INFLUENCE OF THE STATIC FRICTION ON THE SEISMIC RESPONSE OF A BUILDING ISOLATED WITH SLIDING BEARINGS

Virginio QUAGLINI¹, Emanuele GANDELLI², Paolo DUBINI³

ABSTRACT

Dynamic friction at the sliding surfaces is the leading parameter for energy dissipation. However, the use of the dynamic friction only for the design is a common mistake in practice. The study investigates the effect of the static coefficient of friction on the seismic response of a 4-storey framed building isolated with sliding bearings with curved surfaces. The static friction force during the initial sticking of the bearing is simulated by means of mechanical fuses inserted at the base level of the building, while the isolators are modelled using standard isolator elements that incorporate the dependency of the kinetic coefficient of friction on the sliding velocity according to an exponential law. The analyses account for three sliding materials with different coefficient of friction, i.e. a low friction material, a moderate friction material and a high friction material, and for each material, three different ratios of static to kinetic coefficient of friction are examined. The analyses demonstrate that disregarding the static friction can lead to unpredictable response of the isolation system and non-conservative evaluation of accelerations transferred to the superstructure.

Keywords: Curved Surface Slider; Isolation; Coefficient of friction; Breakaway

1. INTRODUCTION

The sliding isolator with curved surfaces, known as Curved Surface Slider (CSS) or Friction Pendulum System (FPS) (Zayas et al. 1987) is among the most popular isolation devices worldwide due to its inherent simplicity, since it provides the four main functions required to the isolation system, i.e. vertical load carrying, lateral flexibility, energy dissipation and re-centering capability, in a single design. In its basic version, the Curved Surface Slider consists of a concave plate and an articulated slider (Figure 1). A sliding surface is formed between the slider and the concave plate to accommodate the horizontal displacement of the superstructure, while the articulation accommodates the rotation of the slider induced by the movement along the curved surface. The concave surface provides a restoring force that is proportional to the horizontal displacement, while the friction force developed during the sliding motion provides energy dissipation, with benefits of reduction in the transmitted lateral force and in the displacement demand. Though improved versions with multiple sliding surfaces have been proposed in recent years, like the Double Concave Surface Slider, and the Triple Friction Pendulum, their behavior follows the same fundamental principles.

Friction at the sliding surface determines the response of the Curved Surface Slider during an earthquake. Two different friction forces are involved (Constantinou et al. 1990): the static, or breakaway, and the dynamic, or kinetic, friction forces, as shown in Figure 2. Static friction is developed during the sticking phase that occur before the first movement and at any instant of temporary sticking of the sliding interface, when the velocity is zero. The dynamic friction manifests during sliding and its magnitude changes with speed, increasing from a minimum value \( \mu_L \) at low velocity to a steady value \( \mu_H \) at very high velocities. Both static and dynamic coefficient of frictions are affected by a number of factors including pressure, temperature, roughness, wear and

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contamination of the sliding surfaces (Constantinou et al. 2007; Dolce et al. 2005; Mokha et al. 1990; Quaglini et al. 2014).

![Figure 1. Curved Surface Slider: (a) centered position; (b) deformed position](image)

### 1.1 Coefficient of friction of sliding isolators

The surface of the slider in contact with the concave plate is lined with a low-friction thermoplastic material, like PolyTetraFluoroEthylene (PTFE), Ultra High Molecular Weight PolyEthylene (UHMWPE) and Polyammide (PA). For such materials, the static coefficient of friction $\mu_{St}$ is noted to be substantially higher than the kinetic friction. Based on experiments on steel – PTFE interfaces, Constantinou et al. (1990) concluded that for unworn PTFE a viable assumption for the ratio of static to low velocity coefficient of friction is about 4; similar figures apply to sliding materials used by European manufacturers (Quaglini et al. 2014; Barone et al. 2017). The static friction is an effect of the chemical bonds that form between the mating surfaces during sticking, and since the number and strength of bonds increases with the duration of sticking, the value of $\mu_{St}$ is higher at the breakaway than after any temporary sticking; experiments also demonstrated that the breakaway friction disappears after one cycle of loading (Mokha et al. 1990).

