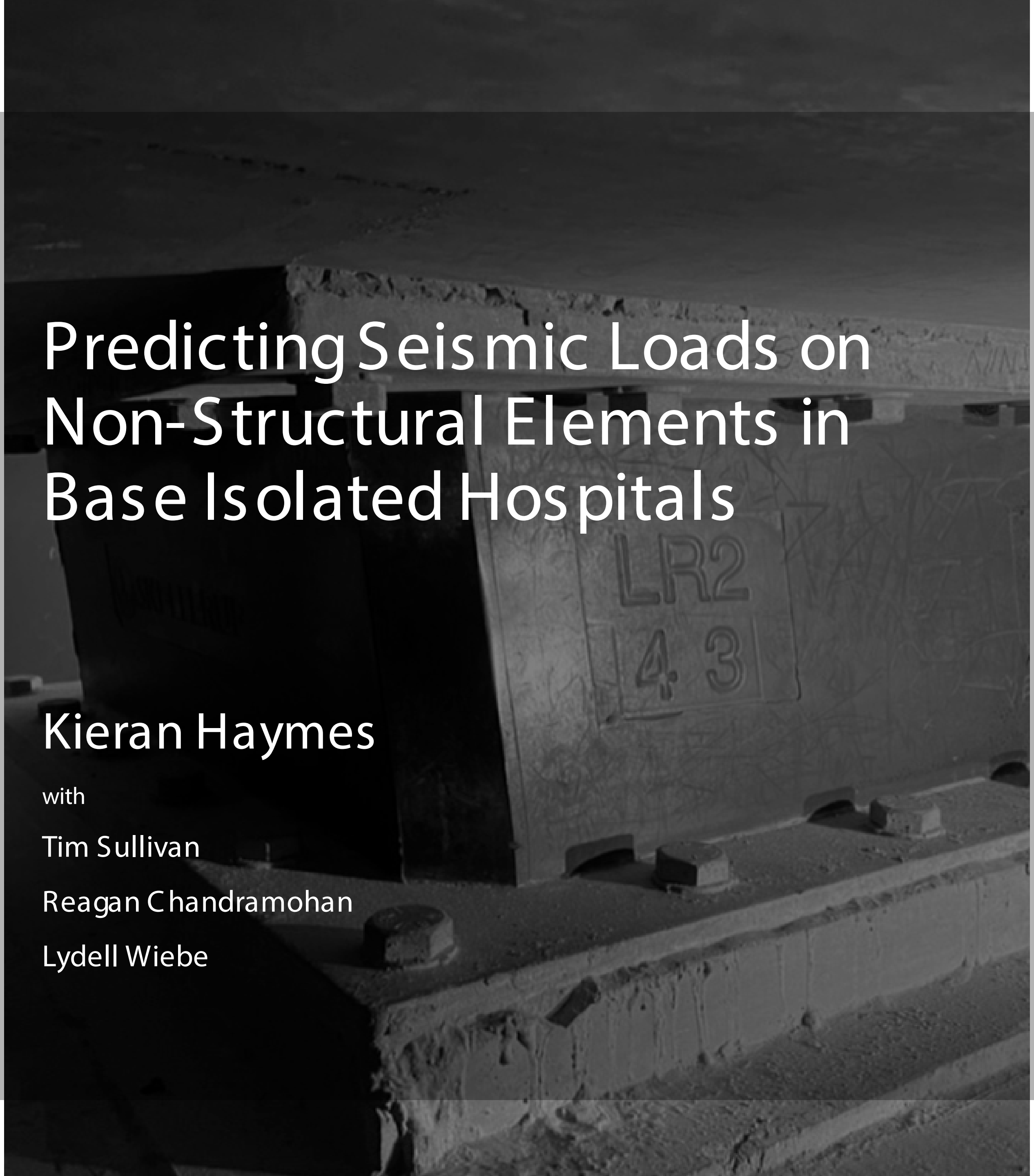

Predicting Seismic Loads on Non-Structural Elements in Base Isolated Hospitals

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CHRISTCHURCH NEW ZEALAND

CHILE-NZ SEISMIC DESIGN OF HOSPITAL WORKSHOP

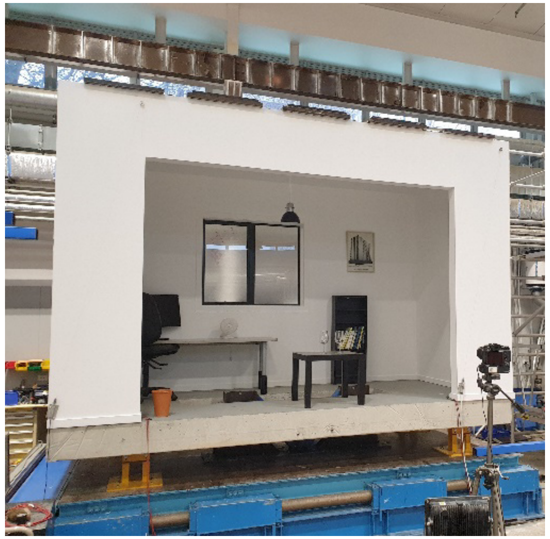
29 July 2024

Examined floor response spectra generated from shake table data and numerical modelling

5-Storey Steel Frame Building [1]
Shake Table Testing

Configured with:

- Triple pendulum friction bearings
- Lead rubber + cross-linear bearings
- Fixed base



