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ENHANCING THE SEISMIC RESILIENCE OF BUILDINGS UTILIZING A RUBBER-SAND GRANULE-BASED DAMPING LAYER

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Abstract

This article investigates the operating mechanism, calculation concept, and efficiency of a damping layer based on rubber-sand granules, placed beneath foundations used in seismically active regions. The study analyzes the elastic-deformational and friction-induced damping properties of the rubber-sand granule layer and evaluates its impact on the dynamic parameters of buildings. Through a specific engineering example, it is demonstrated that the application of the damper layer increases the natural vibration period of the building and reduces seismic inertia forces. The results obtained indicate that rubber-sand granule damping layers can be effectively utilized as passive seismic protection elements compared to conventional sand layers.

Keywords: rubber-sand granule, damping layer, foundation, seismic impact, passive seismic isolation.

1.Introduction

In the design of buildings and structures in seismically active regions, ensuring the resistance of foundation structures against earthquake impacts constitutes one of the fundamental challenges. Conventional approaches primarily achieve seismic stability by enhancing the structural strength. However, such an approach frequently leads to increased material consumption and a reduction in economic efficiency.

In recent years, passive seismic protection systems have been widely adopted in global practice as an alternative method for **mitigating seismic effects**. Instead of allowing the building to absorb the earthquake energy directly, these systems aim to dissipate a significant portion of it. One such method involves the application of damping layers within the foundation nodes.

In engineering practice, configurations involving the placement of a sand layer between the pile cap and the pile foundation are occasionally encountered. Nevertheless, the damping capacity of sand remains limited, failing to yield adequate performance under high-intensity seismic actions. Consequently, investigating the utilization of rubber-sand granule-based mixtures as an effective damping layer constitutes a highly relevant scientific problem.

2. Operational Mechanism of the Rubber-Sand Granule Damping Layer Rubber-sand granules are generally derived from the mechanical shredding of end-of-life tires. These materials

exhibit superior elasticity, high energy dissipation capabilities, and excellent durability against wear.

Under seismic actions, the following core mechanisms function within the rubber-sand granule damping layer:

1. **Elastic deformation** – energy is partially absorbed through the continuous compression and elastic recovery of the granules.
2. **Frictional dissipation** – micro-slippages are induced at both the granule-to-granule and granule-to-concrete interfaces.
3. **Hysteretic damping** – a closed hysteresis loop is generated in the force-displacement relationship, resulting in energy dissipation during each cyclic loading.

Through these combined mechanisms, the seismic waves propagating within the soil skeleton are significantly attenuated by the rubber-sand granule damping layer, thereby reducing the seismic action transmitted to the foundation.

3. Numerical Model and Theoretical Foundation The dynamic behavior and characteristics of the rubber-sand granule damping layer can be formulated using the Kelvin–Voigt rheological model:

$$F=k_r u+c_r \dot{u} \quad (1)$$

where:

k_r — denotes the equivalent stiffness of the layer, calculated using expression (2);
c_r — represents the damping coefficient, evaluated via expression (3);
u — indicates the horizontal displacement;
$\dot{u}$ — is the displacement velocity.

The layer stiffness is defined as follows:

$$k_r=\frac{G_{eff}A}{h} \quad (2)$$

where:

G_{eff} — denotes the effective shear modulus of the rubber-sand mixture;
A — represents the bearing surface area;
h — indicates the thickness of the damping layer.

$$c_r=2\xi\sqrt{k_r M} \quad (3)$$

where:

ξ — is the damping ratio, determined by equation (4);
M — is the mass of the building (kg).

$$\xi=\frac{1}{2\pi}\frac{E_d}{E_s} \quad (4)$$

where:

E_d — is the energy dissipated per cycle;
E_s — is the stored energy.

Research indicates that the damping ratio for rubber-sand granule layers ranges between $\xi = 0{,}10\div0{,}25$ [4], which is several times—specifically 3 to 5 times—higher than that of conventional sand layers. For sand layers, the damping ratio is $\xi=0{,}02\div0{,}05$ [5]. This corresponds to 2–5%, and typically:

it is taken as
in dense sands → $\xi = 0{,}02 – 0{,}03$
in loose sands → $\xi = 0{,}04 – 0{,}05$

Reducing the seismic action on a structure is accomplished by prolonging its natural vibration period. The structural natural vibration period is evaluated using equation (5):

$$T=2\pi\sqrt{\frac{M}{K_{eq}}} \quad (5)$$

where:

$$K_{eq}=\left(\frac{1}{K_{str}}+\frac{1}{k_r}\right)^{-1} \quad (6)$$

Based on equation (6), it can be inferred that prolonging the natural vibration period K_{eq} is achievable by decreasing the horizontal stiffness T at the building's foundation level. In this case, a mitigation of forces in the seismic response spectrum is attained.

