ingegneria sismica
International Journal of Earthquake Engineering
Anno XXXIII – Speciale CTA 2015 – Num. 3

EFFETCS OF CLASS B SITE ON THE SEISMIC RELIABILITY OF BASE-ISOLATED STEEL SYSTEMS

Paolo Castaldo, Guglielmo Amendola, Bruno Palazzo*

Department of Civil Engineering, University of Salerno, Italy

SUMMARY: *Seismic reliability of steel structures isolated using the frictional pendulum system bearings and subjected to artificial earthquake ground motions is studied herein. The superstructure is idealised as a linear shear-type flexible building as well as the FPS devices are described by adopting a widespread model which considers the variation of the friction coefficient with the velocity. The uncertainty affecting both the seismic inputs, modelled as non stationary random processes within the power spectral density method, and the friction coefficient at large velocity is considered through appropriate probability density functions. Incremental dynamic analyses are developed in order to evaluate the fragility curves related to both superstructure and isolation level. Finally, considering the seismic hazard curve related to a site near Sant'Angelo dei Lombardi (Italy), the seismic reliability of the overall steel system is evaluated.*

KEYWORDS: *Seismic isolation, steel superstructure, power spectral density method, Monte Carlo simulations, Latin hypercube sampling method, seismic reliability*

1. INTRODUCTION

In the last decades, seismic dissipation and isolation through friction pendulum system (FPS) 0[Christopoulos and Filiatrault, 2006; Zayas et al., 1990] have emerged as very effective techniques for the protection of building frames which, even if designed according to the most advanced codes, suffer severe damages under strong earthquake events [De Iuliis et al., 2010; Bonessio et al., 2012]. Over the years, many works have developed new design strategies and methodologies [Castaldo, 2014; Castaldo and De Iuliis, 2014; Castaldo et al. 2016d; Castaldo et al. 2016e; De Iuliis and Castaldo, 2012; D'Ayala and Benzoni, 2012; Longo et al., 2012; Palazzo et al. 2014b; Palazzo et al., 2015] as well as probabilistic analyses in structural dynamics, structural reliability methods, and reliability-based analysis have been presented [Giugliano et al., 2011a; Giugliano et al., 2011b; Longo et al., 2009]. Barroso and Winterstein [Barroso and Winterstein, 2002] evaluated the seismic performance of steel buildings isolated with FPS bearings by taking into account the variability of both the seismic intensity and the record characteristics. Seismic reliability analyses of 2D and 3D systems isolated by FPS bearings have been carried out in [Castaldo et al. 2015; Palazzo et al., 2014a; Castaldo et al. 2016a; Castaldo et al. 2016b; Castaldo et al. 2016c] by accounting for the randomness of both the isolator properties (i.e., coefficient of friction) and of the earthquake main characteristics by defining a reliability criterion to assist the design of the isolator dimensions in plan. In [Castaldo and Tubaldi, 2015], the influence of FPS bearing properties and of the structural parameters on the seismic performance of base-isolated structures

*Corresponding author: Paolo Castaldo, Department of Civil Engineering, University of Salerno, Italy.
Email: pcastaldo@unisa.it

through the nondimentionalitation of the motion of equations is analyzed by providing useful results for seismic reliability analyses. In [Castaldo and Ripani, 2016], the optimal values of the friction coefficient are defined as a function of the system properties and of the soil condition in order to minimize the superstructure response in terms of displacement relative the base mass.

In this work, seismic reliability of steel structures isolated using the frictional pendulum system (FPS) bearings and subjected to artificial earthquake ground motions is studied herein by considering both the friction coefficient and soil characteristics as random variables. The superstructure is idealised as a linear shear-type flexible building as well as the FPS devices are described by adopting a widespread model which considers the variation of the friction coefficient with the velocity [Mokha et al., 1990]. The uncertainty affecting both the seismic inputs, modelled as non stationary random processes within the power spectral density method [Pinto et al., 2004; Shinozuka and Deodatis, 1991; Talaslidis et al., 2004], and the friction coefficient at large velocity is considered through appropriate probability density functions. Incremental dynamic analyses are developed in order to evaluate the probabilities exceeding different limit states related to both superstructure and isolation level. According to the PEER-like modular approach [Cornell and Krawinkler, 2000], in the final part of the work, considering the seismic hazard curve related to a site near Sant'Angelo dei Lombardi (Italy) [NTC08, 2008], regarding a structural steel system isolated by FP bearings with a design life of 50 years, reliability curves are derived.

2. EQUATION OF MOTION OF BASE-ISOLATED STRUCTURES

The equation of motion governing the response of a single-degree-of-freedom (SDOF) system on single concave FPS isolation devices to the seismic input $\ddot{u}_g(t)$ is:

$$\begin{aligned} m_s \cdot \ddot{u}_s(t) + c_s \cdot \dot{u}_s(t) + k_s \cdot u_s(t) &= -m_s \cdot \left[\ddot{u}_g(t) + \ddot{u}_b(t) \right] \\ m_b \cdot \ddot{u}_b(t) + f_b(t) + c_b \cdot \dot{u}_b(t) - c_s \cdot \dot{u}_s(t) - k_s \cdot u_s(t) &= -m_b \cdot \ddot{u}_g(t) \end{aligned} \tag{1}$$