1-Storey Lightweight Timber Building [2]
Shake Table Testing

Configured with

- Flat slider friction bearings

9-Storey RC Wall Building [3]
Numerical Modelling

Configured with

- lead rubber + flat slider friction bearings

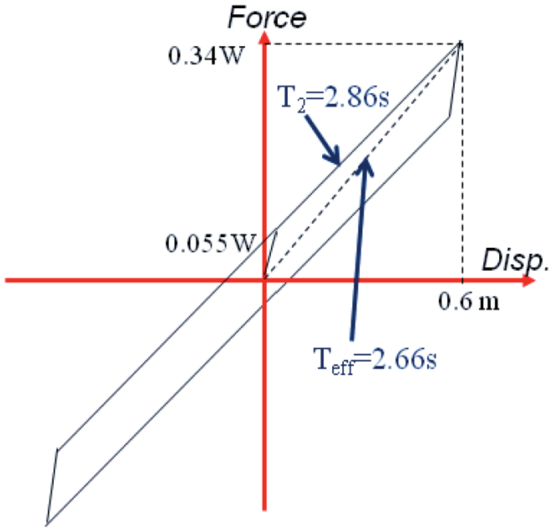
[1] Ryan, K. L., Dao, N. D., Sato, E., Sasaki, T., & Okazaki, T. (2012). Aspects of Isolation Device Behavior Observed from Full-Scale Testing of an Isolated Building at E-Defense. 20th Analysis and Computation Specialty Conference, 25–36. https://doi.org/10.1061/9780784412374.003

[2] Francis, T. C. (2022). Base Isolation of Light-Frame Wood Buildings in New Zealand. University of Canterbury.

[3] Yang, A., Sullivan, T. J., Bradley, B. A., & Pettinga, D. J. (2020). Seismic Performance Assessment of a Base Isolated Building. University of Canterbury.

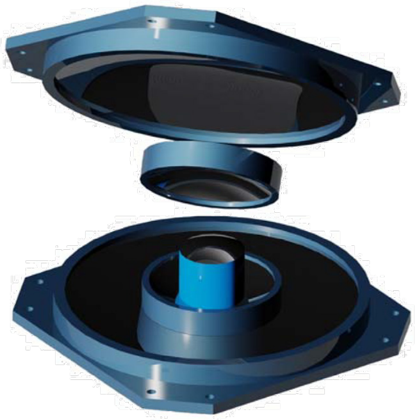
Two common isolator types: Rubber and Friction

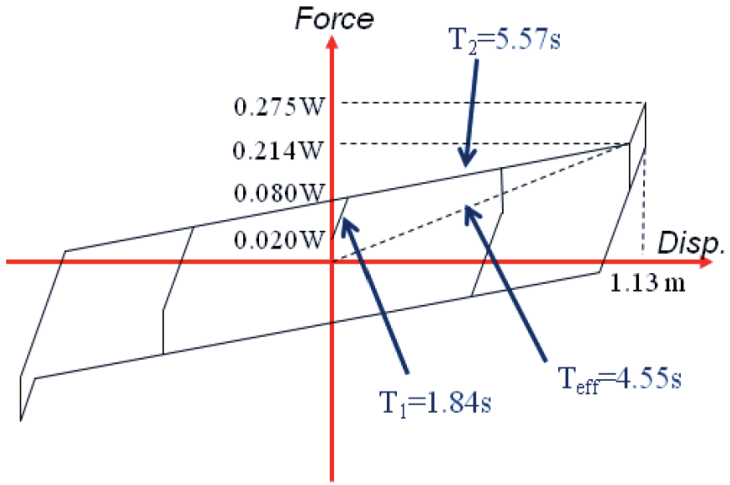
LRBs and TPBs used in 5-Storey Steel E-Defense Testing



Lead rubber bearings (LRB) consist of laminated rubber and steel shims surrounding a lead core

- Dissipates energy by yielding lead core
- Low initial stiffness
- Bilinear force-displacement response