To evaluate the dynamic performance of the rubber-sand granule damping layer, a practical engineering case study is presented. Consider a 12-story building featuring a reinforced concrete structural framework, where the following design parameters are adopted:

- Mass of the building: $M=1{,}2\times10^7$ kg,
- Foundation footprint area: $A=120$ м^2,
- Thickness of the damping layer composed of a 70/30 rubber-sand mixture $h=0{,}1$ м,
- Effective shear modulus of the rubber-sand granule mixture: $G_{eff} = 2$ MPa.

The stiffness (rigidity) of the damping layer is calculated as follows:

$$k_r=\frac{2\times10^6\cdot120}{0{,}1}=2{,}4\times10^9 \text{ Н/м}$$

Next, the effect on the building's natural vibration period is evaluated. Assuming the horizontal stiffness of the structural elements is $K_s=1{,}2\times10^{10}$ N/m, the equivalent horizontal stiffness is determined as follows:

$$K_{eq}=\left(\frac{1}{K_s}+\frac{1}{k_r}\right)^{-1}=\left(\frac{1}{1{,}2\times10^{10}}+\frac{1}{2{,}4\times10^9}\right)^{-1}=2\times10^9 \text{Н/м}$$

The natural vibration period of the structure:

$$T=2\pi\sqrt{\frac{M}{K_{eq}}}=2\times3{,}14\times\sqrt{\frac{1{,}2\times10^7}{2\times10^9}}=0{,}49 \text{ с}$$

In contrast, when utilizing a conventional sand layer, this value is reduced by half, registering at approximately $T\approx0{,}24$ s. This demonstrates that the rubber-sand granule damping layer effectively shifts (prolongs) the natural vibration period of the structure, thereby mitigating the seismic inertial forces induced within the response spectrum.

The rubber-sand granule damping layer positioned underneath the foundation,

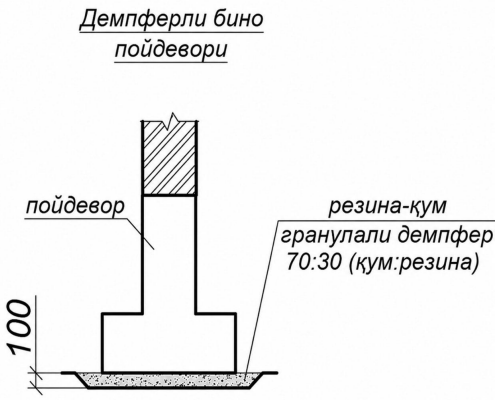


Fig. 1. Design model (analytical scheme) of the foundation featuring a rubber-sand granule damping interlayer.

as illustrated in Fig. 1, features low rigidity and superior damping properties, effectively attenuating the amplitude of seismically induced vibrations. Owing to the resilience and energy dissipation capabilities of this interlayer, the dynamic demands transmitted from the foundation to the superstructure are substantially mitigated, consequently yields a significant reduction in structural stresses and deformations.

As illustrated in Table 1, we can observe the percentage (%) variance in the natural vibration periods of the structure equipped with a rubber-sand granule damper, the structure with a sand granule damper, and the un-damped structure.

Table 1

№	Adopted Seismic Isolation	Vibration Period, T(s)	Vibration Period Difference (%)
1	Building with a rubber-sand (70/30) granule damper (t=10 см)	0,49	59%
2	Building with a sand granule damper (t=10 см)	0,24	16%
3	Un-damped building (Building without a damper)	0,20	-

Secondary recycled materials can be effectively repurposed for the rubber-sand granule damping layer. This solution offers the advantage of being implemented as a damper without requiring major structural modifications. Moreover, although the rubber-sand granule interlayer exhibits superior damping efficiency, critical factors such as long-term shear creep, thermal effects, and water saturation states must be thoroughly considered. Consequently, further experimental investigations are essential to fully incorporate this approach into building codes and regulatory frameworks.

Conclusion

1. The natural vibration period of the building with a rubber-sand granule damper t=10 sm increased by **59% (a 1.59-fold increase)** compared to the building without a damper;
2. The natural vibration period of the building with a sand granule damper t=10 sm increased by **16% (a 1.16-fold increase)** compared to the building without a damper;
3. The damping layer based on rubber-sand granules, when applied between the foundation and a rigid base, enables effective dissipation of seismic energy. The conducted analysis and calculation example demonstrate that such a layer significantly improves the dynamic response of buildings and provides substantially higher efficiency compared to conventional sand layers. Therefore, this solution is considered highly promising for structures located in seismic regions.

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