where u_s denotes the displacement of the superstructure relative to isolation bearing, u_b the isolator displacement relative to the ground, m_s and m_b respectively the mass of the superstructure and of the base, k_s and c_s respectively the superstructure stiffness and inherent viscous damping constant, c_b the bearing viscous damping constant, $\ddot{u}_g(t)$ the ground motion input, the dot differentiation over time, and $f_b(t)$ denotes the FPS bearing resisting force, that is expressed as:

$$f_b(t) = k_b \cdot u_b(t) + \mu(\dot{u}_b)(m + m_b) g Z(t) \tag{2}$$

where $k_b = (m_s + m_b) g / R$, g is the gravity constant, R is the radius of curvature of the FPS, $\mu(\dot{u}_b(t))$ the coefficient of sliding friction, which depends on the bearing slip velocity $\dot{u}_b(t)$, and $Z(t) = \mathrm{sgn}(\dot{u}_b)$, where $sgn(\cdot)$ is the sign function. Experimental results [Constantinou *et al.*, 1990; Constantinou *et al.*, 2007; Mokha *et al.*, 1990] suggest that the coefficient of sliding friction of Teflon-steel interfaces obeys to the following equation:

$$\mu(\dot{u}_b) = f_{\max} - Df \cdot \exp(-\alpha |\dot{u}_b|) \tag{3}$$

in which $f_{\max}$ represents the maximum value of friction coefficient attained at large velocities of sliding, $f_{\min} = f_{\max} - Df$ represents the value at zero velocity. By dividing Eqn. (1a) by m_s, and Eqn. (1b) by m_b, and introducing the mass ratio $\gamma = m_s/(m_s+m_b)$ [Kelly, 1997], Eqn. (1) can be rewritten as:

$$\begin{aligned}&\ddot{u}_s(t)+2\xi_s\omega_s\dot{u}_s(t)+\omega_s^2u_s(t)=-\left[a_g(t)+\ddot{u}_b(t)\right]\\&\ddot{u}_b(t)+\frac{1}{1-\gamma}\left[2\xi_b\omega_b\cdot\dot{u}_b(t)+\omega_b^2\cdot u_b(t)+\mu(\dot{u}_b)g\,\mathrm{sgn}(\dot{u}_b)\right]-2\xi_s\omega_s\frac{\gamma}{1-\gamma}\cdot\dot{u}(t)-\omega_s^2\frac{\gamma}{1-\gamma}\cdot u(t)=-\ddot{u}_g(t)\end{aligned} \tag{4}$$

where the parameters ω_s and ξ_s denote the superstructure circular frequency and damping factor, whereas the parameters $\omega_b=\sqrt{k_b/(m_s+m_b)}=\sqrt{g/R}$ and ξ_b denote the fundamental circular frequency and damping factor for a rigid mass (m_s+m_b) on a linear frictionless isolator of stiffness k_b and viscous damping constant c_b.

3. Random Variables

Seismic reliability assessment of a steel building structure, according to the structural performance (SP) evaluation method [Bertero and Bertero, 2002], is based on the coupling between structural performance levels [Vision, 2000] and associated exceeding probabilities during its design life [Saito et al., 1998]. According to [Cornell and Krawinkler, 2000; Porter, 2003], the uncertainties related to the seismic input intensity are separated from those related to the characteristics of the record (record-to-record variability) by introducing a scale factor, i.e., an intensity measure (IM). The approach is based on calculating the probabilities of exceeding different limit state thresholds given different values of the intensity measure with the aim to define the fragility curves of the system. Afterward, the abovementioned fragility curves integrated with the seismic hazard curve, expressed in terms of the same IM, related to a reference site, lead to the mean annual rates of exceeding the limit states. Using a Poisson distribution, it is possible to transform the mean annual rates of exceeding the limit states into probabilities of exceedance in the time frame of interest (e.g., 50 years). The aim of this work consists of evaluating the seismic reliability of steel structural systems equipped with friction pendulum isolators (FPS) considering both the friction coefficient and earthquake characteristics as random variables.

In order to evaluate the record-to-record variability of the structural system response, several artificial earthquake excitations have been considered. In particular, each earthquake excitation can be modeled as a Gaussian stationary process with mean value equal to zero and two-sided power spectral density (PSD) function $S_{ff}(\omega)$. It follows that the stochastic process $f(t)$ can be simulated by the following series as $N\to\infty$:

$$f(t)=\sqrt{2}\sum_{n=0}^{N-1}A_n cos(\omega_n t+\Phi_n) \tag{5}$$

where $A_n=(2S_{ff}(\omega_n)\Delta\omega)^{1/2}$, $\omega_n=n\Delta\omega$ for $n=0\ldots N-1$, $\Delta\omega=\omega_u/N$, having assumed $T_0=2\pi/\Delta\omega$=31.25s (NTC08) and $\omega_u=50rad/s$, $\Phi_0,\Phi_1,\Phi_2,\ldots\ldots,\Phi_{N-1}$ are independent random phase angles distributed uniformly over the interval [0, 2π]. A sample function $f^{(i)}(t)$ of the simulated stochastic process $f(t)$ can be obtained by replacing the sequence of random phase angles $\Phi_0,\Phi_1,\Phi_2,\ldots\ldots,\Phi_{N-1}$ with their respective i-th realizations $\Phi_0^i,\Phi_1^i,\Phi_2^i,\ldots\ldots,\Phi_{N-1}^i$, sampled through Monte Carlo simulations. In this study, 50 sequence of random phase angles are sampled through Monte Carlo simulations in order to generate 50 input accelorometric signals. The power spectral density function (PSD) of the embedded stationary process, described by the widely-used Kanai and Tajimi [Kanai, 1957; Tajimi 1960] and modified according to Clough and Penzien [Clough and Penzien, 1993], applies:

$$S_f(\omega) = \frac{\omega_g^4 + 4\xi_g^2\omega_g^2\omega^2}{(\omega_g^2-\omega^2)+4\xi_g^2\omega_g^2\omega^2}\cdot\frac{\omega^4}{(\omega_f^2-\omega^2)+4\xi_f^2\omega_f^2\omega^2}S_0 \tag{6}$$