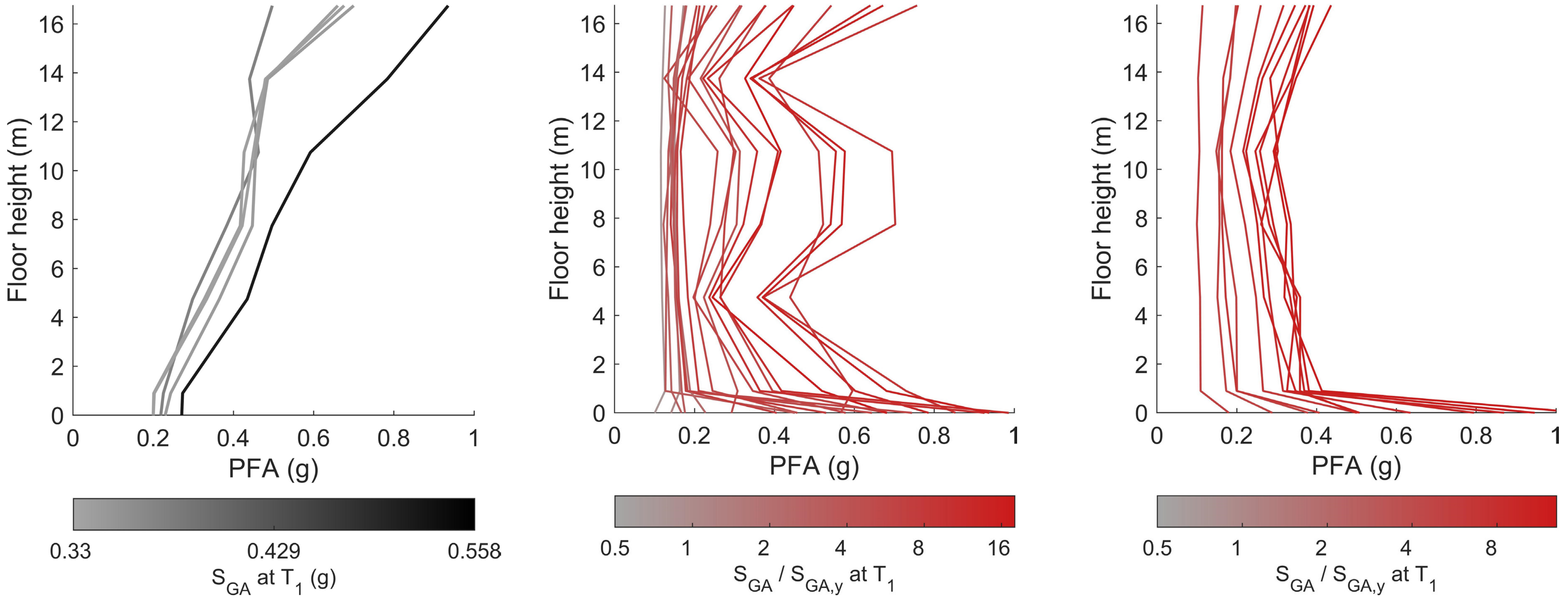




Triple pendulum bearings (TPB) consist of an inner slider, inside of inner and outer concave spherical surfaces

- Dissipates energy through friction by sliding
- High initial stiffness
- Multi-linear force-displacement response proportional to sliding surface curvature

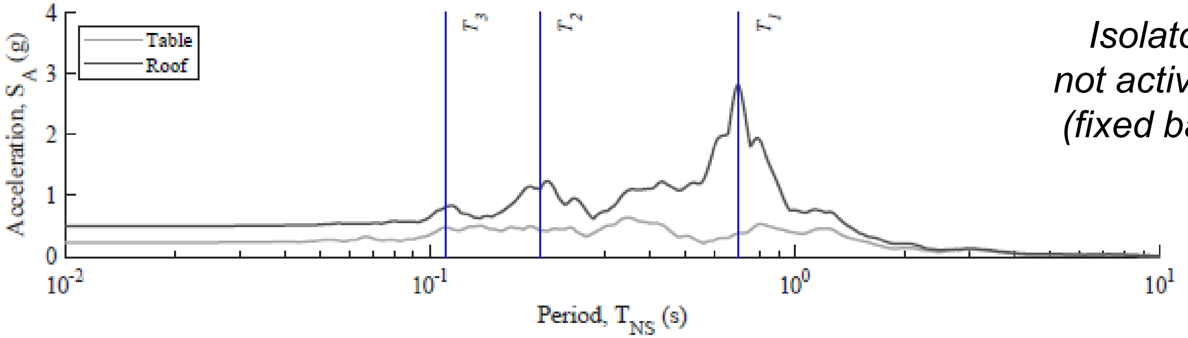
Peak floor acceleration distribution with height observed to significantly reduce after isolation device activation



Fixed base

Triple pendulum bearings

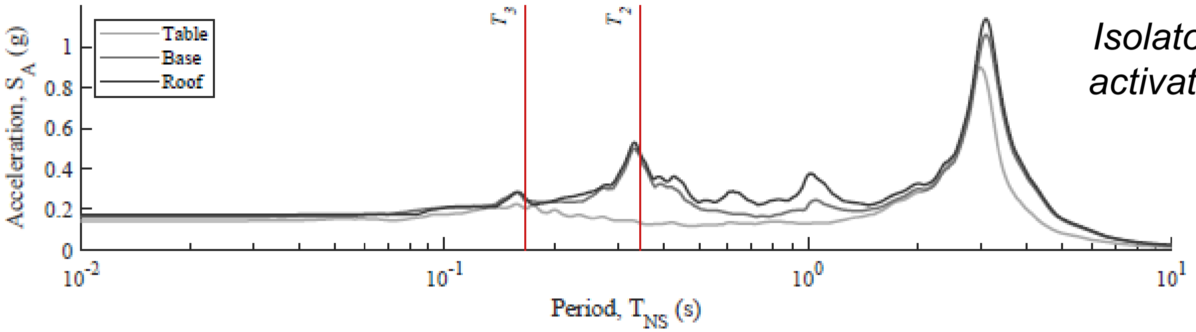
Lead rubber bearings



(A) Fixed base, 80% Westmorland earthquake.

Isolators not activated (fixed base)

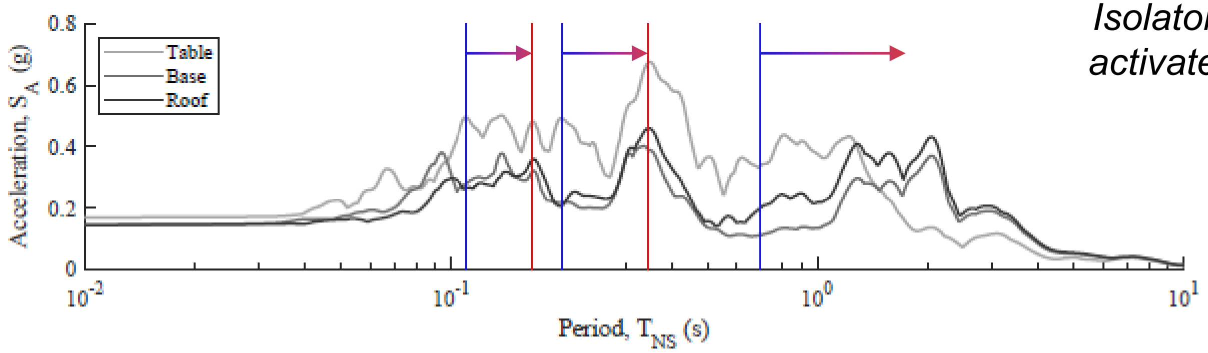
Infer initial modal periods from fixed base superstructure, assuming high initial friction in isolators is effective fixed base



(B) Triple pendulum bearings, sine wave input.

