



Comparative Seismic Response of a Hospital Building Equipped with Lead Rubber and Friction Pendulum Bearings

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Abstract

Hospitals in active seismic regions must maintain structural safety and operational continuity after strong earthquakes. This study compares the seismic response of the Anutapura Medical Center hospital building in Palu using three support configurations: a conventional fixed base, lead rubber bearings (LRBs), and friction pendulum bearings (FPBs). A three-dimensional structural model was developed in ETABS using the as-built geometry, material properties, gravity loads, and seismic parameters prescribed by Indonesian standards. The isolated models incorporated nonlinear bearing properties obtained from the isolator design and numerical characterization. Fundamental period, lateral displacement, interstory drift ratio, horizontal seismic force, and base shear were used as comparative indicators. The fixed-base fundamental period of 1.528 s increased to 2.869 s with LRB and 2.588 s with FPB. At the base level, LRB reduced the base shear by 60.51% in the X direction and 60.89% in the Y direction, whereas FPB achieved reductions of 55.25% and 55.97%, respectively. FPB produced the smaller roof displacement, with reductions of 17.98% in X and 22.50% in Y relative to the fixed-base model; the corresponding LRB reductions were 14.44% and 17.18%. The results indicate a clear performance trade-off: LRB is preferable when reducing seismic force demand is the governing objective, while FPB provides better displacement control. These findings support performance-based selection of isolation systems for essential facilities in high-seismicity areas.

Keywords: Base isolation; Friction pendulum bearing; Hospital building; Lead rubber bearing; Seismic response

1. Introduction

Indonesia is located at the convergence of major tectonic plates and contains numerous active faults. Palu is particularly vulnerable because the city is crossed by the Palu-Koro fault system. The 2018 Sulawesi earthquake caused severe structural and geotechnical damage, including extensive damage to health-care facilities. The reconstruction of the Anutapura Medical Center therefore requires a structural protection strategy that limits both force demand and deformation while preserving the functionality of an essential facility.

Conventional earthquake-resistant design relies on strength, ductility, and controlled inelastic deformation of the superstructure. For hospitals, however, structural survival alone is insufficient because medical equipment, ceilings, partitions, utility lines, and emergency services should remain usable. Seismic isolation addresses this requirement by introducing a flexible and energy-dissipating interface between the foundation and superstructure. Period elongation shifts the dominant structural response away from the high-acceleration region of the design spectrum, while hysteretic or frictional mechanisms dissipate part of the input energy [1]-[4].

Lead rubber bearings combine laminated rubber layers, steel shims, and a lead core. The rubber provides horizontal flexibility and recentering, the steel laminations provide vertical stiffness, and the lead core yields

under cyclic motion to dissipate energy. Friction pendulum bearings use sliding on a concave surface; the curvature provides a gravity-based restoring force, while interface friction dissipates energy. Because these devices rely on different mechanisms, their relative effectiveness depends on the selected stiffness, yield force, friction coefficient, curvature radius, displacement demand, and characteristics of the protected structure [5]-[9].

Previous studies have generally shown that seismic isolation increases the fundamental period and reduces the seismic force transferred to the superstructure. Nevertheless, published comparisons do not identify a universally superior device. Some studies report that friction pendulum systems provide lower displacement or improved energy dissipation, while others show that elastomeric systems achieve greater base-shear reduction for a particular building and hazard level [10]-[15]. This variation indicates that device selection should be based on a consistent comparison for the actual structural system and site conditions rather than on generic assumptions.

The present study evaluates a five-story hospital building with a semi-basement isolation level in Palu. The contribution is a direct, project-based comparison of fixed-base, LRB-isolated, and FPB-isolated configurations using the same building geometry and seismic environment. The paper focuses on global structural indicators suitable for practical design decision-making: fundamental period, lateral displacement, horizontal seismic force, and base shear. Detailed isolator-level finite-element modelling is reserved for a separate study, thereby keeping the current paper focused on structural response and practical selection of the isolation system.

2. Method

2.1. Building description and modelling framework

The case-study structure is the Anutapura Medical Center hospital building located on Kangkung Street, Palu, Central Sulawesi. The building comprises five occupied stories, a reinforced-concrete roof deck, and a semi-basement level used for the isolation devices. The roof elevation is approximately +26.10 m. The structural geometry and member arrangement were established from the project as-built documents. The building was modelled as a three-dimensional reinforced-concrete moment-resisting system with floor diaphragms and the mass contribution of structural components, permanent nonstructural loads, and applicable live loads.

