Affordable seismic isolation: The Rolling Pendulum System

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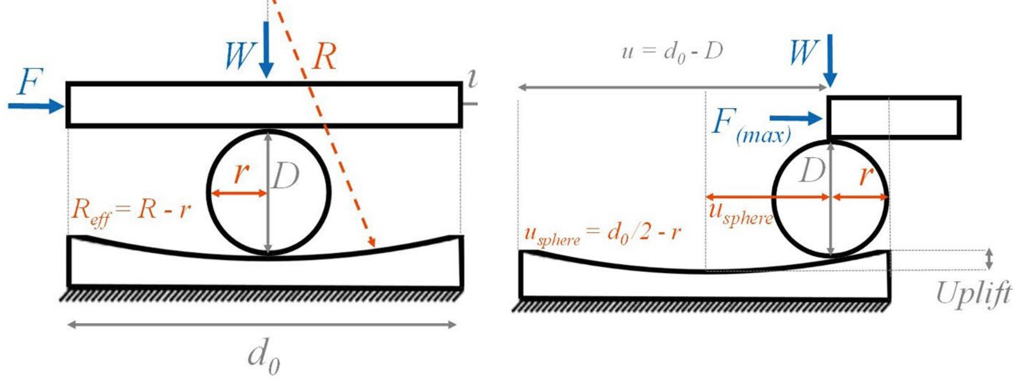
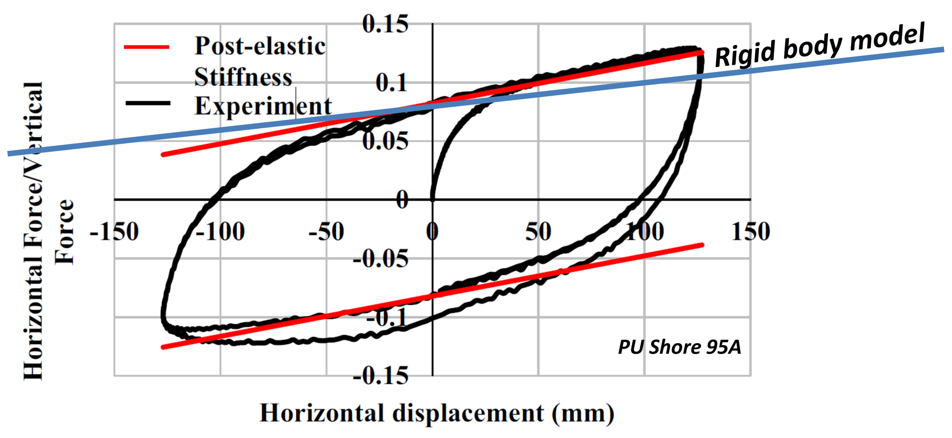
Abstract

Rolling isolation has been suggested as a lower cost alternative to sliding isolation. In this project, we studied the behavior of an isolation system that comprises an elastomeric sphere rolling on a concrete spherical surface. We also explored an alternative where used tennis balls filled with cement grout were utilized as rollers. The aim is to apply such a system in low-rise buildings in low-income countries. We characterized the elastomeric material with a model calibrated in 3 different time scales, rolled the spheres to obtain force-deformation loops, and shake-table tested a masonry building isolated on elastomeric or tennis balls. We showed that, because of creep, the elastomeric sphere deforms to an oval and thus the restoring force fluctuates as the oval rolls. Therefore, the system cannot be described with a bilinear model. Adding a steel core, reduces creep while it maintains a significant amount of rolling friction (around 5%). Tennis balls were able to support > 20kN and behaved bilinearly, because their rubber shell is relatively thin. The shake table tests showed that a) The masonry superstructure did not crack under design-level ground motions b) Double concave sliders should be used to avoid sliding and the subsequent residual displacements.

