mechanical resilience and energy dissipation. This study investigates the fundamental mechanisms of crosslinked viscoelastic biopolymers as a sustainable agent for mitigating earthquake-induced liquefaction. Sand specimens were treated with crosslinked xanthan gum (CrXG) to enhance interparticle bonding and introduce viscoelastic energy dissipating behavior. A dynamic centrifuge test was conducted on treated and untreated samples under a single tapered sinusoidal motion. This study investigated dynamic nonlinear responses of the Xanthan gum treated soil based on shear beam assuption. Cyclic shear stress-strain loops using vertical acccelerometer arrays were derived and damping ratios were calculated to quantify dissipated energy under the cyclic loading. The biopolymer-treated sands maintained structural integrity during shaking, whereas untreated specimens experienced significant deformation.

1 INTRODUCTION

Earthquake-induced liquefaction remains one of the most pervasive and destructive threats to geotechnical infrastructure, necessitating the development of effective and sustainable mitigation methods. Cement-based ground improvement methods often present high material costs and significant environmental footprints. In response, bio-geotechnical approaches, particularly biopolymer treatment, have emerged as a viable, sustainable alternative. This method is distinguished by its ability to introduce viscoelastic behaviour and enhance interparticle bonding in sandy soils, fundamentally improving mechanical resilience. This study evaluates the effectiveness of crosslinked xanthan gum (CrXG) as a sustainable ground improvement method for mitigating liquefaction. A dynamic centrifuge test was conducted on treated and untreated sand specimens under seismic excitation. We introduced an acceleration-based analysis framework concentrated on quantifying damping behaviour through cyclic shear stress-strain loops.

2 EXPERIMENTAL PROGRAM

Dynamic centrifuge test was conducted at 60g using SP silica sand (relative density, $D_r = 50\%$) and 0.5% CrXG treatment ($m_x/m_s\%$). A rigid box with Duxseal was employed to minimize the boundary effects from the reflecting wave. The input excitation was a tapered sine wave (15 main cycles) scaled to 0.3g peak ground acceleration (PGA). The input motion was selected to the previous cyclic direct simple shear testing (Park et al. 2025).

The recorded acceleration data were utilized to derive cyclic shear stress-strain loops at multiple depths based on the shear beam assumption (Zeghal et al. 2018). These loops were then used to calculate the equivalent damping ratios and shear stiffness to quantify the enhanced energy dissipation capacity of the biopolymer-treated sand specimens.

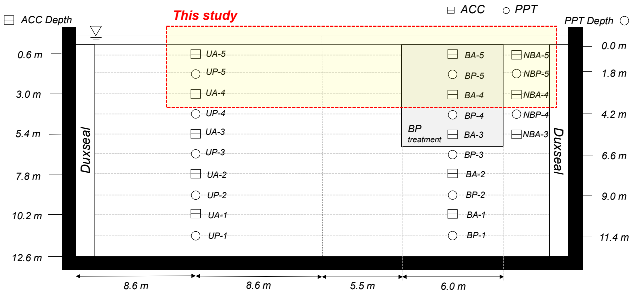

Figure 1. Schematic of the centrifuge model and sensor instrumentation

3 RESULTS AND DISCUSSION

The nonlinear hysteretic behavior of the treated and undtreated sand was characterized through cyclic shear stress-strain loops derived from centrifuge acceleration records (Figure 2). During the early stage of shaking, both untreated and BP-treated soils exhibited similar responses characterized by small strain amplitudes and nearly linear behavior, indicating limited stiffness reduction.

As the input wave amplitude increased, both soils reached comparable shear strain levels. However, the tangent shear modulus of the untreated sand fluctuated significantly, ranging from near-zero to near-infinite values, due to repeated contractive and dilative responses. This phenomenon is associated with cycles of liquefaction and deliquefaction, which were accompanied by higher damping at larger strain levels. In contrast, the BP-treated soil did not exhibit these abrupt changes in tangent stiffness, indicating non-liquefied behavior and enhanced preservation of the soil structure.

The equivalent damping ratio (ξ) was calculated from the area enclosed by the hysteresis loop (Figure 3). During cycles 10 through 13, when the acceleration amplitude exceeded 0.25g, the untreated sand exhibited a significant increase in ξ, reflecting enhanced energy dissipation. Conversely, the BP-treated soil maintained relatively lower damping values. Overall, the results suggest that while both soils demonstrated similar damping patterns under seismic intensities that did not induce liquefaction, the biopolymer treatment resulted in a lower damping ratio at peak input amplitudes. This implies that CrXG treatment effectively can reduce permanent deformation compared to untreated ground during soil liquefaction.

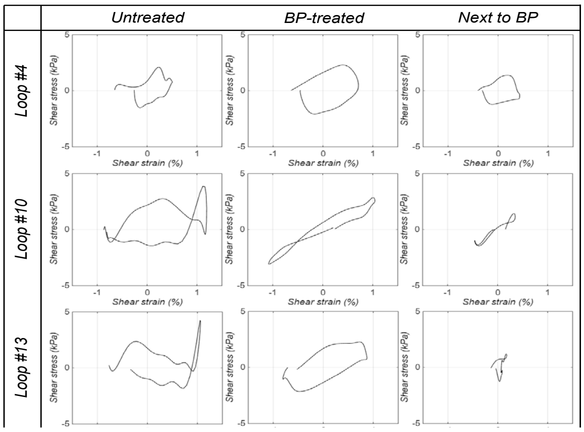

Figure 2. Stress-strain curves with cycle number (4, 10, 13)

4 CONCLUSION

This study demonstrates CrXG treatment fundamentally alters the dynamic response of sandy soils under seismic loading. While both untreated and biopolymer-treated sands exhibit similar linear behaviour at low acceleration, their responses diverge as shaking intensities increase. CrXG treatment prevents abrupt fluctuations during liquefaction-induced cycles and maintains lower equivalent damping ratios at peak amplitudes. By preserving soil fabric and limiting energy-dissipating strain localization, biopolymer intervention effectively reduces permanent deformation, significantly enhancing the overall resilience of geotechnical infrastructure.

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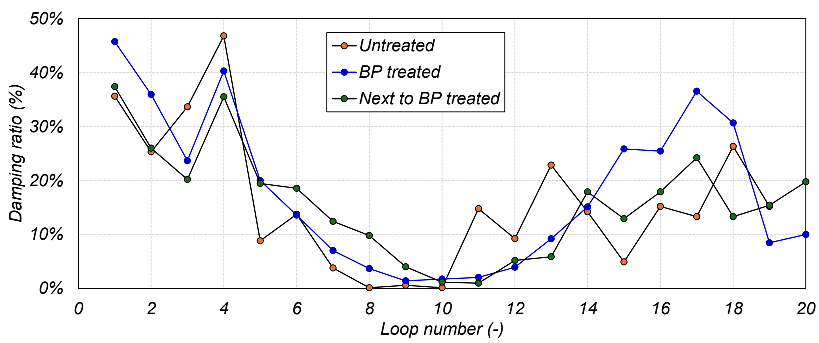

Figure 3. Variation in damping ratio with stress-strain loop number