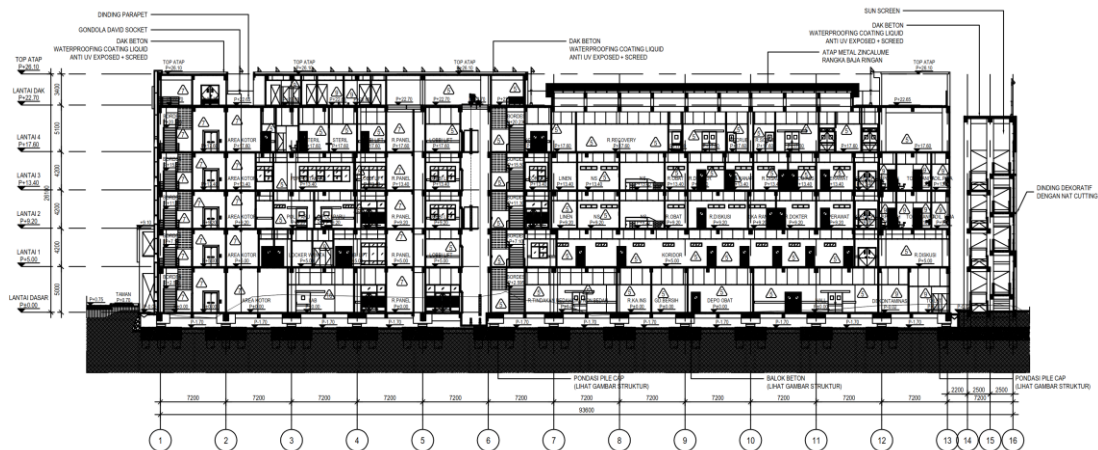


Figure 1. Longitudinal section of the Anutapura Medical Center hospital building

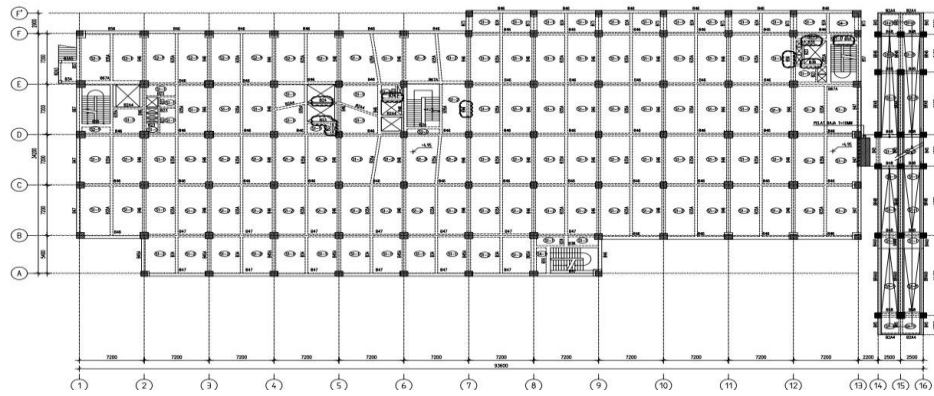


Figure 2. Structural plan of the Anutapura Medical Center hospital building

Three numerical configurations were prepared: Model FB with fixed supports at the base, Model LRB with lead rubber bearings at the isolation interface, and Model FPB with friction pendulum bearings at the same support locations. This modelling strategy ensured that differences in response were caused primarily by the support system. The overall workflow is presented in Figure 3.

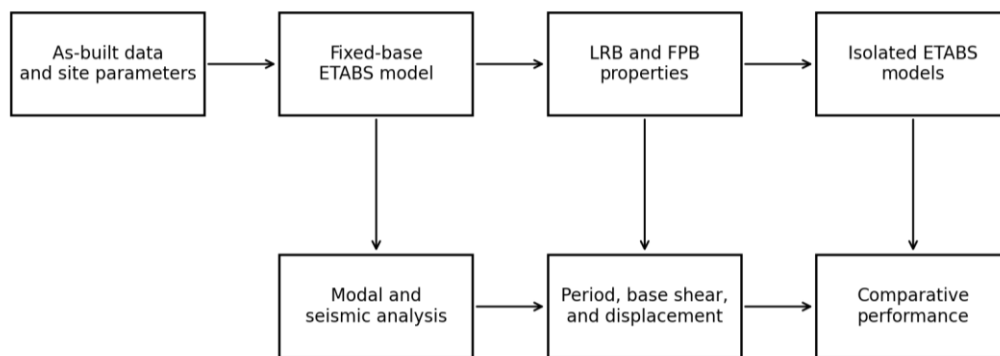


Figure 3. Structural modelling and comparative evaluation workflow

2.2. Design standards and seismic input

The structural and seismic calculations followed SNI 1726:2019 for earthquake-resistant design, SNI 1727:2020 for minimum design loads, SNI 2847:2019 for reinforced concrete, SNI 1729:2020 for structural steel components, SNI 8460:2017 for geotechnical design, and BS EN 15129:2018 for anti-seismic devices. The hospital was treated as an essential facility with the corresponding importance requirements. Site parameters were developed from the project geotechnical information and the Palu design spectrum. From the CPTu data that has been carried out, it can be seen that the land at the RSAP site is included in the SF site class (special land), this is due to the potential for medium-level liquefaction, from the average N-SPT calculation it is included in soft soil (SE site class). The isolated-structure spectrum and time-history inputs were adjusted to represent the longer-period response of the isolation system.