1. Research Questions

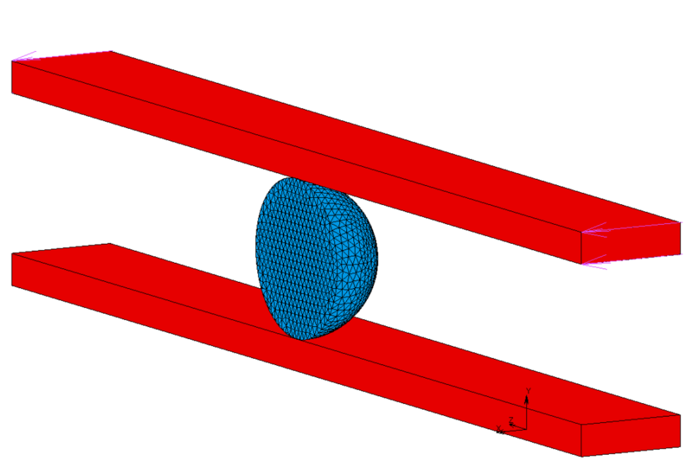
1) Why does rigid body theory deviate from tests?





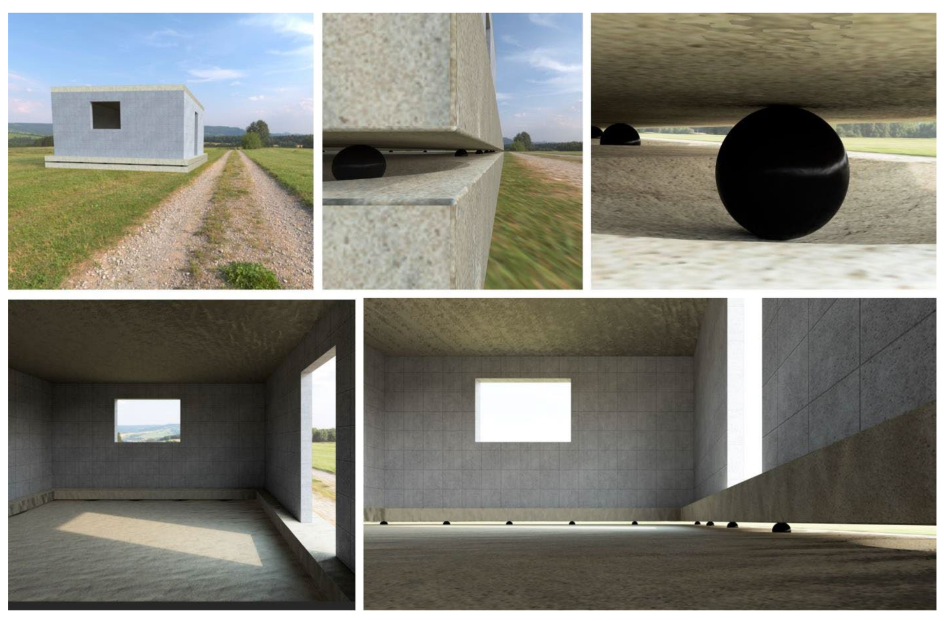
Cilsalar and Constantinou (2019)

2) How do we model the elastomeric material in FE? Where does energy dissipation source from?



3) Can we make it even more affordable by using tennis balls filled with cement grout?

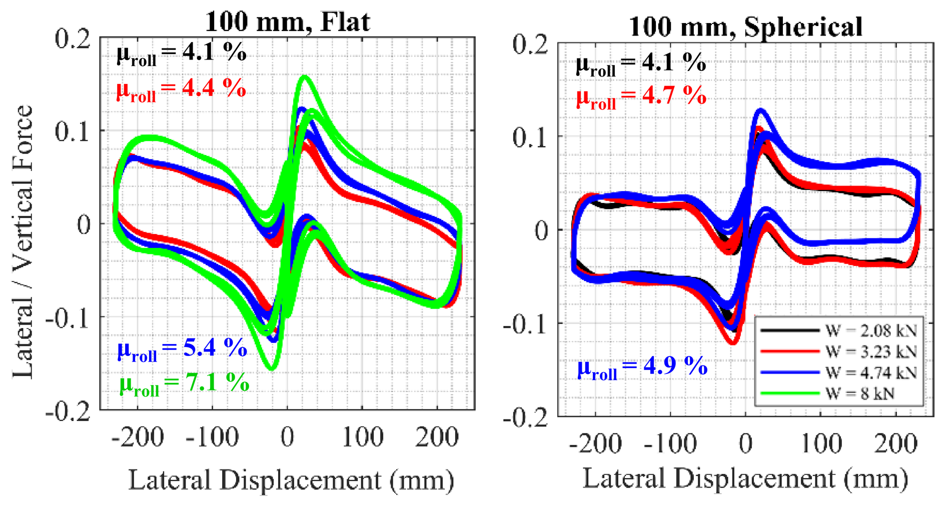
4) How does a masonry structure isolated on such a system behave?