Isolators activated

Infer effective higher modal periods, approximately equal to tangent periods (T_2 and T_3)



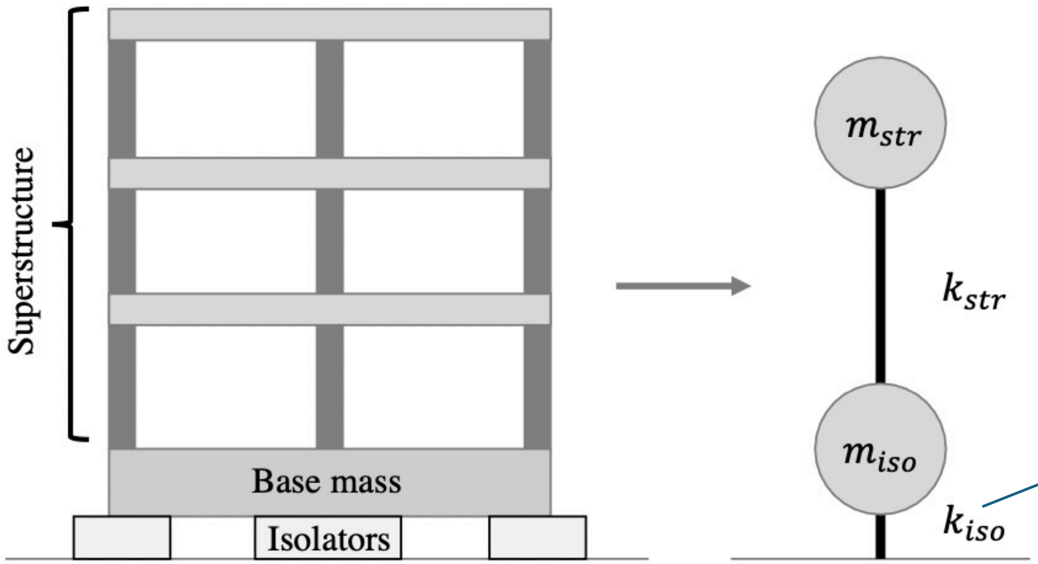
(C) Triple pendulum bearings, 80% Westmorland earthquake.

Isolators activated

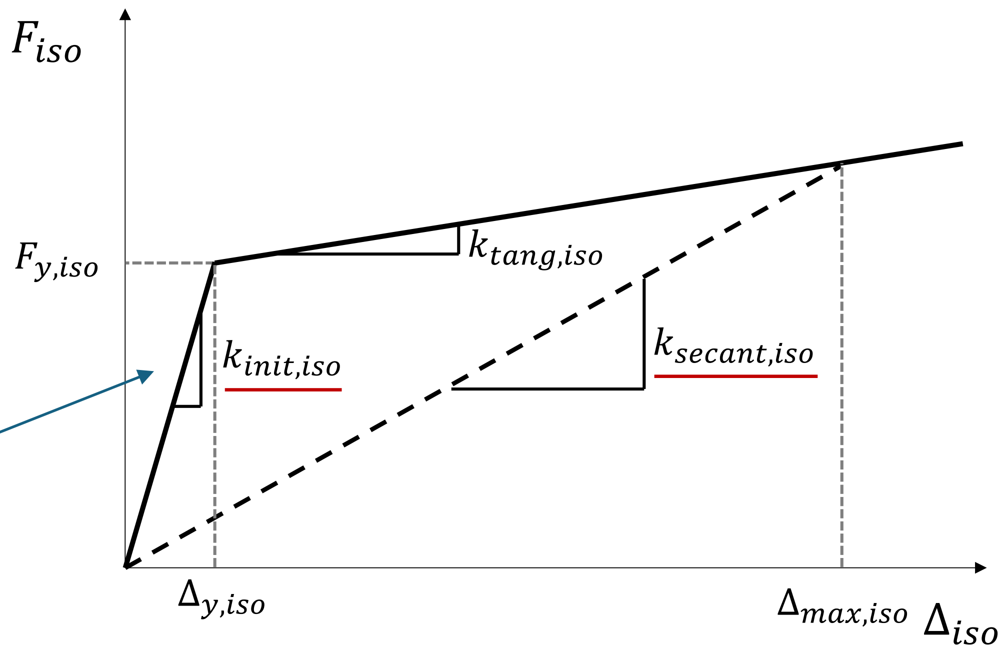
Demands cap at initial modal periods, develop at/towards tangent higher modal periods and effective first modal period

— Recorded at Roof	— Recorded at Isolated Base	— Recorded at Table
— Linear elastic periods	— Nonlinear periods	

How can we represent a base isolated building?



Superstructure and isolators idealised as 2DOF



Isolators idealised with bilinear backbone curve

Dynamic properties of the system will depend on relative

masses: $\frac{m_{iso}}{m_{str}}$ constant throughout ground motions

stiffnesses: $\frac{k_{iso}}{k_{str}}$ changes with nonlinear response from activation of isolators

TS1170.5, Simple "Cascade" approach

based on [5]

Similar to new ASCE 7-22 Approach, following work by [6]

Eurocode 8 uses modal superposition approach

Base Isolated Structures

Replace estimate of PFA

with PFAs from NLTHA (a_i)

4. **Design actions, F_{ph}**
includes reduction (at ULS) by
component reserve strength factor, Ω_p