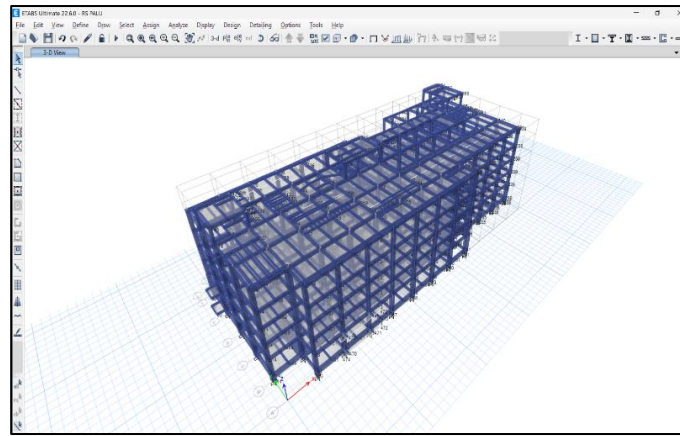


Figure 4. Fix Base ETABS 3D modeling

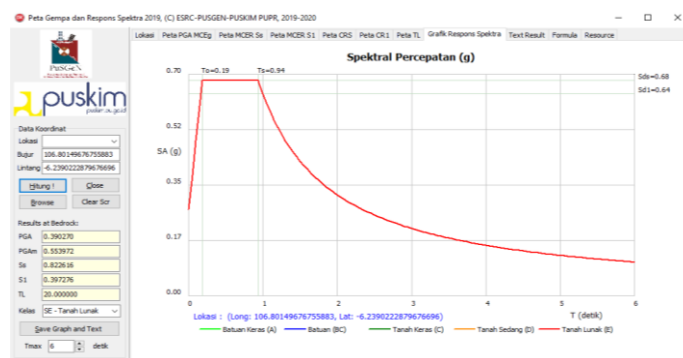


Figure 5. Response Spectrum of the Palu Earthquake ESRC-PUSGEN-PUSKIM PUPR

The database includes eleven earthquake records representing a range of strong-motion characteristics, including Borrego Mountain, El Mayor, Imperial Valley, Irpinia, Kern County, Kobe, Landers, Niigata, San Francisco, St. Elias, and Tabas records. Spectral compatibility and scaling were checked against the target spectrum used for the project. The comparative response values reported in this paper are the governing design outputs from the calibrated structural models.

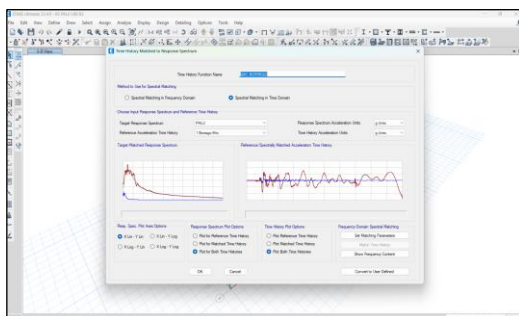


Figure 6. Spring Model of Borrego Mtn Earthquake, El Centro Array of the 1968

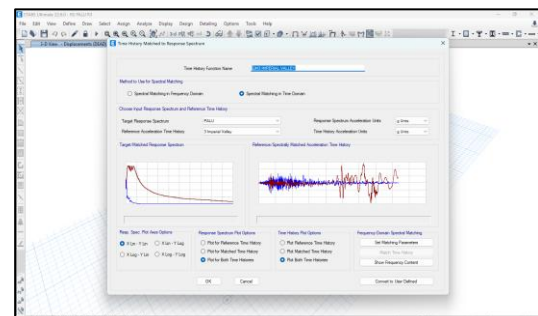


Figure 8. Spring Model of Imperial Valley Earthquake, El Centro Array of the 1938