In the parametric study, with the aim to assume the uncertainty related to earthquake characteristics in terms of soil dynamics parameters corresponding to site class B (according to EC8 [CEN, 2004]), ω_g and ξ_g are modeled as random variables uniformly distributed, respectively, in the intervals [3π,5π] (rad/sec) and [40%,60%] [Pinto et al., 2004; Talaslidis et al., 2004], and sampled through Monte Carlo simulations. In order to obtain non-stationary stochastic processes, a time-modulating function proposed by [Shinozuka and Sato, 1967] is adopted. As regards the friction coefficient, the experimental data 0[Constantinou et al., 1990; Constantinou et al., 2007; Mokha et al., 1990] on sheet type Teflon bearings, have pointed out that friction is a complex phenomenon, not complying with the Coulomb friction law and that several mechanisms contribute to its variability. In this study, a uniform density probability function (PDF), ranging from 3% to 12%, has been assumed to model the sliding friction at large velocity as random variable f_{max}. For the generation of the sampled values of the friction coefficient f_{max}, within the stratified sampling techniques the Latin Hypercube Sampling (LHS) method [Mckey et al., 1979] has been used. In particular, in the following parametric study, 15 sampled values of the random variable f_{max} are employed and a ratio f_{max}/f_{min} equal to 3, based on regression of experimental results, whereas the exponent α of Eqn. (3) equal to 30 [Constantinou et al., 1990; Constantinou et al., 2007; Mokha et al., 1990] are assumed.

4. Incremental Dynamic Analyses (IDA) Results of Base-Isolated Steel Structures

Seismic reliability assessment of equivalent base-isolated systems is based on developing incremental dynamic analyses (IDA) [Vamvatsikos and Cornell, 2002]. In this study, the spectral displacement, $S_D(T_b, \xi_b)$ is assumed as intensity measure [Luco and Cornell, 2007].