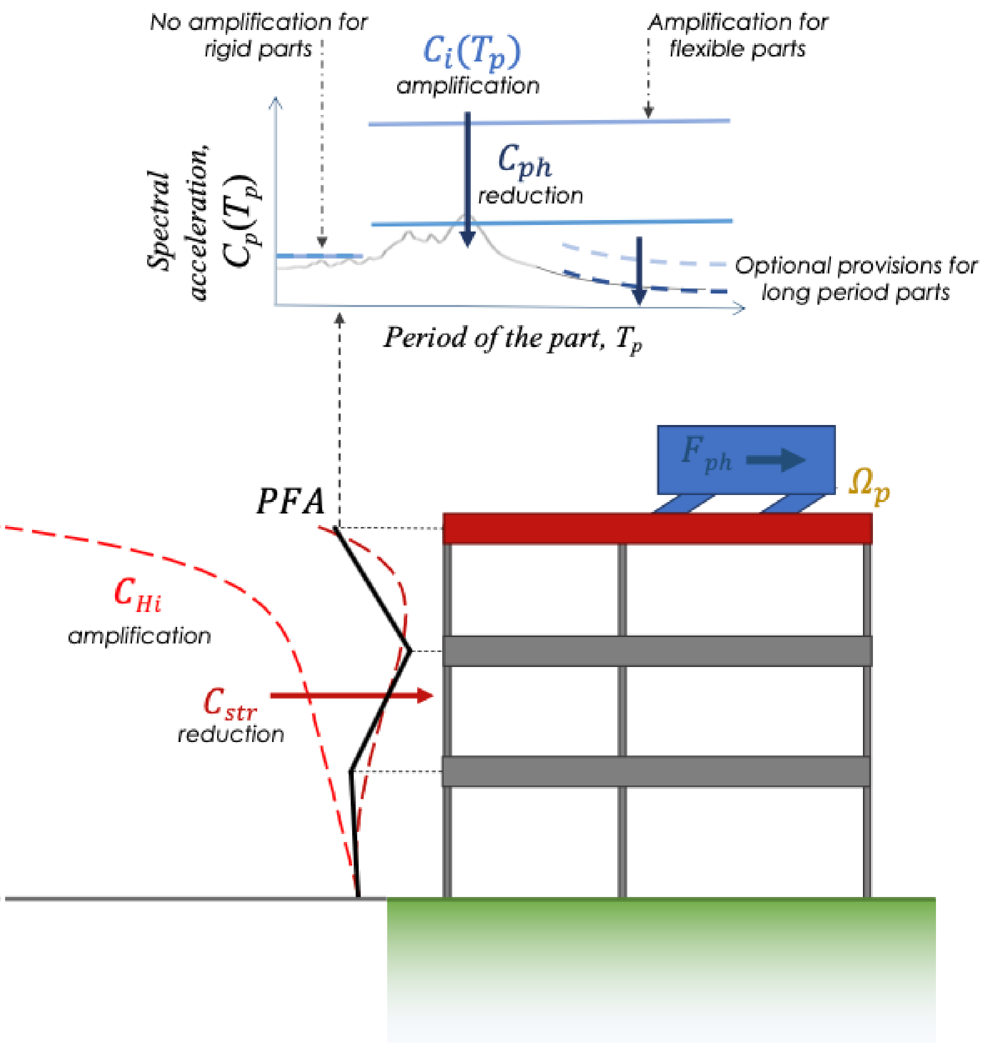
3. *Amplification of part response using*
spectral shape factor, $C_i(T_p)$
reduced by
component response factor, C_{ph}

$$C_p(T_p) = \left(\frac{C_i(T_p)}{C_{ph}}\right) \times PFA$$

2. *Distribution of peak floor accelerations, PFA, as a function of PGA using*
floor height amplification factor, C_{Hi}
reduced by
structural nonlinearity reduction factor, C_{str}

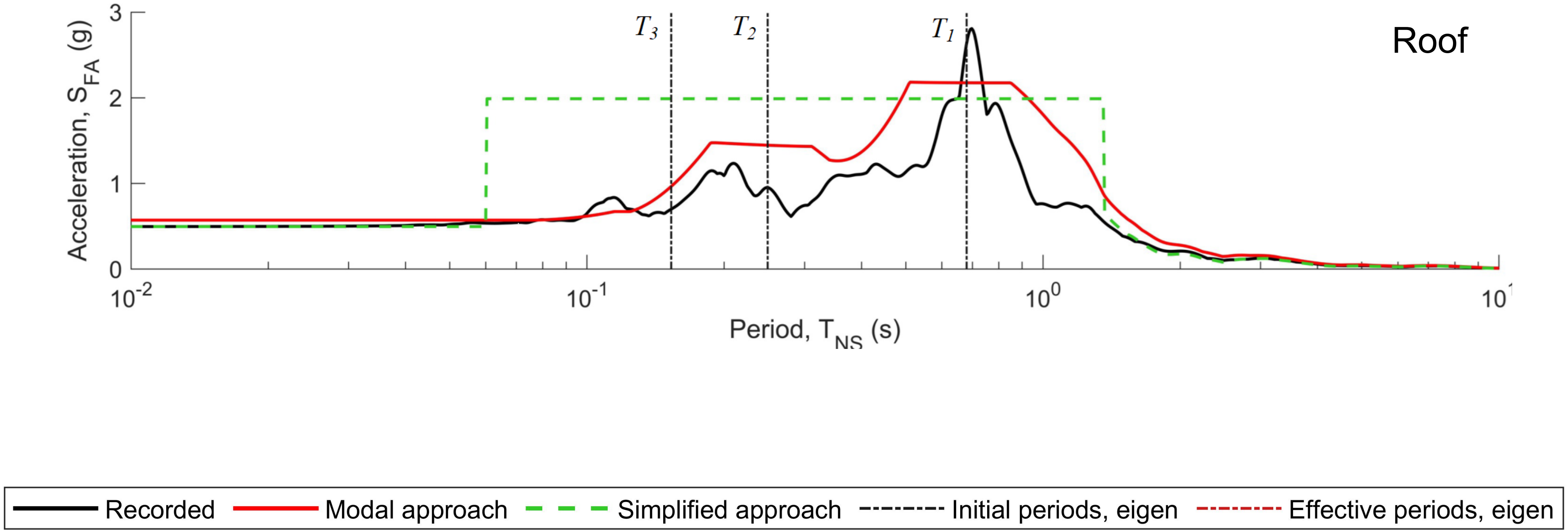
$$PFA = \left(\frac{C_{Hi}}{C_{str}}\right) \times PGA$$