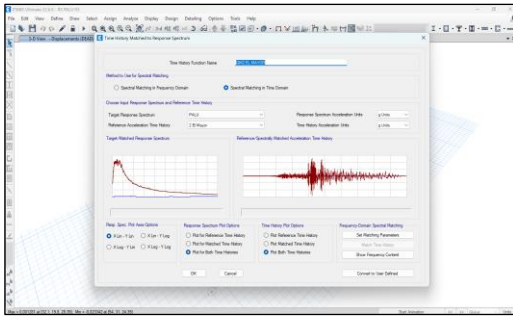


Figure 7. Spring Model of El Mayor Eartquake, Chihuahua of the 2010

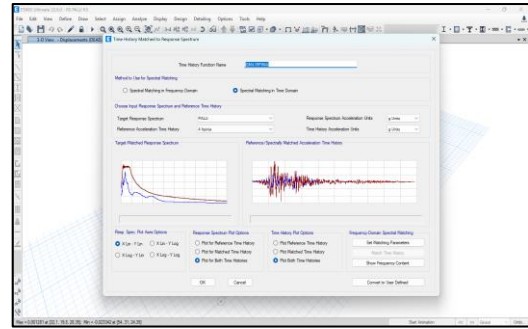


Figure 9. Spring Model of Irpinia Eartquake, Arienzo of the 1980

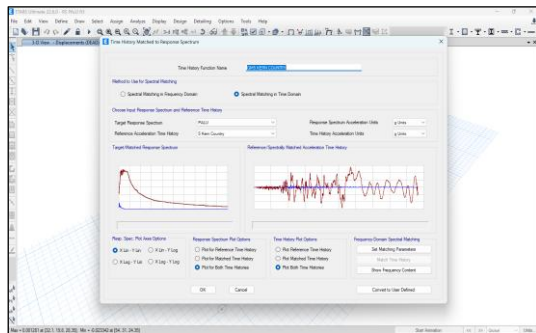


Figure 10. Spring Model of Kern Country Eartquake, LA Hollywood Stor of the 1952

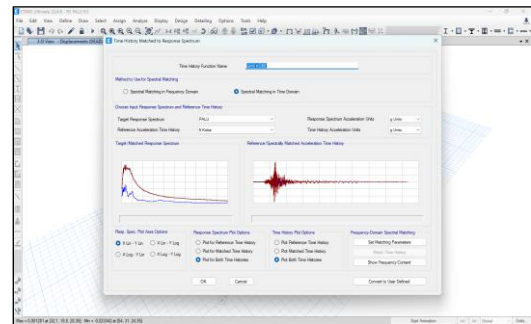


Figure 11. Spring Model of Kobe Eartquake, Abeno of the 1995

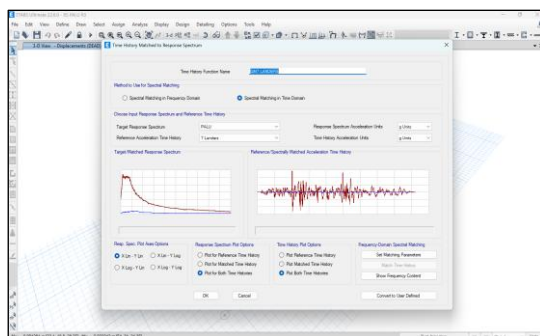


Figure 12. Spring Model of Landers Eartquake, El Centro Array of the 1992

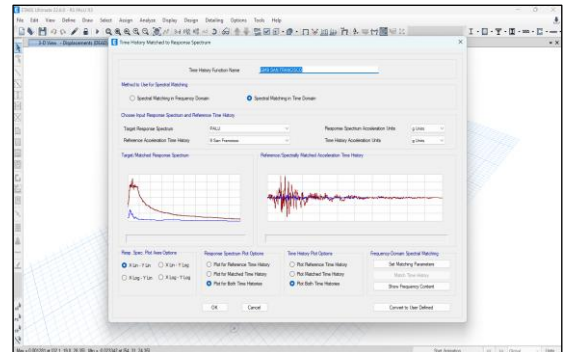


Figure 14. Spring Model of San Fransisco Eartquake, Golden Gate Park of the 1957

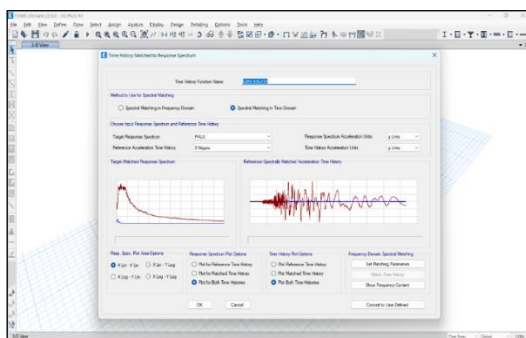


Figure 13. Spring Model of Niigata Eartquake, FKS020 of the 2004

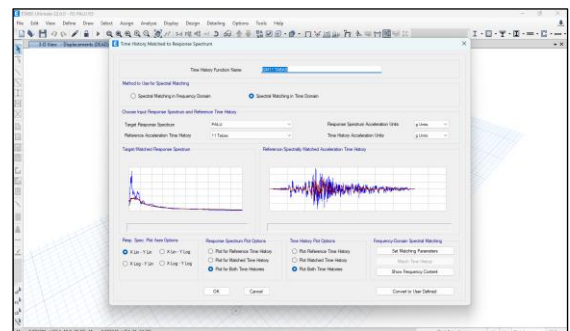


Figure 14. Spring Model of Tabas Eartquake, Bajestan of the 1978

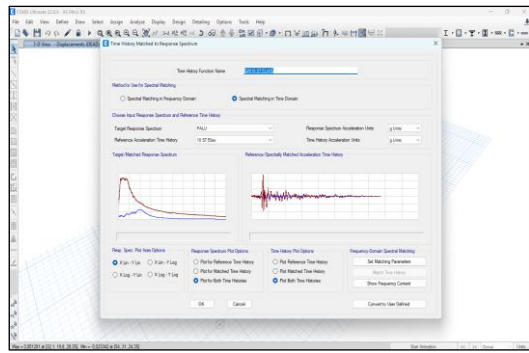


Figure 14. Spring Model of ST Elias Earthquake, Icy Bay of the 1979

Table 1. Time history of earthquake recordings

No.	Record ID	Earthquake	Year	Station	Magnitude (Mw)
1	GM1	Borrego Mountain	1968	El Centro Array #9	6.63
2	GM2	El Mayor	2010	Chihuahua	7.20
3	GM3	Imperial Valley	1938	El Centro Array #9	5.00
4	GM4	Irinia	1980	Arienza	6.90
5	GM5	Kern County	1952	LA-Hollywood Stor FF	7.36
6	GM6	Kobe	1995	Abeno	6.90
7	GM7	Landers	1992	Amboy	7.28
8	GM8	Niigata	2004	FKS 020	6.63
9	GM9	San Francisco	1957	Golden Gate Park	5.28
10	GM10	St. Elias	1979	Icy Bay	7.54
11	GM11	Tabas	1978	Bajestan	7.35

2.3. Isolation-system representation

The LRB A (LRB-S 856x240 Ex.Freyssinet) and LRB B (LRB-S 900x240 Ex.Freyssinet) was represented by a nonlinear bilinear link characterized by initial stiffness, post-yield stiffness, yield force, effective stiffness, and equivalent damping. Two bearing capacities were assigned according to the support reactions and placement plan. The FPB A (FPB 1118x203 Ex.Freyssinet) and FPB B (FPB 1564x284 Ex.Freyssinet) was represented by a friction-pendulum link incorporating the restoring stiffness associated with the concave radius and the sliding resistance associated with the friction coefficient. The vertical bearing stiffness was maintained sufficiently high to transfer gravity loads while permitting the intended horizontal isolation motion.