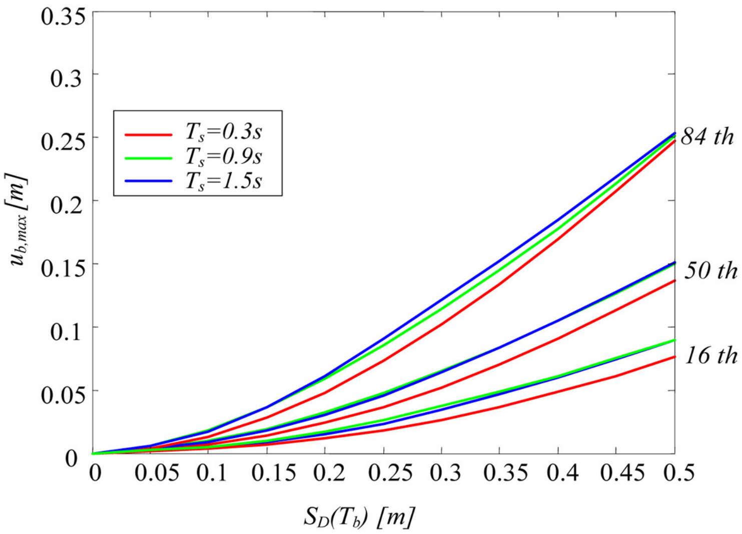

Figure 1. *IDA curves of the isolation level with γ=0.7, for R=4m*

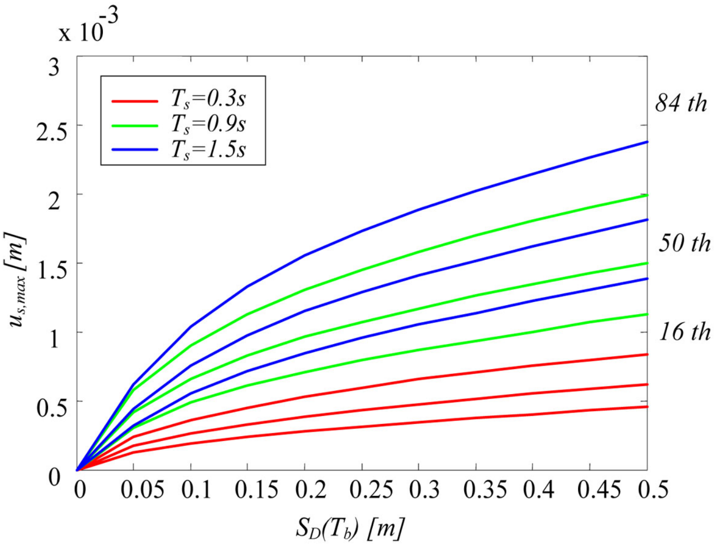

Figure 2. *IDA curves of the superstructure with γ=0.7, for R=4m*

The corresponding IM, hereinafter denoted as $S_D(T_b)$, in the IDA is considered ranging from 0m to 0.5m. The parameters ξ_b and ξ_s are assumed respectively equal to 0% and 2%, γ is considered equal to 0.7, the radius R of the FPS is assumed to be equal 4m, the fixed-base system period T_s is considered equal to 0.3s, 0.9s and 1.5s, respectively. The response parameters u_s and u_b are adopted as the engineering demand parameters (EDPs), assumed to follow a lognormal distribution according to [Castaldo *et al.*, 2015]. A lognormal distribution can be fitted to the both response parameters (i.e., the extreme values of the EDPs), by estimating the sample lognormal mean, $\mu_{ln}(EDP)$, and the sample lognormal standard deviation, $\sigma_{ln}(EDP)$, through the maximum likelihood estimation method. Figs. 1-2 illustrate the IDA results regarding both the isolation level response u_b and the superstructure response u_s. Each figure contains some surface plots, corresponding to different values of percentile (50^{th}, 84^{th} and 16^{th}). Fig. 1 shows the IDA results regarding the isolation bearings response u_b. The lognormal mean and dispersion decrease for lower values of T_s (high value of the isolation degree [Palazzo, 1991]). Fig. 2 shows the IDA results regarding the superstructure response u_s. The lognormal mean and dispersion slightly decrease for lower values of T_s. The trend of the IDA curves is consistent with the results in terms of the median and response percentiles obtained by [Barroso and Winterstein, 2002].

5. Seismic Fragility of Base-Isolated Steel Structures

With reference to performance levels of the steel superstructure, four discrete performance levels or limit states (*LS1,LS2,LS3,LS4*), corresponding respectively to “fully operational”, “operational”, “life safety” and “collapse prevention” are provided from Vision 2000 [Vision, 2000]. In accordance to [FEMA274, 1997; FEMA356, 2000; Castaldo *et al.*, 2015], in Table 1, the *LS1* and *LS2* thresholds of fixed-base steel buildings as well as the corresponding failure probabilities in a design life of 50 years are reported. The performance limit states for the seismic fragility of base-isolated steel buildings, in accordance to NTC08 [NTC08, 2008] provisions, have been defined by limiting the response of the lateral-load-resisting superstructure system, IDI limits, to a fraction of the limits provided for designing comparable fixed-base buildings. In particular, with regard to NTC08 [NTC08, 2008] provisions the limit response of the lateral-load-resisting superstructure system of a base-isolated building is equal to about two-third of the IDI limit of a comparable fixed-base building as also reported in Table 1. In the hypothesis of regular buildings, the Eqn. (7), according to NTC08, is considered as relationship between the fixed-base building period and its height H, and is employed to estimate the height H as the integer multiple of the inter-storey height assumed equal to h=3m and, so, the corresponding total number of floors N_f.

$$T_s = 0.085 H^{\frac{3}{4}} \tag{7}$$

Table 1. *Limit state thresholds for the superstructure [FEMA274, 1997; FEMA356, 2000; Castaldo et al., 2015]*

	LS1 *fully operational*	*LS2* *operational*
Inter-story drift (ISD) index of fixed-base steel buildings	0.7%	1.5%
Inter-story drift (ISD) index of base-isolated steel buildings [NTC08, 2008]	0.47%	1.0%
p_f*(50 years)*	$5.0 \cdot 10^{-1}$	$1.6 \cdot 10^{-1}$

For each $T_s = 2\pi/\omega_s$, assuming the building floor mass equal to $m_{s,i}$ = 1000 kNs^2/m, for $i=1 \dots N_f$, it is possible to determinate the floor stiffness and vector Φ_1 containing the floor displacements of the first mode of the fixed-base structure normalized to the top floor displacement. The base mass m_b is assigned in order to respect the mass ratio γ [Kelly, 1997]:

$$\gamma = \frac{\Gamma_1^2 M_{s1}}{\sum_{i=1}^{N_f} m_{s,i} + m_b} \tag{8}$$

where Γ_1 and M_{s1} represent respectively the participation factor and modal mass of the fundamental mode of the fixed-base structure. It follows that the maximum absolute inter-story drift of the 1st floor can be evaluated as $u_{s,1,\max} = \Gamma_1 \phi_{11} u_{s,\max}$, and this response parameter, divided by the inter-storey height assumed equal to h=3m, corresponds to the overall maximum interstorey drift index experienced over the different stories that controls the performance of the superstructure.

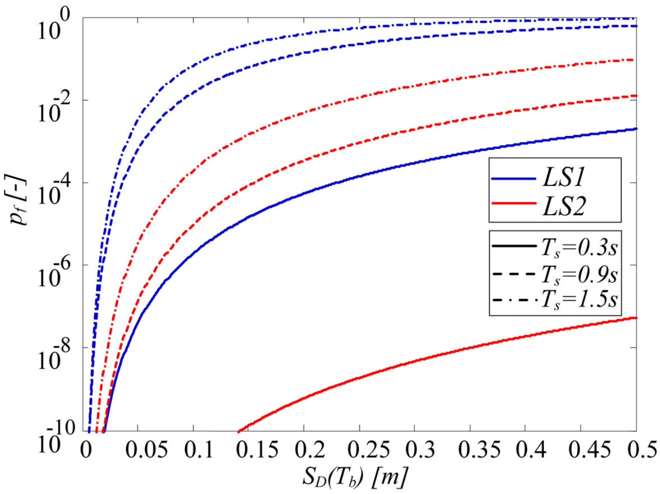

Figure 3. *Seismic fragility curves of the superstructure 1st floor with γ=0.7, for R=4m*

At each value of the intensity measure *IM*, the probabilities p_f exceeding different limit states related to the superstructure have been numerically and fitted by a lognormal distribution. Fig. 3 shows the fragility curves regarding the superstructure 1st floor for three values of T_s (0.3s, 0.9s and 1.5s) The seismic fragility of the superstructure increases for higher values of T_s (lower values of the isolation degree).