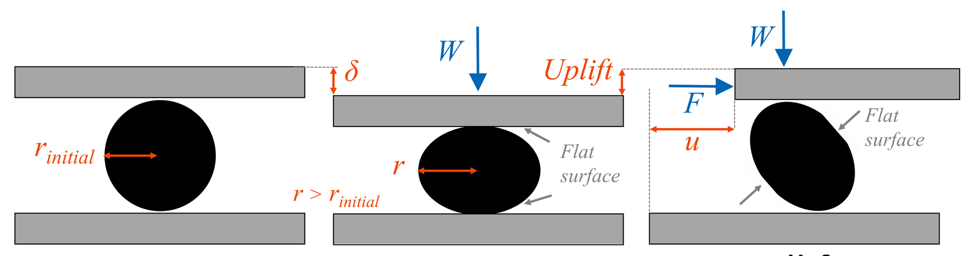


2. Component level testing

1) Shore 95A Thermoplastic polyurethane spheres (cost: $15)

Tested 100mm diameter spheres under different compressive loads, W. Two cases where studied: Flat/Flat and Flat/Spherical concrete plates.



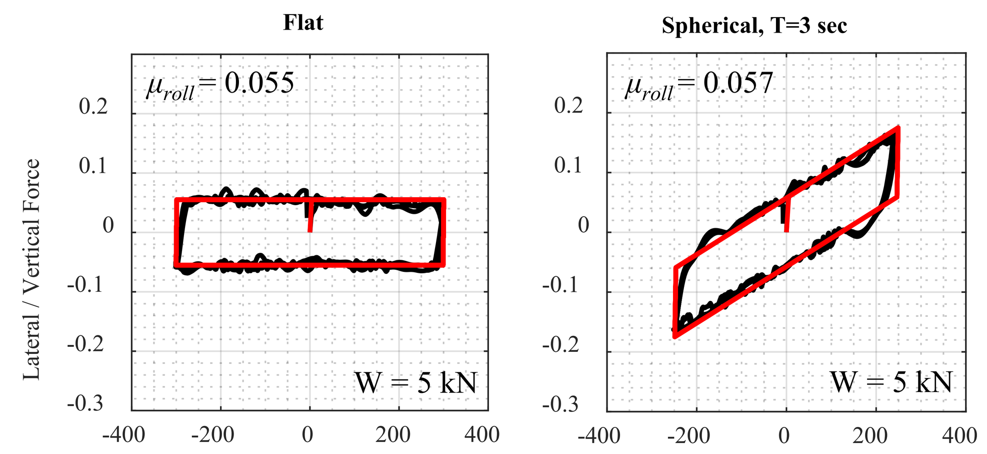


Start — Creep for 1 week — Roll for seconds

We creeped the spheres for a week and then we rolled for seconds. Apparently, we were not rolling a ball, but an oval. Hence the restoring force fluctuated. What was stiffer than the rigid body models for small rotations, will become softer for larger ones.

We can reduce creep and ovalness by using a steel core. As the steel core increases, the behavior tends to bilinear.