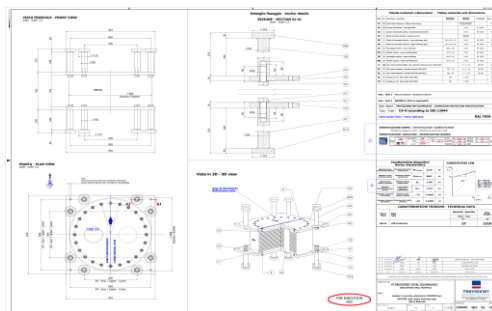


Figure 15. LRB-A (856x240 Ex. Freyssinet)

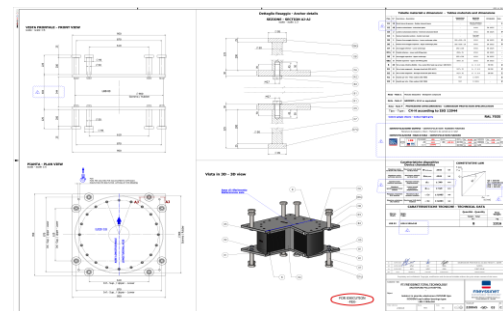


Figure 16. LRB-B (900x240 Ex. Freyssinet)

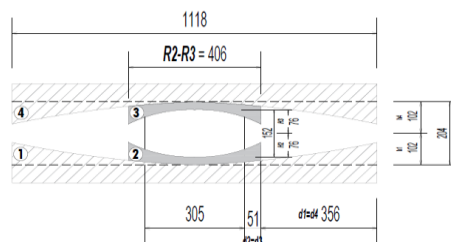


Figure 17. FPB-A (1118x203 Ex. Freyssinet)

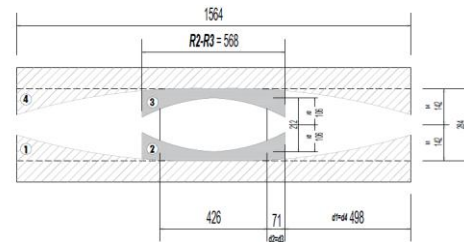


Figure 18. FPB-B (1564x284 Ex. Freyssinet)

For both device types, isolator properties were verified against the design calculations and separate finite-element simulations. The device models were then assigned at the semi-basement isolation level. Modal analysis was conducted first to verify the translational modes and quantify period elongation. Seismic analyses were subsequently performed to obtain floor displacement and force distributions in both principal directions.

2.4. Response indicators

The fundamental period was used to quantify the flexibility introduced by each isolation system. Base shear was taken at the bottom of the isolation or support level and used as the principal force-demand indicator. Floor displacement profiles were extracted at the diaphragm centre of mass. Reduction ratios were calculated relative to the fixed-base model using Eq. (1), where R is the percentage reduction, Q_{FB} is the fixed-base response, and Q_{ISO} is the isolated response.

$$R = (Q_{FB} - Q_{ISO}) / Q_{FB} \times 100\% \quad (1)$$

Table 2. Numerical configurations used in the comparative analysis.

Configuration	Support idealization	Principal mechanism	Primary evaluated response
Fixed base	Restrained base	Conventional structural resistance	Reference period, force, and displacement
LRB	Nonlinear bilinear bearing	Rubber recentering and lead-core yielding	Period elongation and force reduction
FPB	Nonlinear sliding bearing	Pendulum restoring force and friction	Period elongation and displacement control

3. Results and Discussion

3.1. Fundamental period

The first-mode period of the fixed-base building was 1.528 s. Installing LRB increased the period to 2.869 s, whereas FPB increased it to 2.588 s, as shown in Figure 2. Relative to the fixed-base condition, the period increased by 87.76% with LRB and 69.37% with FPB. This result confirms that both isolation systems decoupled the superstructure from the ground motion, but the LRB configuration provided the more flexible effective support system for the selected device properties.

Period elongation is a principal source of isolation efficiency because it generally reduces the spectral acceleration transmitted to the superstructure. However, a longer period is not by itself sufficient to identify the better device. Excessive flexibility may increase isolator displacement and seismic-gap demand. Therefore, the period results were evaluated together with the force and displacement responses.

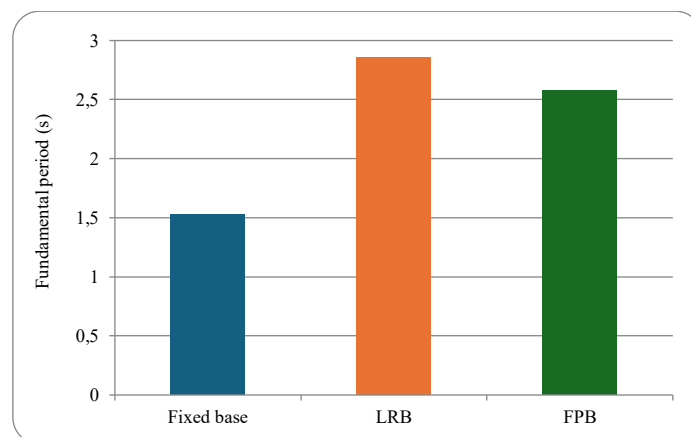


Figure 19. Fundamental period of the fixed-base, LRB, and FPB models.