Several formulations have been proposed to model the dynamic coefficient of friction of sliding bearings and isolation systems (Chang et al. 1990; Constantinou et al. 1990; Kumar et al. 2015; Lomiento et al. 2013), whereas the static coefficient of friction has been generally not considered, primarily due to the complexities introduced in numerical models from the non-monotonic dependency of the coefficient of friction on velocity after the breakaway. Also the European and the North American seismic codes (CEN 2005; AASHTO 2014; ASCE/SEI 2017) disregard the static friction, allowing the designer to model the nonlinear horizontal force – displacement relationship of sliding isolators by using a bilinear constitutive law and accounting for all sources of variability by applying suitable property variation factors to the isolator’s design parameters.

![Figure 2. Variation of the coefficient of friction $\mu$ with velocity $V$. $\mu_{St}$: static coefficient of friction; $\mu_{LV}$: dynamic coefficient of friction at low velocity; $\mu_{HV}$: dynamic coefficient of friction at high velocity](image)
1.2 Theoretical considerations

Dynamic friction at the sliding surfaces is the leading parameter for energy dissipation. However neglecting the static coefficient of friction can lead to unsafe conclusions for the design of the isolators and of the structure. This can be demonstrated through a simple example referring to a two degrees of freedom system consisting of two masses $M_{SS}$ and $M_{BS}$ connected to the ground by a sliding bearing with coefficient of friction $\mu$ (Figure 3). As long as the bearing is in sticking condition, the base slab mass $M_{BS}$ is fixed to the ground, and the superstructure behaves as a single degree of freedom with fundamental period $T_{SS}$. Sliding initiates when the shear force through the bearing, which is the resultant of the inertial forces acting on the superstructure mass $M_{SS}$ and on the base slab mass $M_{BS}$, exceeds the frictional force at the isolator’s interface. This condition is achieved when the ground acceleration $a_g$ is larger than the threshold level $a_{cr}$:

$$a_{cr} = \frac{M_{SS} + M_{BS}}{\beta \cdot M_{SS} + M_{BS}} \cdot g \cdot \mu$$

(1)

where $\beta$ is the ratio between the spectral acceleration $Sa(T_{SS})$ of the superstructure and the ground acceleration. According to Equation (1) the threshold acceleration depends on the coefficient of friction of the sliding system, which counts $\mu_{St}$ during sticking, on the dynamic characteristics of the isolated structure (mass distribution between base slab and superstructure, and fundamental period of the superstructure), and on the spectral acceleration of the ground motion.

In most of software programs, the variation of the coefficient of friction with the velocity of sliding $V$ is formulated through the exponential law (Constantinou et al. 1990):

$$\mu = \mu_{HV} - (\mu_{HV} - \mu_{LV}) \cdot \exp (-\alpha V)$$

(2)

where $\mu_{LV}$ and $\mu_{HV}$ are the low velocity and high velocity dynamic coefficients of friction already introduced with reference to Figure 2, and $\alpha$ is a parameter that governs the transition from the low velocity to the high velocity regime. Since Equation (2) does not incorporate the static coefficient of friction, during the sticking phase with $V = 0$ the coefficient of friction $\mu$ counts $\mu_{LV}$; using this value in Equation (1) instead of $\mu_{St}$ will underestimate the threshold acceleration and lead a possible unsafe design of the superstructure when $\mu_{St}$ is large in comparison to $\mu_{LV}$. The larger $a_{cr}$, the longer the time the isolation system stays in the sticking phase, inducing a significant increase of the acceleration transferred to the superstructure.
1.3 Motivations and aims of the study

Though the significance of the static friction at breakaway and the need of further specific research has been generally acknowledged, nevertheless to date this subject has not yet been investigated in detail. Constantinou et al. (1990) demonstrated that the effects of the static friction are important when the ratio of static-to-minimum sliding coefficient of friction ($\mu_{St}/\mu_{LV}$) is greater than the ratio of maximum-to-minimum sliding coefficient of friction ($\mu_{HV}/\mu_{LV}$). Nevertheless, no study further investigated the matter. Quaglini et al. (2014) modified Equation (2) by adding a second exponential term to describe a smooth transition from $\mu_{St}$ to $\mu_{LV}$, and implemented the final equation into the general purpose software program Abaqus, but the study was limited to the calculation of the response of a single Curved Surface Slider under displacement-controlled time histories. Fagà et al. (2015) adapted Equation (2) by replacing the parameter $\mu_{LV}$ with the static coefficient of friction at motion reversal $\mu_{rev}$ in order to model the stick-slip motion; the conclusions of the study was that, in case of substantial difference between $\mu_{LV}$ and $\mu_{rev}$, ignoring the static friction seems to have a small effect on the maximum displacement, but leads to a not negligible underestimation of the internal forces in the structure.