With reference to the performance levels of the isolation system, several different values for the plan dimension of the isolator are considered. In Table 2, the limit state thresholds assumed for the seismic fragility of the FPS isolation level are reported. Fig. 4 shows the fragility curves regarding the isolation level for three values of T_s (0.3s, 0.9s and 1.5s) and the different values of the limit state thresholds varying in the range *LS1-LS9*. The fragility curves are plotted in logarithmic scale in the range between 10^0-10^{-6}. The seismic fragility of the isolation level increases for higher values of T_s (lower values of the isolation degree).

Table 2. *Limit state thresholds for the isolation level*

	LS1	*LS2*	*LS3*	*LS4*	*LS5*	*LS6*	*LS7*	*LS8*	*LS9*
Maximum relative displacement [m]	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5

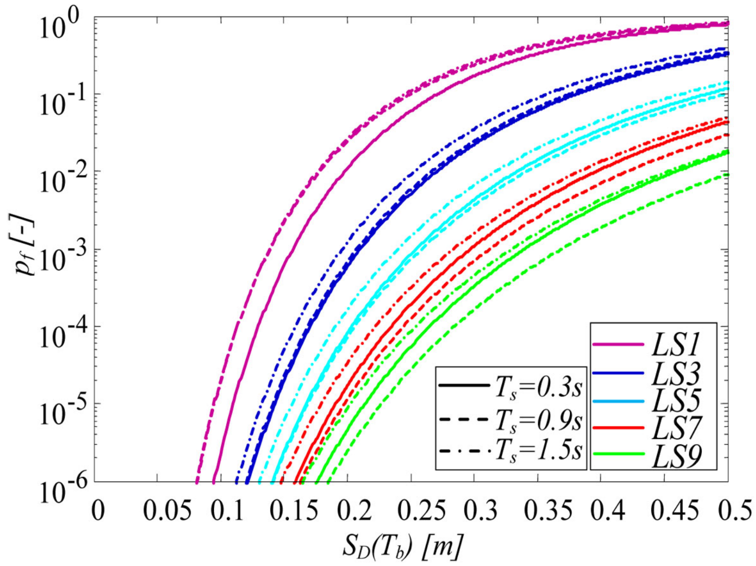

Figure 4. *Seismic fragility curves of the isolation level with γ=0.7, for R=4m*

6. Seismic Reliability of Base-Isolated Steel Structures

Considering a site near Sant'Angelo dei Lombardi (Italy) as the reference site, in Figure 5 the seismic hazard curve, expressed in terms of the same IM=$S_D(T_b)$, related to the isolated period (*R*=4m), is plotted according to NTC08. The abovementioned curve represents the average values of the annual rate λ of exceeding the IM=$S_D(T_b)$ level. Integrating the fragility curves related to both the superstructure and isolation level with the seismic hazard curve and using a Poisson distribution, it is possible to evaluate the seismic reliability of the overall steel system in the time frame of interest (50 years). The seismic reliability of the steel superstructure increases for low values of Ts (high values of the isolation degree), as shown in Figure 6.

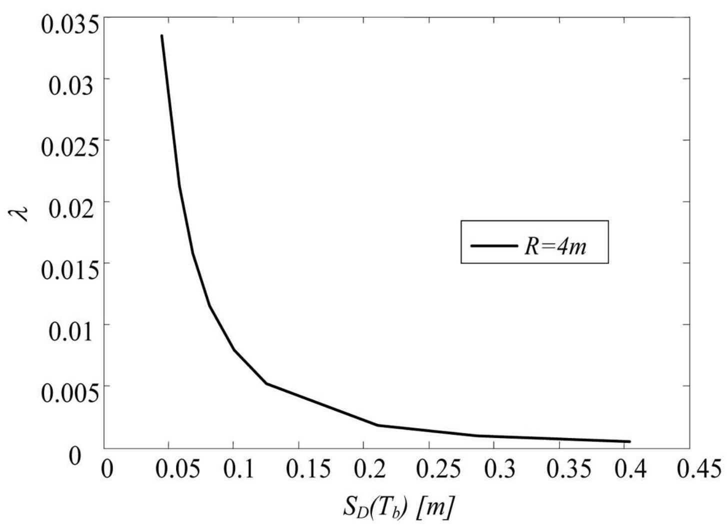

Figure 5. *Seismic hazard curves related to a site near Sant'Angelo dei Lombardi (Italy)*