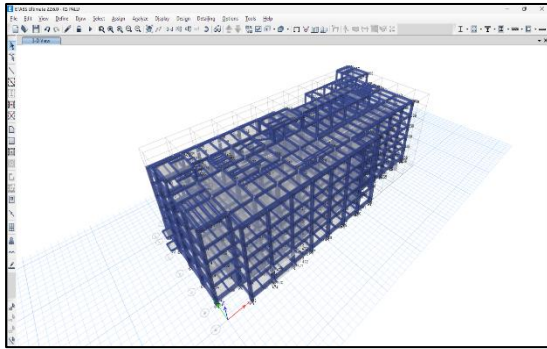


Figure 20. Fix Base ETABS 3D modeling

FIX BASE														
TABLE: Modal Participating Mass Ratios														
Case	Mode	Period	UX	UY	UZ	SumUX	SumUY	SumUZ	RX	RY	RZ	SumRX	SumRY	SumRZ
		sec												
Modal	1	1.528	0.6258	0.0001	0	0.6258	0.0001	0	0.0001	0.3711	0.0045	0.0001	0.3711	0.0045
Modal	2	1.489	0.0003	0.6153	0	0.6261	0.6153	0	0.3768	0.0002	0.0091	0.3768	0.0002	0.0091
Modal	3	1.378	0.0049	0.0096	0	0.631	0.6249	0	0.0034	0.0022	0.6162	0.3802	0.3735	0.6299
Modal	4	0.472	0.0089	8.54E-06	0	0.729	0.6249	0	2.51E-05	0.1963	0.0033	0.3802	0.5698	0.6332
Modal	5	0.465	9.82E-07	0.1033	0	0.729	0.7282	0	0.1903	1.28E-06	0.0015	0.5705	0.5698	0.6347
Modal	6	0.434	0.0031	0.0006	0	0.7321	0.7288	0	0.0015	0.0062	0.0999	0.572	0.576	0.7346
Modal	7	0.287	0.0001	0.0087	0	0.7322	0.7375	0	0.0067	0.0001	7.46E-06	0.5787	0.5761	0.7346
Modal	8	0.284	0.011	7.01E-06	0	0.7432	0.7375	0	5.79E-06	0.0093	0.0003	0.5787	0.5854	0.7349
Modal	9	0.268	0.0102	4.27E-05	0	0.7535	0.7376	0	3.05E-05	0.0074	0.0002	0.5787	0.5928	0.7369
Modal	10	0.249	0.0001	0.0232	0	0.7536	0.7608	0	0.0183	0.0001	0.001	0.5971	0.5929	0.7379
Modal	11	0.246	0.007	0.0003	0	0.7605	0.7611	0	0.0002	0.0039	0.0009	0.5973	0.5968	0.7388
Modal	12	0.243	0.0009	0.0035	0	0.7614	0.7646	0	0.0022	0.0006	0.0299	0.5995	0.5974	0.7688
Modal	13	0.208	0.0064	0.0019	0	0.7678	0.7665	0	0.0018	0.0065	0.0026	0.6013	0.6038	0.7714
Modal	14	0.206	0.0146	0.0007	0	0.7824	0.7672	0	0.0007	0.0147	0.0001	0.602	0.6185	0.7715
Modal	15	0.205	4.08E-05	0.0001	0	0.7825	0.7673	0	0.0001	0.0001	4.71E-05	0.6022	0.6186	0.7716
Modal	16	0.198	0.0033	0.0006	0	0.7858	0.7679	0	0.0007	0.0037	0.0009	0.6028	0.6223	0.7725
Modal	17	0.193	0.0001	0.0171	0	0.7859	0.785	0	0.0189	0.0001	0.0012	0.6216	0.6224	0.7737
Modal	18	0.176	0.0002	0.0004	0	0.7862	0.7854	0	0.0004	0.0003	0.0195	0.6222	0.6227	0.7832
Modal	19	0.13	0.0247	0.0003	0	0.8108	0.7856	0	0.0004	0.0369	0.0002	0.6236	0.6597	0.7834
Modal	20	0.128	0.0004	0.0219	0	0.8112	0.8075	0	0.0313	0.0007	0.0028	0.6539	0.6603	0.7961
Modal	21	0.115	2.7E-05	0.0038	0	0.8113	0.8114	0	0.0059	0.0001	0.0217	0.6598	0.6604	0.8178
Modal	22	0.086	0.0098	0.0012	0	0.8211	0.8125	0	0.0018	0.0149	0.0004	0.6616	0.6753	0.8182
Modal	23	0.086	0.0014	0.0084	0	0.8225	0.8209	0	0.0127	0.0021	0.0024	0.6742	0.6774	0.8205
Modal	24	0.076	2.28E-06	0.0023	0	0.8225	0.8232	0	0.0036	2.66E-06	0.008	0.6779	0.6774	0.8285
Modal	25	0.049	0.177	4.52E-05	0	0.9995	0.8232	0	0.0001	0.3216	0.0004	0.6779	0.9991	0.8289
Modal	26	0.046	0.0001	0.1715	0	0.9996	0.9947	0	0.3124	0.0002	0.0043	0.9904	0.9993	0.8333

Fundamental Period = 1.528 sec
 Mode 1 translation in UX 0.6258
 Mode 2 translation in UY 0.6153
 Mode 3 rotation in Z 0.6162
 Modal Check
 Max number of modes 12
 Sum UX 99% OK
 Sum UY 99% OK
 OK meet the requirements