As a matter of fact, the static coefficient of friction is generally not considered in dynamic analyses of base isolated structures, and there is an evident lack of guidance in this sense. The aim of the research is to give some insight into this matter, by investigating the effect of the static coefficient of friction on the seismic response of a case-of-study building isolated with Curved Surface Sliders.

In order to incorporate the static friction in the numerical code, an elastic-brittle Truss element is combined in parallel with a conventional CSS element. The Truss acts as a mechanical fuse, providing an overstrength that simulates the effect of static friction until the beginning of sliding. Nonlinear Response History Analyses are conducted on a four-story framed building, and different ratios of $\mu_{St}$ to $\mu_{LV}$ are examined by changing the strength of the Truss element. The results demonstrate the non-negligible influence of the static friction on the global and local seismic response of the base-isolated structure especially under serviceability limit states, and allow drawing some practical considerations.

2. NUMERICAL ANALYSES

2.1 Case study

A regular reinforced concrete frame is investigated. The structure has four stories at 3 m, and two bays of 5 m length in both longitudinal and transversal directions, and is supported by a rigid base slab (Figure 4). Rectangular ($300 \times 500$ mm$^2$) floor beams are supported by nine square ($400 \times 400$ mm$^2$) columns. The seismic weight of each floor, including the base slab, is 1000 kN, resulting in a total weight of 5000 kN, and a vertical load on each column of 555 kN. The fundamental period of the superstructure is $T_{SS} = 0.324$ s.

The isolating system, placed between the base slab and the foundation, is comprised of nine curved surface sliders, one isolator underneath each column. The sliders have an effective radius of curvature $R = 3000$ mm, corresponding to an undamped period $T_{IS} = 3.47$ s.

The structural model is formulated in OpenSees (Open System for Earthquake Engineering Simulation) software program, v.2.5.4, assuming a moment-resisting frame in either direction of the building. In accordance with the Italian Building Code (NTC 2008) provisions for base-isolated structures, the behavior of the superstructure is modelled as elastic and ElasticBeamColumn elements (OpenSees 2017) are used for the structural members. The bending stiffness of the columns is $K_c = 3.534 \times 10^7$ kN/mm. At each level, a RigidFloorDiaphragm multi-points constraint (OpenSees 2017) is introduced to account for the in-plane stiffness of the floor slabs. The internal damping of the superstructure is defined as stiffness proportional (Ryan and Polanco 2008), and adjusted to provide 5% viscous damping ratio at 3.47 s period; this is achieved by assigning in the expression of the superstructure damping matrix

$$C_{SS} = a_0 \cdot M_{SS} + a_1 \cdot K_{SS}$$  (3)
the coefficients values $a_0 = 0$ and $a_1 = 2 \times 0.05 / 1.808 = 0.0553$, where $\xi = 0.05$ is the target viscous damping ratio, and $\omega_{IS} = 1.808$ Hz is the circular frequency corresponding to $T_{IS} = 3.47$ s.

The nodes at foundation level are constrained by means of rigid joints and subjected to the application of UniformExcitation seismic input (OpenSees 2017).

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Figure 4. Section of the case-of-study building; $m_{\text{floor}}$ is the mass of each floor, $M_{BS}$ is the mass of the base slab

### 2.2 Formulation of Curved Surface Sliders incorporating the static friction

The SingleFPSimple3d element (OpenSees 2017), which describes a Curved Surface Slider with a single curved surface, is used to model the hysteretic behavior of the isolators. Under the assumption of constant axial load $N$ and coefficient of friction $\mu$, the force – displacement relationship of the SingleFPSimple3d element in one horizontal direction is represented by the bilinear curve in Figure 5(a). This relationship is expressed by three parameters: the characteristic strength $F_0 = \mu N$, the post-yield stiffness $K_2 = N/R$, and the initial stiffness $K_1$, which represents the effect of the deformation in shear of the sliding material. With consideration of the mass of the building and the radius of the curved surface slider, the case-of-study sliders for have a post-yield stiffness $K_2 = 0.185$ kN/mm and an initial stiffness $K_1 = 18.5$ kN/mm, where $K_1 = 100 \ K_1$. The yield displacement $d_y$ is related to the three parameters above through the relation:

$$d_y = \frac{F_0}{K_1 - K_2} = \frac{\mu N}{K_1 - K_2} = \frac{\mu N}{K_1}$$

When the isolator is subjected to a horizontal displacement from $d = 0$, for $0 \leq d < d_y$ the friction force prevents sliding and the displacement is accommodated by the elastic deformation of the sliding material; at $d = d_y$ the shear force acting through the bearing matches the friction force and for $d > d_y$ sliding eventually takes place at the interface.