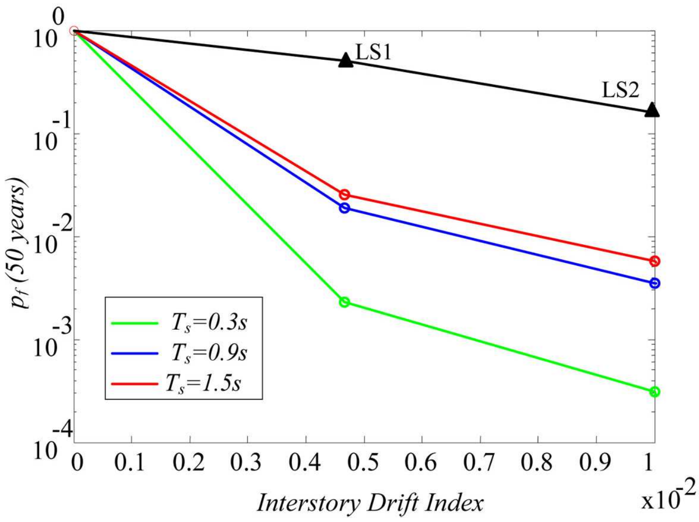

Figure 6. *Seismic reliability curves of the superstructure 1st floor for γ=0.7 and R=4m*

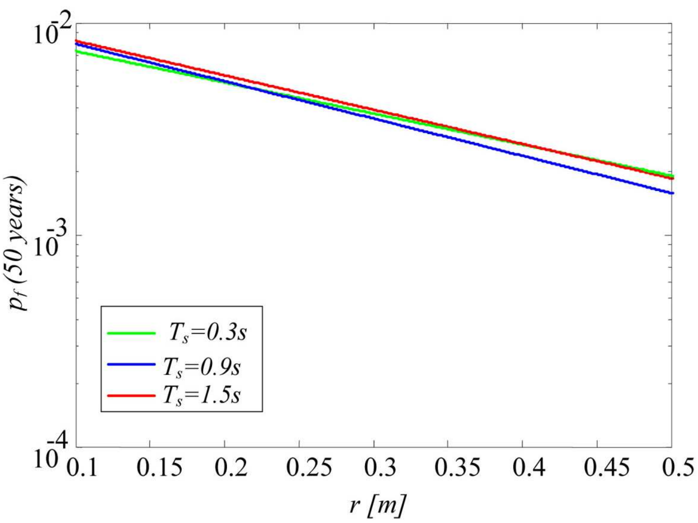

Figure 7. *Seismic fragility curves of the isolation level for γ=0.7 and R=4m*

The seismic reliability of the isolation level decreases slightly depends on the values of T_s (Figure 7). An exceeding probability of p_f=1.5·10^{-3} (related to the collapse limit state, reliability index β=3 in 50 years) is achieved through a radius in plan r ranging from about 0.35 m to about 0.45 m depending on system properties. The results are consistent with those obtained by Castaldo *et al.* [2016a] considering r.c. superstructures in ordinary conditions [Etse *et al.*, 2013; Etse *et al.*, 2014; Etse *et al.*, 2015; Etse *et al.*, 2016; Mroginski *et al.*, 2015; Ripani *et al.*, 2014; Vrech *et al.*, 2015; Ripani *et al.* 2016] and L'Aquila as reference site.

7. Conclusions

This paper deals with the seismic reliability of steel systems equipped with friction pendulum isolators (FPS) considering both the friction coefficient and earthquake characteristics as random variables. The uncertainty in the seismic inputs is taken into account by considering a set of artificial records related to class B site. Incremental dynamic analyses are developed to evaluate the probabilities exceeding different limit states related to both superstructure and isolation level for different structural properties.

In the final part, considering the seismic hazard curve related to a site near to Sant'Angelo dei Lombardi (Italy), according to NTC08, and regarding steel structures isolated by FP bearings with a design life of 50 years, reliability curves are derived.

8. References

Barroso L.R., Winterstein S. [2002] "Probabilistic seismic demand analysis of controlled steel moment resisting frame structures," Earthquake Engineering and Structural Dynamics 31(12):2049–2066.

Bertero, R.D., Bertero, V.V. [2002] "Performance-based seismic engineering: the need for a reliable conceptual comprehensive approach," Earthquake Engineering and Structural Dynamics 31:627–652.

Bonessio N., Lomiento G. and Benzoni G. [2012] Damage identification procedure for seismically isolated bridges, Struct. Control Health Monit., 19:565–578.

Building Seismic Safety Council [1997] NEHRP commentary on the guidelines for the seismic rehabilitation of buildings. Provisions (FEMA 274). Washington, DC.

Building Seismic Safety Council [2000] NEHRP commentary on the guidelines for the seismic rehabilitation of buildings. Provisions (FEMA 356). Washington, DC.

Castaldo, P., [2014] Integrated Seismic Design of Structure and Control Systems. Springer International Publishing: New York,. DOI 10.1007/978-3-319-02615-2.

Castaldo P., Amendola G., & Palazzo B. [2016a] Seismic fragility and reliability of structures isolated by friction pendulum devices: Seismic reliability-based design (SRBD), Earthquake Engineering and Structural Dynamics, DOI: 10.1002/eqe.2798.

Castaldo, P., Amendola, G. & Palazzo, B. [2016b]. Seismic reliability-based design of structures isolated by FPS. ECCOMAS Congress2016, Crete Island, Greece, 5–10 June 2016.

Castaldo P., De Iuliis M. [2014] "Optimal integrated seismic design of structural and viscoelastic bracing-damper systems," Earthquake Engineering and Structural Dynamics 43(12):1809–1827, DOI: 10.1002/eqe.2425.

Castaldo P., Palazzo B., Della Vecchia P. [2015] "Seismic reliability of base-isolated structures with friction pendulum bearings," Engineering Structures 95:80-93.