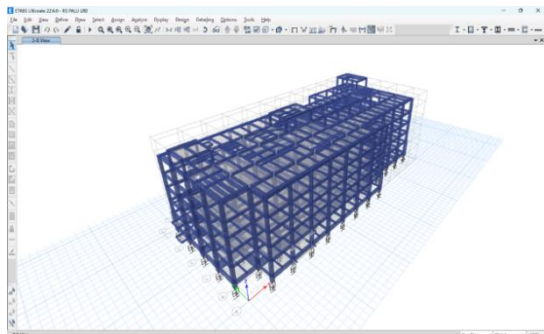


Figure 21. LRB ETABS 3D modeling

LRB															
TABLE: Modal Participating Mass Ratios															
Case	Mode	Period sec	UX	UY	UZ	SumUX	SumUY	SumUZ	RX	RY	RZ	SumRX	SumRY	SumRZ	Keterangan
Modal	1	2.869	0.975	0.0016	0	0.975	0.0016	0	3.36E-05	0.0204	0.0024	3.36E-05	0.0204	0.0024	Translasi OK
Modal	2	2.85	0.0034	0.7875	0	0.9794	0.7891	0	0.0144	4.38E-05	0.1927	0.0145	0.0204	0.1951	Translasi OK
Modal	3	2.758	0.0007	0.1942	0	0.9793	0.9833	0	0.002	0	0.7899	0.0165	0.0204	0.985	Rotasi OK
Modal	4	0.825	0.0198	1.05E-05	0	0.9989	0.9833	0	0.0007	0.9602	0.0004	0.0172	0.9707	0.9853	
Modal	5	0.782	0.0001	0.014	0	0.9989	0.9973	0	0.8568	0.0046	0.0017	0.8741	0.9752	0.9871	
Modal	6	0.743	0.0002	0.0019	0	0.9993	0.9992	0	0.1141	0.0113	0.0122	0.9882	0.9986	0.9993	
Modal	7	0.39	0.0008	0	0	0.9999	0.9992	0	0	0.0025	3.14E-05	0.9892	0.989	0.9993	
Modal	8	0.369	0	0.0007	0	0.9999	0.9999	0	0.0028	0	2.52E-06	0.9909	0.989	0.9993	
Modal	9	0.352	1.74E-05	6.57E-07	0	0.9999	0.9999	0	1.7E-05	0.0001	0.0006	0.9909	0.9892	0.9999	
Modal	10	0.272	1.91E-05	0	0	0.9999	0.9999	0	7.71E-07	0.0009	0	0.9909	0.9901	0.9999	
Modal	11	0.258	0	1.88E-05	0	0.9999	0.9999	0	0.0013	3.02E-05	0	0.9922	0.9901	0.9999	
Modal	12	0.257	2.85E-05	0	0	0.9999	0.9999	0	4.31E-06	0.0022	3.44E-06	0.9922	0.9923	0.9999	SUM UX & SUM UY > 90% OK

Fundamental Period = 2.869 sec
 Mode 1 translation in UX 0.975
 Mode 2 translation in UY 0.7875
 Mode 3 rotation in Z 0.7899
 Modal Check
 Max number of modes 12
 Sum UX 99% OK
 Sum UY 99% OK
 OK meet the requirements

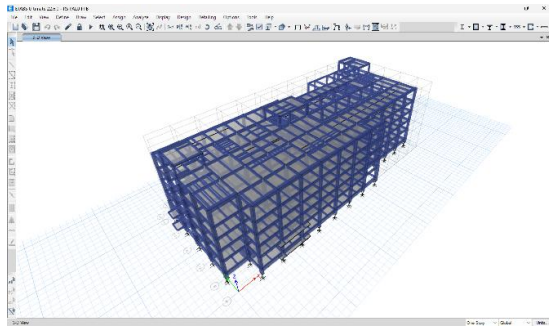


Figure 22. FPB ETABS 3D modeling

Case	Mode	Period	UX	UY	UZ	SumUX	SumUY	SumUZ	RX	RY	RZ	SumRX	SumRY	SumRZ	Keterangan
		sec													
Modal	1	2.588	0.9669	0.0006	0	0.9999	0.0006	0	1.57E-05	0.0312	0.0006	1.57E-05	0.0312	0.0006	Translasi OK
Modal	2	2.555	0.001	0.8174	0	0.9679	0.818	0	0.0217	0.001	0.1569	0.0217	0.0312	0.1575	Translasi OK
Modal	3	2.432	0.0001	0.1575	0	0.988	0.9755	0	0.0024	0.001	0.8186	0.0241	0.0313	0.9762	Rotasi OK
Modal	4	0.798	0.0302	1.43E-05	0	0.9982	0.9755	0	0.0006	0.9429	0.0004	0.0248	0.9742	0.9766	
Modal	5	0.753	0.0001	0.0193	0	0.9983	0.9948	0	0.8012	0.0038	0.0039	0.826	0.978	0.9805	
Modal	6	0.712	0.0001	0.0038	0	0.9984	0.9987	0	0.1591	0.0058	0.0182	0.9851	0.9838	0.9887	
Modal	7	0.388	0.0014	0	0	0.9999	0.9987	0	6.76E-07	0.004	0.0001	0.9851	0.9878	0.9988	
Modal	8	0.367	0	0.0012	0	0.9998	0.9998	0	0.0043	0	4.08E-06	0.9894	0.9878	0.9988	
Modal	9	0.35	2.58E-05	2.48E-06	0	0.9998	0.9998	0	9.29E-06	0.0001	0.0011	0.9894	0.9879	0.9988	
Modal	10	0.271	3.33E-06	0	0	0.9999	0.9998	0	7.94E-07	0.0011	0	0.9894	0.989	0.9988	
Modal	11	0.258	5.28E-07	3.27E-05	0	0.9999	0.9999	0	0.0014	2.42E-05	5.33E-07	0.9908	0.989	0.9988	
Modal	12	0.256	0.0001	0	0	0.9999	0.9999	0	1.58E-06	0.0026	6.84E-06	0.9908	0.9905	0.9999	SUM UX & SUM UY > 90% OK