2) Tennis balls testing (cost: a few cents)

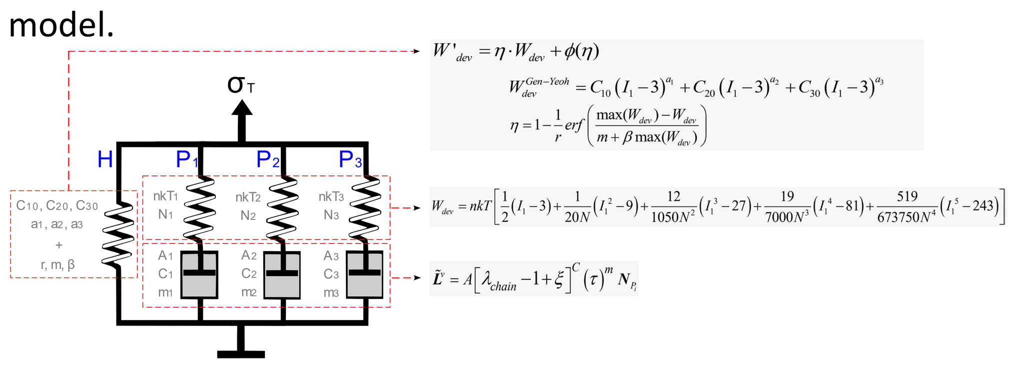


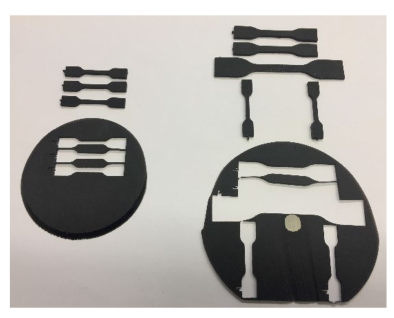
For a w/c ratio of 0.3, they take around 25kN in compression. They behave almost bilinearly in rolling.

Katsamakas et al. (2021, 2022, 2023)
Katsamakas and Vassiliou (2023)

3. Numerical modelling

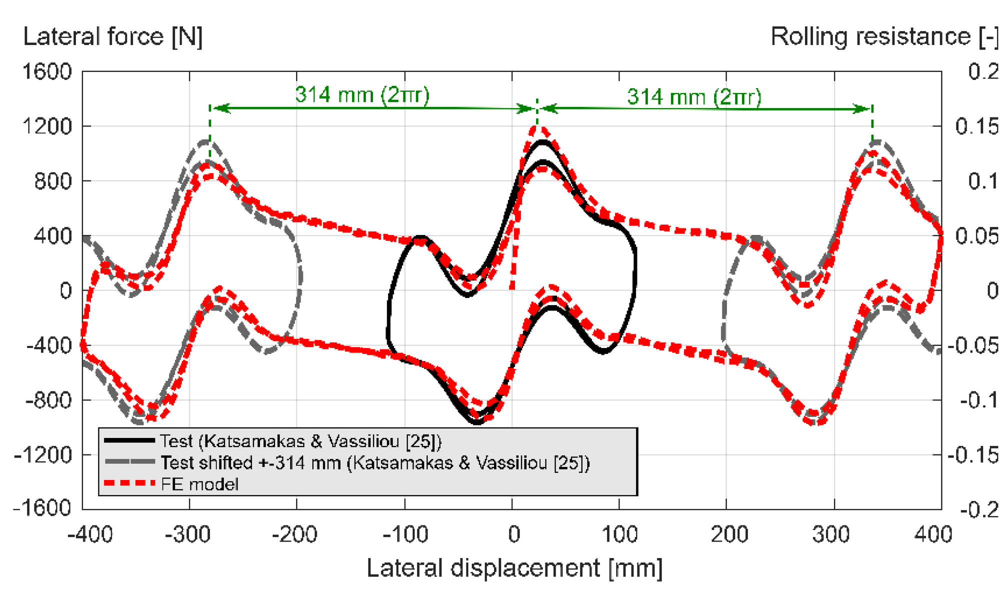
Because creep and rolling evolve in different time scales and because there are residual sphere deformations, a *k* and *c* do not suffice. We used a 4 chain generalized Yeaoh + Mullins material model.



