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DYNAMIC CHARACTERIZATION OF POLYURETHANE GEL FOR GEOTECHNICAL SEISMIC ISOLATION APPLICATIONS

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Abstract

This study presents the dynamic characterization of a polyurethane gel intended for use as a material in geotechnical seismic isolation systems. Resonant column and cyclic torsional shear tests were conducted to evaluate the material properties, including shear modulus and damping ratio, over a wide range of shear strain levels. The polyurethane gel used in this study demonstrated promising characteristics, with a very low shear modulus of approximately 300 kPa and a less pronounced decrease in shear modulus compared to soils. It also exhibited a very high damping ratio, even at low shear strain levels, which is advantageous for dissipating seismic energy. The tests indicated that the gel's mechanical response is not particularly dependent on shear strain and is almost unaffected by confinement pressure, while showing significant energy dissipation over a wide range of strain levels, making it a promising candidate for seismic isolation. The gel's unique viscoelastic behavior suggests it could effectively reduce seismic loads transmitted to overlying structures. This dynamic characterization provides a fundamental understanding of the material's suitability for mitigating earthquake-induced vibrations in geotechnical applications, contributing to safer and more resilient infrastructure designs.

Keywords: Geotechnical Seismic Isolation, Polyurethane Gel, Dynamic Characterization, Resonant Column Test, Cyclic Torsional Shear Test.

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1 INTRODUCTION

A geotechnical seismic isolation system is a potentially useful technique for mitigating the effects of an earthquake, primarily on newly constructed buildings. This technique involves placing around the foundation or interposing between the foundation and the subsoil a layer of material to reduce the accelerations that the subsoil would impose on the superstructure (Fig. 1).

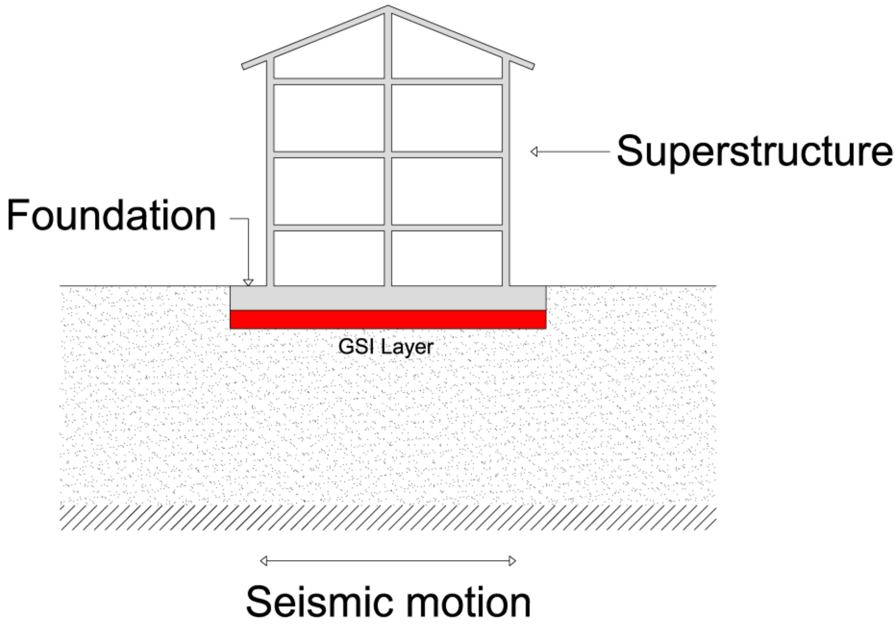

Figure 1: Geotechnical Seismic Isolation (GSI) system.

This can be done by taking advantage of the beneficial effects of soil-foundation-structure-interaction (SFSI) lengthening the fundamental period of the soil-foundation-structure system, by using high-damping materials to facilitate the dissipation of seismic energy or by implementing low strength materials due to their "inability" to transmit shear stresses and therefore to impose accelerations on the superstructure. The idea of Geotechnical Seismic Isolation was first defined in 2008 by Tsang [1]. This technique was initially designed for applications in developing countries exposed to seismic risk, as the materials deemed suitable were mainly mixtures of granular soil and waste products, such as rubber from recycled tires [1-4]. These applications ensured the possibility of applying the technique to newly constructed buildings, aiming at lower costs compared to those associated with seismic isolation interventions using devices.

