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Dynamic centrifuge modelling of geotechnical seismic isolation (GSI) systems: a summary

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ABSTRACT: Dynamic soil-foundation-structure interaction (SFSI) is central to the principle of geotechnical seismic isolation (GSI). Experimental and field validation of the SFSI response behaviour, GSI mechanism, and system performance represents one of the research challenges. This paper presents a summary of the series of dynamic centrifuge testing conducted by the author and his colleagues.

1 GEOTECHNICAL SEISMIC ISOLATION

GSI is a geotechnical solution to seismic resilience, which was put forward in Tsang (2009) as a suite of earthquake-resistant design technologies analogous with conventional structural seismic isolation systems. It is a versatile method that can be universally applied to various types of structures located anywhere in the world. It fits well with the low-damage resilient design approach that becomes increasingly common in practice. A state-of-the-art overview of GSI has been published in the journal of *Soil Dynamics and Earthquake Engineering* (Tsang, 2025), in which four branches of GSI systems have been defined.

GSI systems of the first branch lengthen the natural period of the coupled soil-foundation-structure system based on lowering foundation stiffness by softening foundation soil. The second branch decouples the structure-foundation system from ground shaking by creating a low-friction sliding or rolling interface. The third branch modifies incident waves based on impedance contrast and/or dissipating seismic energy by material damping, while the fourth branch is based on fully mobilising combined foundation bearing capacity by under-designing structural foundation.

Essentially, the first and fourth branches of GSI systems facilitate the favourable effects of dynamic inertial SFSI to reduce structural demands. For the third branch, an artificial system can be created in the ground to modify the characteristics of the input motions, which aims to enhance the beneficial effects of kinematic SFSI to reduce motion at the foundation compared to free-field ground motion.

The first three branches of GSI systems typically involve the use of synthetic materials surrounding the foundation systems or as part of the foundation systems. The required material properties and the four main groups of materials suitable for GSI have been discussed in a review paper (Tsang, 2026) published as a part of a themed issue in the journal *Geosynthetics International*.

This article focuses on a series of centrifuge testing program that was carried out for the first branch of GSI systems, of which the stress field and nonlinearity of the subsoil as well as the SFSI response behaviour can be realistically captured.

2 DYNAMIC CENTRIFUGE TESTING

The dynamic centrifuge testing program was carried out at the Centrifuge Modelling Laboratory at National Central University (NCU) in Taiwan. The centrifuge apparatus has a nominal radius of 3 m, while the shaker has a maximum payload of 400 kg at a maximum acceleration field of 80 g.

GSI first branch systems involve replacement of existing foundation soils by well-controlled low-modulus geosynthetic materials. The first set of the test was based on the use of gravel-rubber mixtures (with two different rubber contents) to form a GSI layer surrounding the entire foundation slab of a frame structure. The results and findings from these tests were reported in Tsang et al. (2021).

The second set of the tests explored alternative materials, namely, high-damping polyurethane and expanded polystyrene (EPS) beads-sand mixtures, for creating GSI systems of different configurations, which includes a scheme that is particularly suitable for retrofitting existing structures. The detailed results can be found in Tsang et al. (2024) and Tsang and Tran (2026) respectively.

Apart from the series of tests on GSI led by the author, Somma et al. (2022) has conducted dynamic centrifuge modelling on a lateral disconnection system, which can be categorised as a first branch system, while Nappa et al. (2016) has done it for a couple of GSI systems of the third branch.

3 RESULTS AND DISCUSSION

Generally, the peak structural demands, in terms of roof acceleration, inter-storey drift, and bending strain of column, could be reduced by 50% on average, among all the cases with the use of different GSI foundation materials and based on different GSI design configurations. The root-mean-square values of the structural response time series were shown to be reduced even more significantly.

GSI materials with lower modulus were shown to be more effective in reducing structural demands. High-damping polyurethane has the lowest modulus among the four materials being explored, and it led to the best isolation performance. Also, gravel-rubber mixtures with 40% rubber by weight performed better than the mixtures with 30% rubber by weight.

Due to the low modulus of GSI foundation material, the horizontal and rocking stiffnesses of the foundation system would be lowered. This led to the lengthening of the fundamental natural period of the coupled soil-foundation-structure system, and in turn, the reduction of structural demands. The favourable effects of inertial SFSI explain the seismic isolation mechanism of GSI. A design procedure has been proposed in Tsang (2023), consistent with those procedures recommended in various design guidelines and standards related to SFSI analysis.

While natural soil usually shifts the fundamental natural period of a fixed-base frame by up to 15%, surrounding the entire foundation slab by low-modulus GSI materials can lengthen the system's natural period by 30 to 85%. Meanwhile, the subsoil material will undergo nonlinear response under strong earthquake shaking, which would further reduce the material modulus and foundation stiffnesses, and elongate the natural periods.

It is noteworthy that, while the immediate settlement of the GSI systems investigated in this study was found to be larger, they were well within the acceptable limits stipulated in various design codes and standards. Importantly, the vertical settlement of the GSI systems during ground shaking was significantly smaller than that for non-isolated structures sitting on natural soil.

4 CONCLUSIONS

GSI is a low-damage seismic resilient design method that shifts the focus from structural modification to subsoil intervention. In this article, the isolation performance of GSI systems of the first branch has been proven by a series of dynamic centrifuge modelling based on the use of different foundation materials and various GSI configurations. The response behaviours and isolation mechanisms have also been discussed and explained.

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