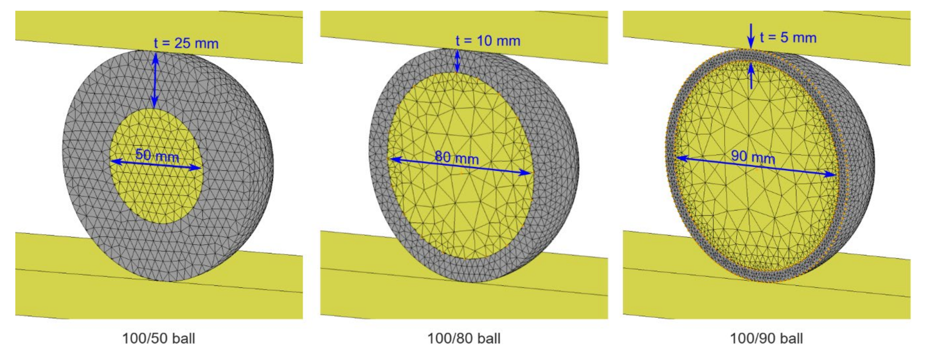


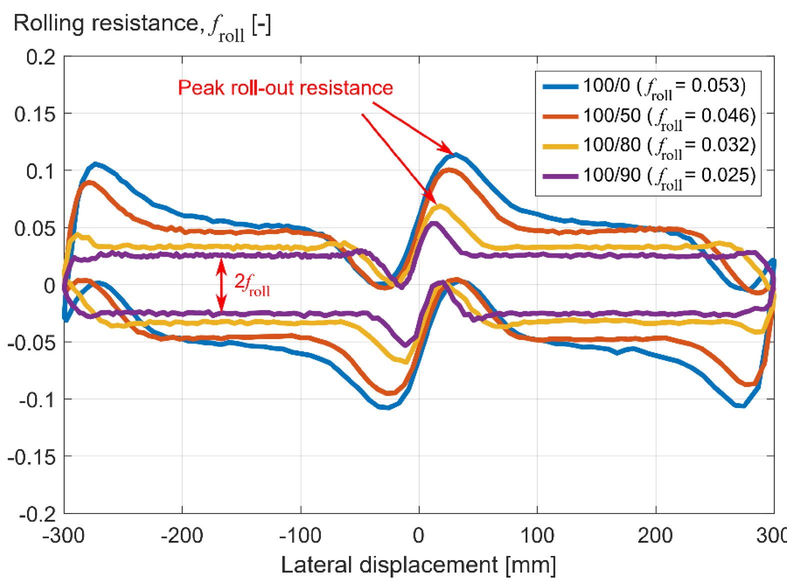
We calibrated on tensile, compressive and volumetric tests using custom protocols.

We validated on rolling tests and used the FE model to understand how the sphere behaves.



3. Numerical modelling cont'd





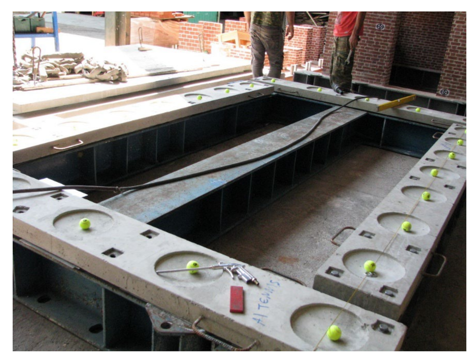
Rolling between flat plates

We concluded that most of the creep comes from the center of the sphere, while most of the energy dissipation comes from the outer part. Hence, adding a steel core of relatively large size would reduce creep and lead to an almost bilinear behavior, while keeping some energy dissipation.

Reyes et al. (2024, 2025)

4. Shake table testing

We tested two versions: With Natural Rubber balls and with Tennis balls distributed under the walls.



The masonry specimen was designed for the seismic hazard of Santiago de Cuba. It was tested under multiple design-level earthquakes, some of which with strong vertical component, without any damage.

However, there was sliding between the spheres and the top rolling surface that resulted in: a) Residual displacement of the specimens; and b) Damaging of some balls – but even when the balls were damaged, they rolled and efficiently protected the superstructure.

5. Conclusions

a) The system is efficient, even with masonry structures.
b) If bilinear behavior is sought, a relatively thin layer of rubber should be used. Otherwise, the force deformation loops are hard to describe.
c) Even the version with the tennis balls worked, with a load of around 5kN per sphere.
d) A double concave isolator is necessary, to promote rolling over sliding.
e) The spheres per se are of very low cost. Low cost methods for the construction of the spherical concrete parts are currently being devised.

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