1. *Ground motion excitation at base considering limit state design*
peak ground acceleration, PGA



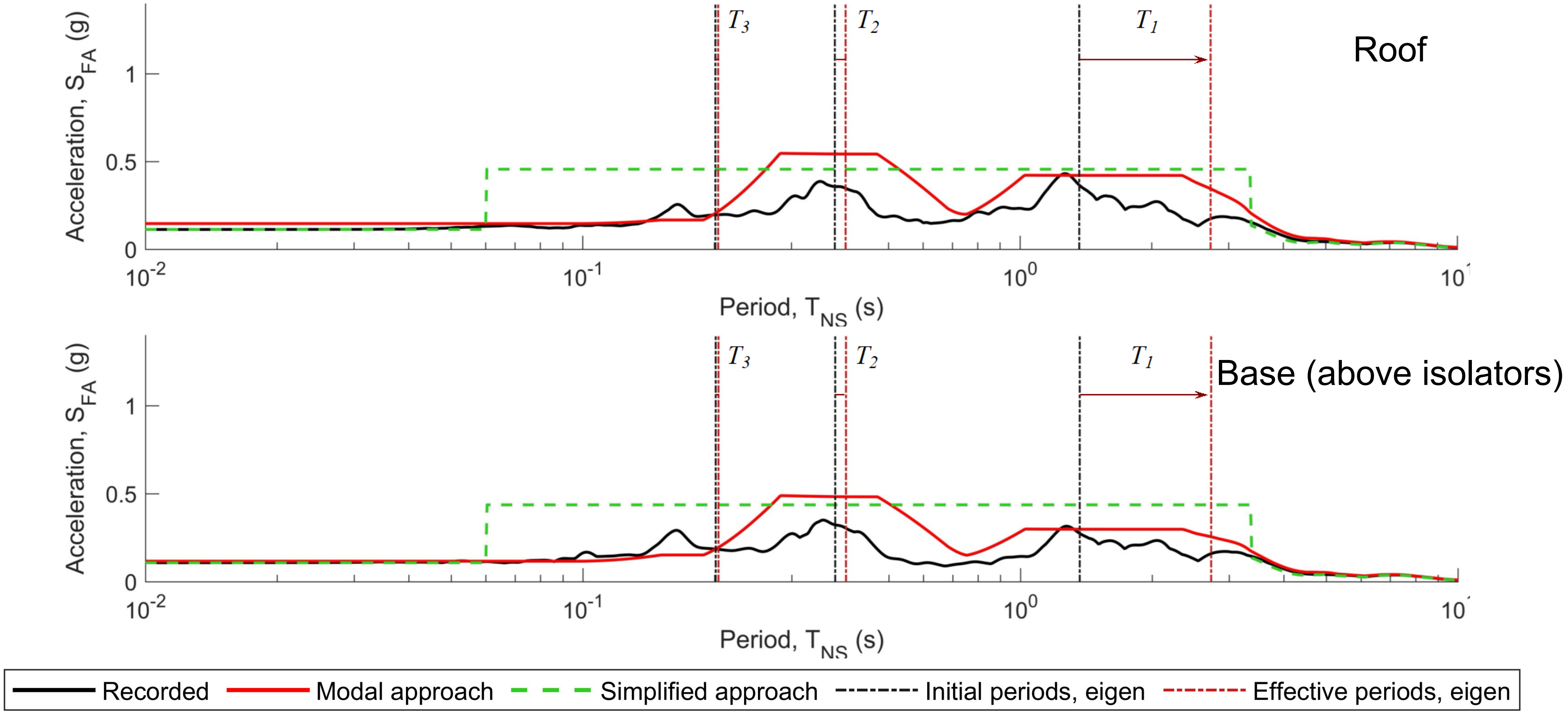
[5] Haymes, K., Sullivan, T. J., & Hare, J. (2024). Recommendations for the revision of the approach for seismic design of parts and components in New Zealand design standards. Bulletin of the New Zealand Society of Earthquake Engineering, accepted.
[6] Applied Technology Council. (2018). Recommendations for improved seismic performance of nonstructural components. https://doi.org/10.6028/NIST.GCR.18-917-43