In order to simulate the static coefficient of friction during the sticking phase, one-directional Truss elements (OpenSees 2017) are introduced in the numerical model, aligned to the longitudinal direction of the building frame and placed between the base slab and the ground, in parallel to the isolator elements, i.e. linking the same nodes. The force – displacement behavior of the Truss element is described through the MinMax material object (OpenSees 2017) which corresponds to a linearly elastic material with assigned stiffness $K_f$ until the deformation achieves a limit value $d_f$, at which the material fails; from that point on, stiffness and axial force are set to zero (Figure 5(b)). Finally, by setting $d_f = d_y$, the force – displacement behavior of the combination of isolator and truss elements illustrated in Figure 5(c) is obtained. At the beginning of motion, for $0 \leq d < d_y$ the response is elastic with initial stiffness $K_{1e} = K_1 + K_f$ and the horizontal force is proportional to the
displacement:
\[ F = \left( K_1 + K_f \right) \cdot d \]  
\[ (5) \]

The MinMax material fails at \( d_f = d_y \), and for \( d > d_f \) the typical post-yield response of the CSS element is obtained:
\[ F = K_1 \cdot d_y + K_2 \cdot (d - d_y) \]  
\[ (6) \]

The stiffness \( K_f \) of the MinMax material object is hence assigned in order to provide, at \( d = d_y \), the resisting force corresponding to the design static coefficient of friction of the sliding material:
\[ \left( K_1 + K_f \right) \cdot d_y = \mu_{st} \cdot N \]  
\[ (7a) \]
\[ K_f = \frac{\mu_{st} \cdot N}{d_y} - K_1 = \left( \mu_{st} - \mu_{LV} \right) \cdot \frac{N}{d_y} \]  
\[ (7b) \]

It is here recalled that the stiffness of the truss element \( K_f \) is switched to zero at the first occurrence of \( d \geq d_f \), thereby the static coefficient of friction is accounted only at the breakaway.

![Figure 5. Force – displacement curves: (a) SingleFPSimple3d element; (b) Truss element with MinMax material object; (c) parallel combination of the two elements](image)

2.3 Friction model

In the analyses the coefficient of friction of the CSS element is modelled through the VelDependent friction object (OpenSees 2017), which accounts for the variation of friction with velocity according to Equation (2). The three parameters needed for its implementation are the low velocity and high velocity coefficients of friction \( \mu_{LV} \) and \( \mu_{HV} \), and the exponential parameter \( \alpha \).

Three friction cases were considered in the study, corresponding to a low friction material (LF) with \( \mu_{LV} = 0.01 \) and \( \mu_{HV} = 0.025 \), a moderate friction material (MF) with \( \mu_{LV} = 0.03 \) and \( \mu_{HV} = 0.075 \), and a high friction material (HF) with \( \mu_{LV} = 0.05 \) and \( \mu_{HV} = 0.125 \), respectively; the coefficient \( \alpha = 0.0055 \) s/mm was assumed whichever the material (Cardone et al. 2015). The three cases correspond to the behavior at regular temperature (10°C to 30°C) of lubricated PTFE and UHMWPE pads sliding against polished steel (LF material), of unlubricated PTFE and UHMWPE pads (MF material), and of filled PTFE (HF material), respectively (Cardone et al. 2015; Quaglini et al. 2014).

Three values of the ratio of \( \mu_{st} / \mu_{LV} \) were reproduced by adjusting the stiffness \( K_f \) according to Equation (7b): (a) \( \mu_{st} / \mu_{LV} = 1 \) (no breakaway effect), (b) \( \mu_{st} / \mu_{LV} = 2 \) (low breakaway effect), and (c) \( \mu_{st} / \mu_{LV} = 4 \) (high breakaway effect). The ratio \( \mu_{st} / \mu_{LV} = 1 \) represents the baseline reference for further comparison since it corresponds to the standard friction model implemented in the software, while the ratio \( \mu_{st} / \mu_{LV} = 4.0 \) aims at reproducing the effects of low temperature and poor maintenance conditions of the sliding surfaces. The investigated combinations are summarized in Table 1.
Table 1. Friction cases investigated and relevant parameters.