Castaldo P., Palazzo B., Della Vecchia P. [2016c] "Life-cycle cost and seismic reliability analysis of 3d systems equipped with FPS for different isolation degrees," Engineering Structures 125:349–363, http://dx.doi.org/10.1016/j.engstruct.2016.06.056.

Castaldo, P., Palazzo, B., Perri, F., Marino, I., Faraco, M.M. [2016d]. Seismic retrofit of existing buildings through the dissipative columns. ECCOMAS Congress2016, Crete Island, Greece, 5–10 June 2016.

Castaldo, P., Palazzo, B., Perri [2016e] "FEM simulations of a new hysteretic damper: the dissipative column". Ingegneria Sismica - International Journal of Earthquake Engineering, Anno XXXIII – Speciale CTA 2015 – Num. 1-2:34-45.

Castaldo P., Ripani M. [2016] "Optimal design of friction pendulum system properties for isolated structures considering different soil conditions", Soil Dynamics and Earthquake Engineering, 90:74–87, DOI: 10.1016/j.soildyn.2016.08.025.

Castaldo P., Tubaldi E. [2015] "Influence of FPS bearing properties on the seismic performance of base-isolated structures," Earthquake Engineering and Structural Dynamics 44(15):2817–2836.

CEN - European Committee for Standardization [2004] Eurocode 8—Design of Structures for Earthquake Resistance. Part 1: General Rules, Seismic Actions and Rules for Buildings, Brussels.

Christopoulos, C., Filiatrault, A. [2006] Principles of Passive Supplemental Damping and Seismic Isolatio, IUSS Press: Pavia, Italy.

Clough, R.W., Penzien, J. [1993] Dynamics of Structures, 2nd edn. McGraw-Hill, New York.

Constantinou, M.C., Mokha, A., Reinhorn, A.M. [1990] "Teflon Bearings in Base Isolation. II: Modeling," J. Struct. Eng. 116(2):455-474.

Constantinou, M.C., Whittaker, A.S., Kalpakidis, Y., Fenz, D.M., Warn, G.P. [2007] "Performance of Seismic Isolation Hardware Under Service and Seismic Loading," Technical Report MCEER-07-0012.

Cornell, C.A., Krawinkler, H. [2000] "Progress and challenges in seismic performance assessment," PEER Center News 4(1):1-3.

D'Ayala D., and Benzoni G., [2012] Historic and Traditional Structures during the 2010 Chile Earthquake: Observations, Codes, and Conservation Strategies, Earthquake Spectra, 28;S1:S425-S451

De Iuliis M, Castaldo P. [2012] "An energy-based approach to the seismic control of one-way asymmetrical structural systems using semi-active devices," Ingegneria Sismica - International Journal of Earthquake Engineering XXIX(4):31-42.

De Iuliis M., Castaldo P., Palazzo B. [2010] "Analisi della domanda sismica inelastica del terremoto de L'Aquila su sistemi dimensionati secondo le NTC2008," Ingegneria Sismica, Patron Editore XXVII(3):52–65.

Etse, G.J., Ripani, M., Vrech, S.M. [2013] "Fracture energy-based thermodynamically consistent gradient model for concrete under high temperature," Proceedings of the 8th International Conference on Fracture Mechanics of Concrete and Concrete Structures, FraMCoS 2013, 1506-1515.

Etse, G., Ripani, M., Caggiano, A. & Schicchi, D.S. [2015] "Strength and durability of concrete subjected to high temperature: continuous and discrete constitutive approaches," American

Concrete Institute, ACI Special Publication American Concrete Institute, ACI Special Publication 2015-January (SP 305), 9.1-9.18.

Etse, G., Ripani, M. & Mroginski, J.L. [2014] "Computational failure analysis of concrete under high temperature," Computational Modelling of Concrete Structures - Proceedings of EURO-C 2014, 2:715-722.

Etse, G., Vrech, S.M. & Ripani, M. [2016] "Constitutive theory for Recycled Aggregate Concretes subjected to high temperature," Construction and Building Materials, 111: 43-53.

Giugliano, M.T., Longo, A., Montuori, R., Piluso, V. [2011a] "Influence of homoschedasticity hypothesis of structural response parameters on seismic reliability of CB-frames," Georisk 5(2): 120-131.

Giugliano, M.T., Longo, A., Montuori, R., Piluso, V. [2011b] "Seismic reliability of traditional and innovative concentrically braced frames," Earthquake Engineering and Structural Dynamics 40(13): 1455–1474.

Kanai, K. [1957] "Semiempirical formula for the seismic characteristics of the ground," Bulletin of earthquake research institute 35, 309-325.

Kelly, J.M. [1997] Earthquake-Resistant Design with Rubber, 2nd ed. Berlin and New York: Springer-Verlag.

Longo, A., Montuori, R., Piluso, V. [2009] "Seismic reliability of V-braced frames: Influence of design methodologies," Earthquake Engineering and Structural Dynamics 38(14): 1587–1608.

Longo, A., Montuori, R., Piluso, V. [2012] "Failure mode control and seismic response of dissipative truss moment frames," Journal of Structural Engineering 138(11), 1388-1397.

Luco, N., Cornell, C.A. [2007] "Structure-specific scalar intensity measures for near-source and ordinary earthquake ground motions," Earthquake Spectra 23(2): 357-92.

Mckey, M.D., Conover, W.J., Beckman, R.J. [1979] "A comparison of three methods for selecting values of input variables in the analysis from a computer code," Technometrics 21:239-45.