Fixed base
Well predicted by both approaches



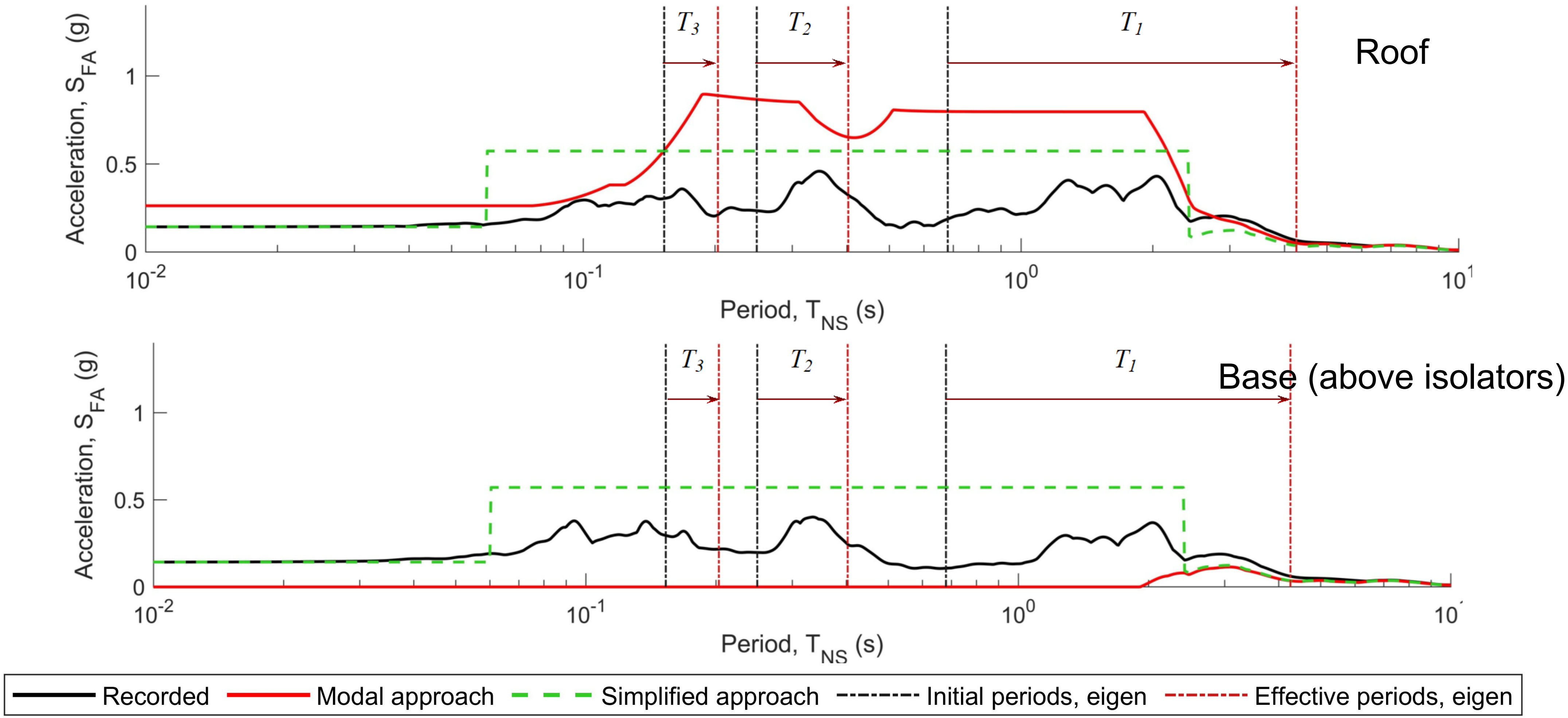
Predicted and recorded acceleration response spectra at roof and base levels of the building in three configurations for the 80% Westmorland earthquake motion

Lead rubber bearing + Cross linear bearing system



Predicted and recorded acceleration response spectra at roof and base levels of the building in three configurations for the 80% Westmorland earthquake motion

Triple Pendulum Bearings



Predicted and recorded acceleration response spectra at roof and base levels of the building in three configurations for the 80% Westmorland earthquake motion

Hospitals have post-event functionality requirements
SLS2 Design Requirements may govern

$$F_{ph} = \frac{C_\mathrm{p}(T_\mathrm{p})}{\Omega_\mathrm{p}} R_\mathrm{p} W_\mathrm{p} \qquad C_p(T_p) = a_i \left[\frac{C_i(T_p)}{C_{ph}}\right]$$