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<tr>
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<th>$\mu_{LV}$</th>
<th>$\mu_{HV}$</th>
<th>$\alpha$</th>
<th>$\mu_{St}$</th>
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<td>LF</td>
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<td>0.025</td>
<td>0.0055</td>
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<tr>
<td>MF</td>
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<td>0.075</td>
<td>0.0055</td>
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<td>HF</td>
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<td>0.125</td>
<td>0.0055</td>
<td>0.05; 0.10; 0.20</td>
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2.4 Seismic inputs

The response of the isolated structure to two earthquake intensity levels, corresponding to the Damage Limit State (SLD) and the Life Safety Limit State (SLV), was examined in Nonlinear Response History Analyses (NRHAs). Target elastic spectra were determined in agreement with the Italian Building Code (NTC 2008) provisions for a critical structure (functional class IV) with nominal life 100 years, corresponding to a reference period of 200 years, located in Naples, Italy (14.2767° longitude, 40.863° latitude), topographic category T1, on soil type A (stiff soil or rock). For either intensity level, twenty-one unidirectional ground motions were selected from the European Strong-motion Database (Ambraseys et al. 2002) using REXEL v3.4 beta software (Iervolino et al. 2010). The magnitude (Mw) of the ground motions was chosen within the interval (5.3 – 7.3), and the epicentral distance (Rep) in the range (0 – 60 km), and more precisely 7 accelerograms with Rep in the range (0 – 20 km), 7 accelerograms with Rep in the range (20 – 40 km), and 7 accelerograms with Rep in the range (40 – 60 km), in order to cover different fault-site distances.

The selected waveforms (Tables 2 and 3) were scaled to the design Peak Ground Acceleration (PGA) level of either 0.120 g (SLD intensity level) or 0.260 g (SLV intensity level). The scaled spectra at 5% damping are shown in Figure 6; at either limit state, the average spectrum of the accelerogram suite matches the target spectrum with a tolerance of -10/+30% in the period range 0.15 – 4.0 s.

Figure 6. Scaled ground motion acceleration spectra and comparison to target spectrum ($\xi = 5\%$) according to (NTC 2008) for the examined seismic intensity levels. Range of periods: 0.15 s to 4 s

3. RESULTS

Figure 7 shows the force – displacement curves of the SingleFPSimple3d isolator element (a), of the Truss element with MinMax material object (b), and of their combination (c), calculated in NRHAs. The plots are in good agreement with the expected behavior shown in Figure 5. The procedure proves to be a viable means for incorporating in the OpenSees framework, with minimal computational effort, the contribution of the static coefficient of friction developed by Curved Surface Sliders before breakaway under unidirectional ground motions.
Figure 7. Force – displacement curves induced from the 005089ya ground motion record: (a) response of the SingleFPSimple3d element; (b) response of the Truss element with MinMax material object; (c) overall response ($\mu_{LV} = 0.05$, $\mu_{HV} = 0.125$, $\mu_{St} = 0.20$)

Table 2. Accelerograms selected for analyses at Damage Limit State (SF: scale factor).

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<th>Fault</th>
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mean 6.1 29.2 3.5837
Table 3. Accelerograms selected for analyses at Life Safety Limit State (SF: scale factor).

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In a large number of analyses at SLD intensity level, the ground acceleration was insufficient to
trigger the sliding of the isolators in presence of high static friction. For Moderate Friction isolators,
failure to trigger the sliding occurred in 20 analyses (out of 21) when \( \mu_{\text{s}/\mu_{LV}} = 4 \), while for High Friction isolators the activation of the isolators failed in 21 analyses with \( \mu_{\text{s}/\mu_{LV}} = 4 \), and in 13 analyses with \( \mu_{\text{s}/\mu_{LV}} = 2 \) (Figure 8). No apparent influence of the epicentral distance of the ground
motion was observed. At SLV intensity level, failure to trigger sliding occurred in 8 analyses relevant
to High Friction isolators and \( \mu_{\text{s}/\mu_{LV}} = 4 \).