Mokha, A., Constantinou, M.C., Reinhorn, A.M. [1990] "Teflon Bearings in Base Isolation. I: Testing," J. Struct. Eng. 116(2): 438-454.

Mroginski, J.L., Etse, G., Ripani, M. [2015] "A non-isothermal consolidation model for gradient-based poroplasticity," PANACM 2015 - 1st Pan-American Congress on Computational Mechanics, in conjunction with the 11th Argentine Congress on Computational Mechanics, MECOM 2015, pp. 75-88.

NTC08 - Norme tecniche per le costruzioni. Gazzetta Ufficiale del 04.02.08, DM 14.01.08, Ministero delle Infrastrutture.

Palazzo B., Castaldo P., Della Vecchia P. [2014a] "Seismic reliability analysis of base-isolated structures with friction pendulum system," 2014 IEEE Workshop on Environmental, Energy and Structural Monitoring Systems Proceedings, Napoli, September 17-18.

Palazzo , B. [1991] "Seismic Behavior of base-isolated Buildings," Proc. International Meeting on earthquake Protection of Buildings, Ancona.

Palazzo, B., Castaldo, P., Marino, I. [2014b] "The steel column damper: a new hysteretic device providing additional stiffness and damping," EUROSTEEL 2014, September 10-12, Naples, Italy.

Palazzo, B., Castaldo, P., Marino, I. [2015] "The Dissipative Column: A New Hysteretic Damper," Buildings 5(1), 163-178; doi:10.3390/buildings5010163.

Pinto P., Giannini R., Franchin P. [2004] Seismic Reliability Analysis of Structures, Iuss Press.

Porter, K.A. [2003] "An overview of PEER's performance-based earthquake engineering methodology;" Proceedings, Proceedings of the 9th International Conference on Application of Statistics and Probability in Civil Engineering (ICASP9), San Francisco, California, 973-980.

Ripani, M., Etse, G., Vrech, S. & Mroginski, J.L. [2014] "Thermodynamic gradient-based poroplastic theory for concrete under high temperature," International Journal of Plasticity, 61: 157-177.

Ripani, M., Etse, G., Vrech, S. [2016] "Recycled aggregate concrete: localized failure assessment in thermodynamically consistent non-local plasticity framework", Computers and Structures, doi: 10.1016/j.compstruc.2016.08.007.

Saito T., Kanda J., Kani N. [1998] "Seismic reliability estimate of building structures designed according to the current Japanese design code," Proceedings of the Structural Engineers World Congress.

Shinozuka, M., Deodatis, G. [1991] "Simulation of stochastic processes by spectral representation," Applied Mechanics Reviews 44(4): 191-203.

Shinozuka, M., Sato, Y. [1967] "Simulation of nonstationary random process," J. Engrg.Mech.Div. 93(1), 11-40.

Tajimi, H. [1960] "A statistical method of determining the maximum response of a building structure during an earthquake," Proc. 2nd World Conf. on earthquake Engineering II, 781-798.

Talaslidis, D.G., Manolis, G.D., Paraskevopoulos E.A., Panagiotopoulos C.G. [2004] Risk analysis of industrial structures with hazardous materials under seismic input, 13th World Conference on Earthquake Engineering, Vancouver, B.C., Canada, August 1-6.

Vamvatsikos, D., Cornell, C.A. [2002] "Incremental dynamic analysis," Earthquake Engineering and Structural Dynamics 31(3): 491–514.

Vision 2000 - SEAOC - Committee. Performance-based seismic engineering. Report prepared by Structural Engineers Association of California, Sacramento, 1995.

Vrech, S.M., Ripani, M. & Etse, G. [2015] "Localized versus diffused failure modes in concrete subjected to high temperature," PANACM 2015 - 1st Pan-American Congress on Computational Mechanics, in conjunction with the 11th Argentine Congress on Computational Mechanics, MECOM 2015, pp. 225-236.

Zayas, V.A., Low, S.S., Mahin, S.A. [1990] "A simple pendulum technique for achieving seismic isolation," Earthquake Spectra 6:317–33.

ingegneria sismica
International Journal of Earthquake Engineering
Anno XXXIII – Speciale CTA 2015 – Num. 3

EFFETTI DI SUOLO DI CATEGORIA B SULL'AFFIDABILITA' SISMICA DI SISTEMI IN ACCIAIO ISOLATI ALLA BASE

Paolo Castaldo, Guglielmo Amendola, Bruno Palazzo*

Department of Civil Engineering, University of Salerno, Italy

SOMMARIO: *Il presente lavoro valuta l'affidabilità sismica di sistemi in acciaio isolati alla base con dispositivi attritivi a pendolo scorrevole e soggetti a registrazioni accelerometriche artificiali corrispondenti a suolo di categoria B. La sovrastruttura è modellata con un comportamento elastico mentre gli isolatori sono descritti con un modello che tiene conto della variazione del coefficiente di attrito con la velocità. L'incertezza relativa sia all'azione sismica che al coefficiente di attrito è considerata assumendo opportune funzioni di densità di probabilità. Analisi dinamiche non lineari incrementali sono sviluppate al fine di definire le curve di fragilità relative sia alla sovrastruttura che livello di isolamento. Infine, considerando come sito di riferimento Sant'Angelo dei Lombardi (Italia), l'affidabilità sismica dell'intero sistema è valutata.*

*Corresponding author: Paolo Castaldo, Department of Civil Engineering, University of Salerno, Italy.
Email: pcastaldo@unisa.it