Most research in literature has therefore focused on the mechanical characterization of binary sand-rubber mixtures due to their ability to dissipate seismic energy [3,4]. The effectiveness of this system as a possible solution to reduce seismic actions on structures has been studied over the last twenty years by various authors also via numerical and analytical studies [5-8], shaking table and centrifuge tests [9, 10].The main drawbacks of this approach concern the practical applicability of the technique only to newly constructed buildings and the frequent need for significant thickness of the isolation layer [11].

This study presents some experimental results on new materials that promise to be suitable for implementing geotechnical seismic isolation techniques not only on newly constructed buildings but also on existing buildings. This latter aspect would greatly expand its applicability, especially in a country like Italy, where much of the buildings were constructed in the immediate post-war period. The materials considered in this work are polyurethan gels.

2 POLYURETHAN GEL SAMPLES

In this work three similar polyurethan gels (Fig. 2) have been tested to evaluate their suitability for use as materials to be employed in geotechnical seismic isolation systems.

Polyurethan gel is a very soft, flexible and highly elastic material made from polyurethan polymers. It combines the properties of both solids and liquids offering excellent flexibility, durability, shock absorption and energy-dissipation characteristics, and it is widely used in various industries due to its viscoelastic properties and adaptability to different applications. Polyurethan gels are formulated through a reaction between polyol and isocyanate, with additional additives to enhance specific properties. Polyol (soft segment), which is the primary backbone of the polymer, provides flexibility and softness, while isocyanate (hard segment) reacts with polyol to form a stable polymer network. To obtain a more flexible and hydrolysis-resistant response polyether polyols should be used while to achieve UV-resistant material and increase the durability aliphatic isocyanates are recommended.

In this work, the samples provided by the Italian company Geelli C.S. S.r.l. were used. The three types of polyurethan gel used herein are easily distinguishable as they have been purposely colored differently, namely black, red and mustard. Samples have practically the same mass density of about 1.05 t/m^3.

Figure 2: Polyurethane gel samples tested in this work: height 100 mm, diameter 50 mm.

3 DYNAMIC CHARACTERIZAZION

The dynamic characterization of these three polyurethane gels was performed via resonant column tests (RCT) and cyclic torsional shear tests (CTS) in the Geotechnical Lab of the Department of Civil and Industrial Engineering of the University of Pisa. Additionally, some cyclic simple shear tests (CSS) and cyclic triaxial tests are underway to fully investigate their response under cyclic and dynamic conditions.

Figure 3: Resonant Column and Cyclic Torsional Shear Tests Apparatus.

3.1 Resonant Column and Cyclic Torsional Shear Tests Apparatus

The apparatus available at the University of Pisa (Fig. 3) can perform both cyclic torsional shear and resonant column tests. This system includes a powerful magnetic motor that allows torsional excitation (up to 10Nm) of a cylindrical specimen whose diameter is between 38 mm and 70 mm via a torsional and/or longitudinal stress with variable amplitude and frequency. The apparatus has sensors capable of measuring angular deformation and torsional load. In particular, the measurement of angular deformation is obtained through two proximity probes. The system is composed of a pressure cell, a control unit and a PC equipped with the control signal acquisition and generation cards. The acquisition and control cards allow the generation and the reading of all the signals of interest. The cell operates up to 1.5 MPa and is equipped with an electromagnetic motor with selected coils and sintered Neodymium-Iron-Boron (NdFeB) magnets. The vertical settlement of the specimen is monitored by an LVDT, and the cell pressure is measured by transducers and controlled by PC through electro-pneumatic converters.

3.2 Resonant Column and Cyclic Torsional Shear Tests results

Resonant column and cyclic torsional shear tests were conducted to evaluate shear modulus (*G*) and damping ratio (*D*) over a quite wide range of shear strain levels (Figs. 4, 5 and 6). In resonant column tests the resonant frequency of the system composed by the sample and the drive system was about 4÷6 Hz, while cyclic torsional shear tests were carried out applying cyclic (sinusoidal) torques at a frequency of 0.1 Hz. All the samples were tested at three different values of the confinement pressure, namely 50 kPa, 100 kPa and 150 kPa.