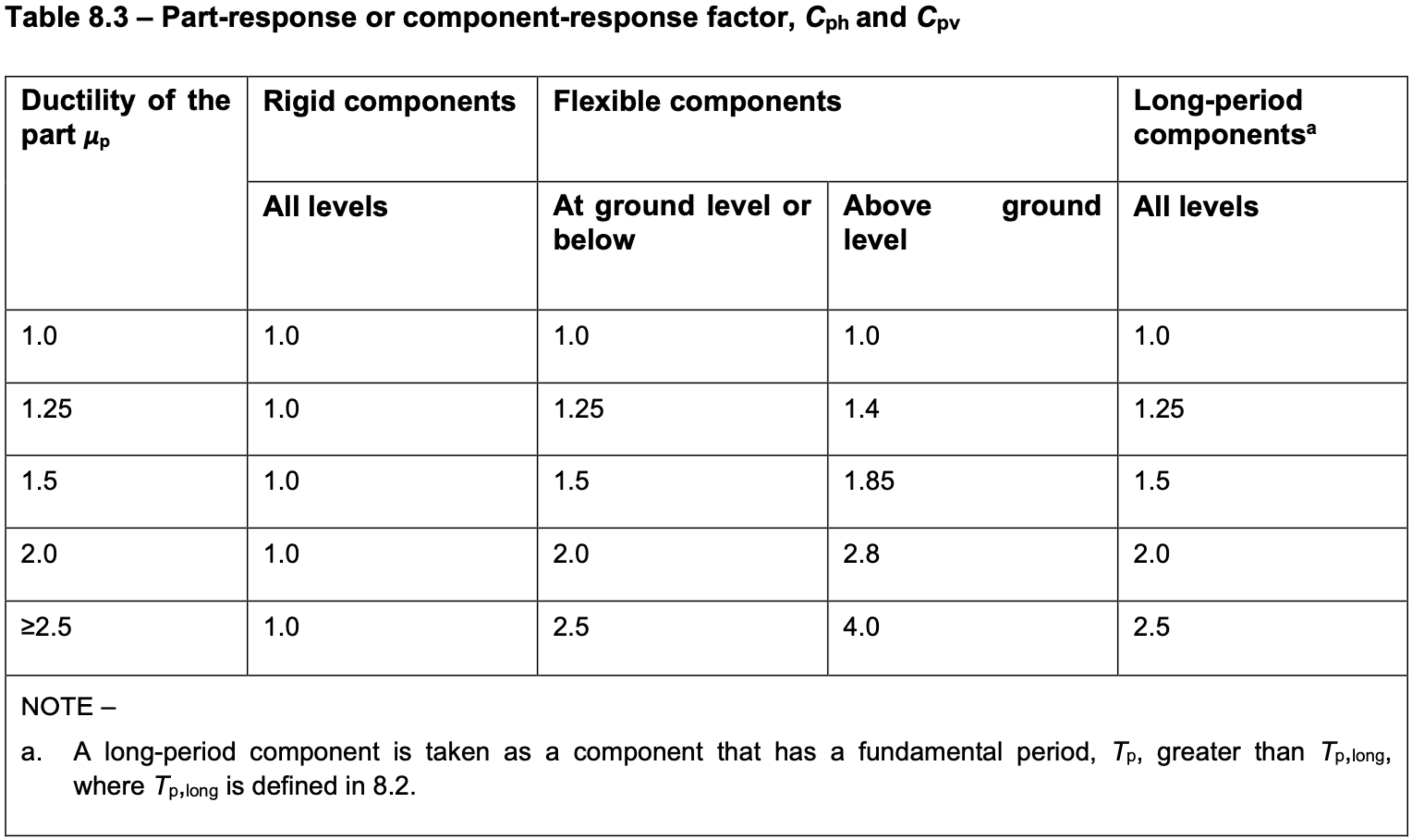


Table 8.3 – Part-response or component-response factor, C_{ph} and C_{pv}

Ductility of the part μ_p	Rigid components	Flexible components		Long-period components[a]
	All levels	At ground level or below	Above ground level	All levels
1.0	1.0	1.0	1.0	1.0
1.25	1.0	1.25	1.4	1.25
1.5	1.0	1.5	1.85	1.5
2.0	1.0	2.0	2.8	2.0
≥2.5	1.0	2.5	4.0	2.5

NOTE –

a. A long-period component is taken as a component that has a fundamental period, T_p, greater than $T_{p,long}$, where $T_{p,long}$ is defined in 8.2.

SLS2

$\mu_p \leq 1.25 \;\therefore C_{ph} \leq 1.4$

$\Omega_p = 1$

ULS

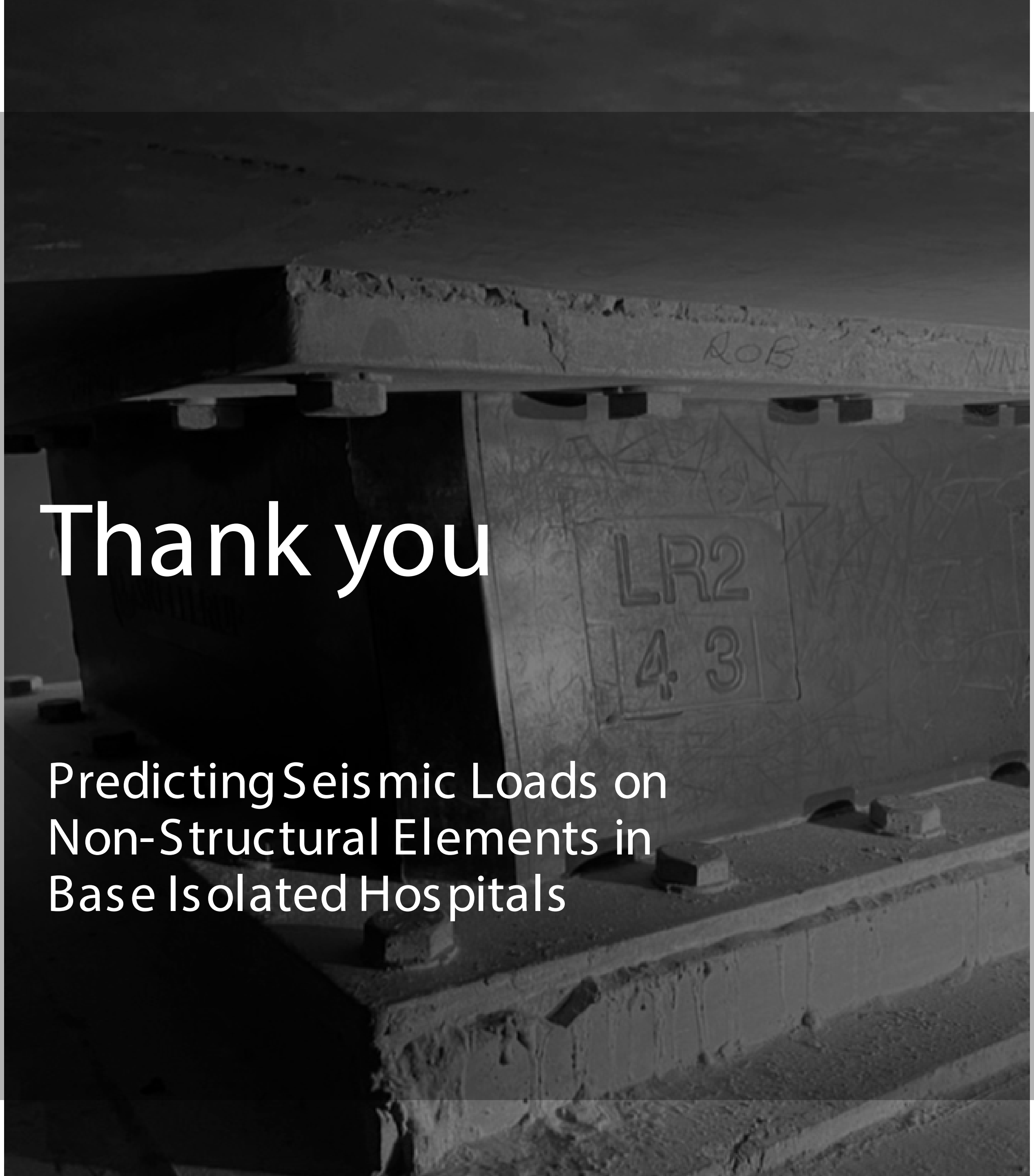
$\mu_p \geq 1.25 \;\therefore C_{ph} \geq 1.4$

for all but the most brittle

$\Omega_p = 1.5$

If PFAs are similar, ULS are smaller by at least 1/1.5, likely more

SLS2 assumptions may be over conservative. More work needed.



Thank you

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