Three parameters have been considered to evaluate the response of the superstructure, namely: (i) the
story drift ratio, equal to the maximum interstory drift \( d_r \) divided by the story height \( h \); (ii) the base
shear \( V_b \) normalized to the seismic weight (\( N_{SS} \)) of the superstructure; (iii), the maximum floor
acceleration \( A_{\text{max}} \). The results for either limit state are summarized in Figures 9 and 10. The
improvement in the prediction capability of NRHAs carried by the incorporation of the static
coefficient of friction is discussed hereinafter in comparison to the baseline results provided by the
conventional analyses with the VelDependent friction model only (\( \mu_{\text{B}/\mu_{LV}} = 1 \)).
The main effect of static friction, as evidenced in the analyses performed at Damage Limit State, is
that for low-to-moderate intensity earthquakes, the seismic ground acceleration can be not sufficient to
trigger the sliding of the isolators. This occurrence has been observed for the MF isolator, when
\(\mu_S/\mu_{LV} = 4\), and for the HF isolator. When sliding is not triggered, the superstructure behaves as a fixed base structure, inducing a substantial increase in internal forces and deformation, and in maximum floor acceleration over the baseline values; it is worth noting that the increase is higher for MF (+70% on average) than for HF isolators (+14% on average). Though in the examined cases the entity of drift and base shear is low even in case of not activation of the sliders, and does not represent a practical issue for the serviceability of the structure, the increase of peak floor acceleration observed for MF isolators could become a concern for the serviceability of technological equipment installed in the building, if designed to resist the accelerations calculated in standard analyses.

Also at Life Safety Limit State, the effect of static friction on the structural response is minimal when a Low Friction isolator is used, but can become important when either MF or HF isolators are examined. A high static friction coefficient (\(\mu_S/\mu_{LV} = 4\)) increases the maximum superstructure drift (MF case: +24%; HF case: +50%), and maximum floor acceleration (MF case: +59%; HF case: +67%); on the contrary a moderate static friction coefficient (\(\mu_S/\mu_{LV} = 2\)) seems to induce no significant changes. It is important to draw the attention to the fact that, in those situations where sliding is eventually triggered, increasing the static friction at the breakaway induces the isolators to stay more time in the sticking phase, increasing the accelerations transferred to the superstructure and hence internal forces and deformations. This is evident in Figure 10 by comparing, for the MF isolator, the response parameters for \(\mu_S/\mu_{LV} = 2\) and \(\mu_S/\mu_{LV} = 4\) cases.
Figure 10. Average response of the superstructure in NRHAs at Life Safety Limit State intensity level: (a) maximum interstory drift to story height; (b) base shear normalized to the seismic weight of the superstructure; (c) maximum floor acceleration

4. SUMMARY AND CONCLUSIONS

The study investigates the effects on the response of an isolated building induced by the incorporation of the static friction coefficient in NRHAs. A simple modelling procedure to account for the contribution of static friction under unidirectional ground motion has been formulated within the OpenSees software framework, and NRHAs have been performed considering both serviceability and limit states.

The main conclusions can be summarized in the next points:

1) for low-friction materials, the static friction has been shown to have negligible or little importance in practice, and the friction models already implemented in current software programs are a viable tool for nonlinear analyses;

2) under seismic events of low or medium intensity, the static friction can prevent the activation of the sliders, and the superstructure demonstrates the response of a fixed base structure; floor acceleration could represent an issue for serviceability of the technological content;

3) under high intensity seismic event, the effect of static friction turns out to be important only for very high values of the static friction (HF isolators, ratio $\mu_{SV}/\mu_{LV} = 4$); though full not-activation of the isolators seems to be unlikely in practice, the isolating devices stay longer in the sticking phase leading to significant increase of the acceleration transferred to the superstructures;

4) the largest increase in the response parameters in comparison to the baseline response (no breakaway) is observed for the MF isolators; the results of NRHAs can significantly overestimate the actual response of the isolated structure in presence of a high static friction (e.g. at low design pressure, low temperature, or in case of wear and contamination of the sliding interfaces).

Although limited to a single case study and two target spectra, the study provides some information of interest to researchers and practitioners, warning against over-simplification of the behavior of Curved Surface Sliders at the modelling stage. The importance of accounting for the static coefficient of friction during the design has been pointed out, but further investigation is needed considering a large variety of situations in terms of dynamic properties of buildings and characteristics of ground motions.
5. ACKNOWLEDGMENTS

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6. REFERENCES


Barone S, Pavese A, Calvi GM (2017). Characterization of frictional properties of different sliding materials for Curved Surface Sliders. Proceedings of 7th International Conference on Advances in Experimental Structural Engineering, 6-8 September, Pavia, Italy.