In resonant column tests of the black sample, the shear modulus (*G*) reached approximately 420 kPa at a shear strain of about 0.017% and decreased to around 315 kPa at 0.95% strain, while the damping ratio (*D*) increased slightly from 10% to 15% as the shear strain increased. In cyclic torsional shear tests, *G* ranged from roughly 300 kPa at a shear strain of 0.005% to about 200 kPa at 0.5% strain, with *D* remaining nearly constant at 10%.

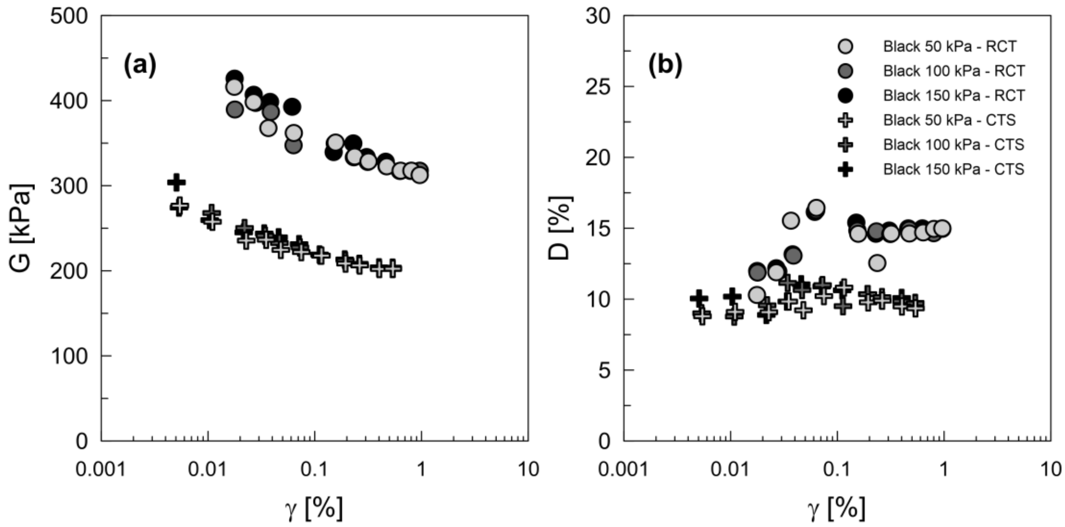

Figure 4: Shear modulus vs. Shear Strain (*G*-*γ*), and Damping ratio vs. Shear Strain (*D*-*γ*) curves: Black Sample.

In resonant column tests on the mustard sample, the shear modulus (*G*) reached a maximum of roughly 335 kPa and a minimum of about 195 kPa at shear strains of approximately 0.015% and 0.7%, respectively. Additionally, the damping ratio (*D*) increased from 10% to 20% with increasing shear strain. In contrast, cyclic torsional shear tests showed that *G* varied between approximately 215 kPa and 120 kPa at shear strains of about 0.007% and 0.45%, respectively, while *D* remained nearly constant at around 12%.

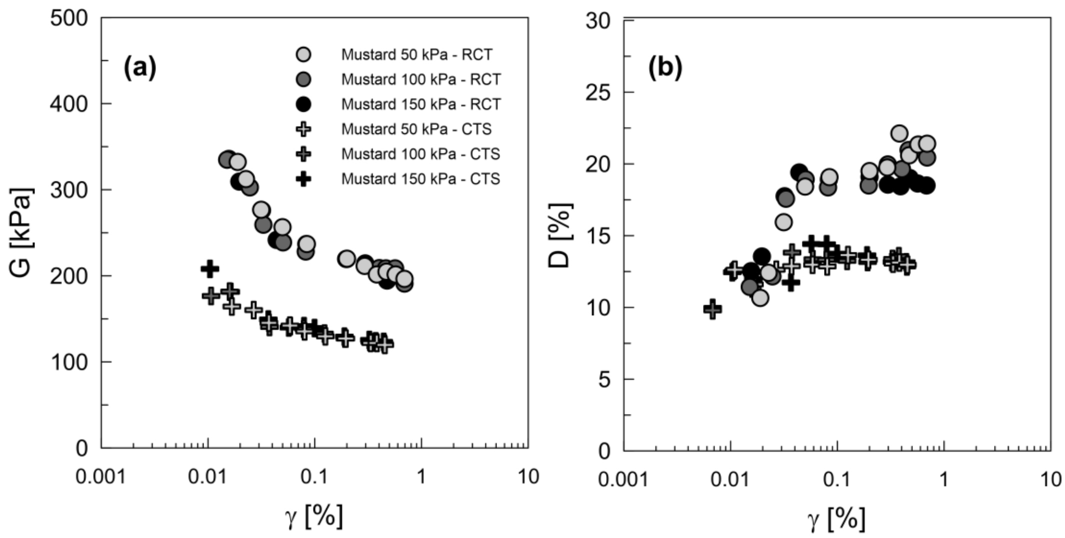

Figure 5: Shear modulus vs. Shear Strain (*G*-*γ*), and Damping ratio vs. Shear Strain (*D*-*γ*) curves: Mustard Sample.

Finally, in resonant column tests on the red sample, the shear modulus (*G*) reached about 340 kPa at a shear strain of approximately 0.015% and dropped to around 160 kPa at a strain of 0.8%, with the damping ratio (*D*) rising from 12% to 25% as the strain increased. In cyclic torsional shear tests, *G* varied from roughly 240 kPa at a shear strain of 0.005% to about 100 kPa at 0.5%, while *D* exhibited a slight increase from 12% to 20% with higher strains.

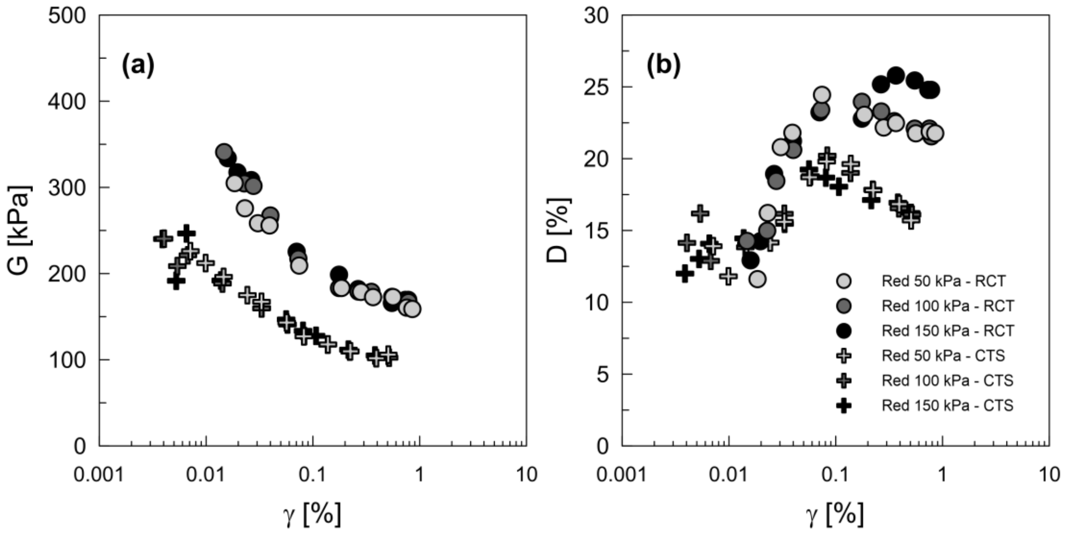

Figure 6: Shear modulus vs. Shear Strain (G-γ), and Damping ratio vs. Shear Strain (D-γ) curves: Red Sample.

4 CONCLUDING REMARKS

Results shown in the previous section indicate that the polyurethane gel's response is not affected by confinement pressure. The material exhibited promising properties, with a very low shear modulus ranging from 100 to 450 kPa and a less pronounced reduction in shear modulus with increasing shear strain compared to soils. Notably, the samples exhibited a high damping ratio even at low shear strain levels, which is advantageous for dissipating seismic energy. However, these observations will be further verified in upcoming tests. In fact, during resonant column tests (RCT) and cyclic torsional shear (CTS) tests, reliable measurements of both *G* and *D* were obtained at shear strain levels larger than approximately 5×10^{-3} I – 10^{-2} %, thus, it would be interesting to assess them also at extremely small shear strain levels (i.e., below 10^{-4} – 10^{-5} %). Furthermore, new cyclic torsional shear tests are planned to assess the material's response by varying the frequency of the applied cyclic torque.

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