Fundamental Period = 2.588 sec
 Mode 1 translation in UX 0.9669
 Mode 2 translation in UY 0.8174
 Mode 3 rotation in Z 0.8186
 Modal Check
 Max number of modes 12
 Sum UX 99% OK
 Sum UY 99% OK
 OK meet the requirements

Table 3. Fundamental-period comparison

Model	Fundamental period (s)	Increase relative to fixed base (%)
Fixed base	1.528	-
LRB	2.869	87.76
FPB	2.588	69.37

3.2. Base-shear response

The fixed-base model developed base shears of 1491.823 tonf and 1511.477 tonf in the X and Y directions, respectively. The LRB system reduced these values to 589.019 tonf in X and 591.070 tonf in Y. The corresponding FPB values were 667.530 tonf and 665.545 tonf. Thus, LRB reduced base shear by 60.51% in X and 60.89% in Y, whereas FPB reduced it by 55.25% and 55.97%. The results in Figure 23 show that both systems substantially reduced the force transferred to the superstructure, with LRB producing an additional reduction of approximately five percentage points.

The stronger force reduction of LRB is consistent with its longer effective period and the selected bilinear hysteretic properties. The lead core yields and dissipates energy during cyclic motion, while the rubber layers provide stable recentering. The FPB also dissipates energy through sliding friction; however, its larger effective stiffness for the adopted curvature and friction parameters resulted in a somewhat higher base shear. This comparison should not be generalized to all devices because the relative response can change when lead-core diameter, rubber shear modulus, friction coefficient, or curvature radius is modified.

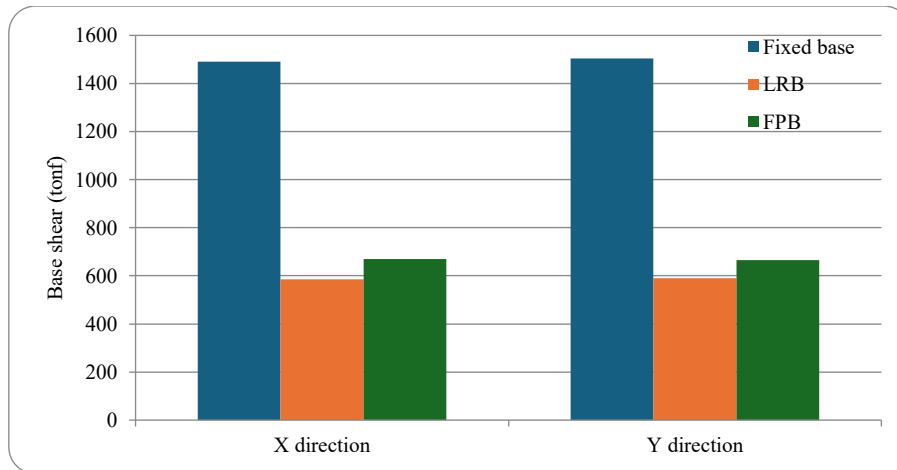


Figure 23. Base shear in the principal directions.

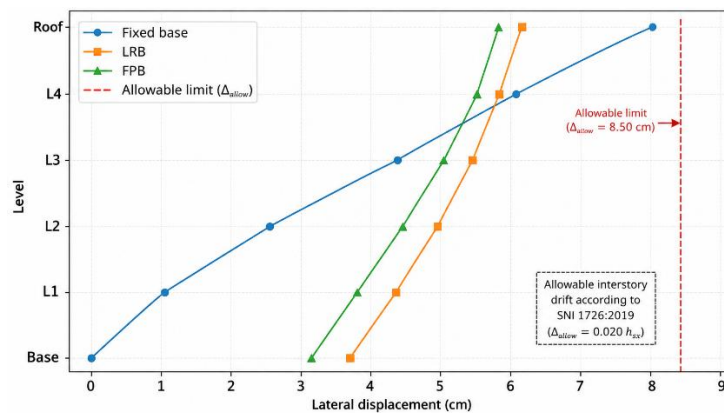
Table 4. Base-shear comparison and reduction ratios

Direction	Fixed base (tonf)	LRB (tonf)	FPB (tonf)	LRB reduction (%)	FPB reduction (%)
X	1491.823	589.019	667.530	60.51	55.25
Y	1511.477	591.070	665.545	60.89	55.97

3.3. Lateral displacement response

The floor displacement profiles are shown in Figures 24 and 25. In the fixed-base model, displacement accumulated gradually from the base to the roof, reaching 7.984 cm in X and 7.955 cm in Y. The isolated models exhibited a large displacement at the isolation level followed by a flatter superstructure profile, which indicates that the upper building moved more nearly as a rigid body. This is the expected kinematic behaviour of a properly isolated building: deformation is concentrated in the isolation interface, while story-to-story distortion in the superstructure is reduced.

At the roof, LRB produced displacements of 6.831 cm in X and 6.589 cm in Y, corresponding to reductions of 14.44% and 17.18% from the fixed-base response. FPB produced the smaller roof displacements of 6.548 cm and 6.165 cm, corresponding to reductions of 17.98% and 22.50%. The FPB system therefore provided better global displacement control for the adopted parameters. The difference was more pronounced in the Y direction, where the FPB roof response was approximately 6.4% lower than the LRB response.



Note: The allowable interstory drift limit (Δ_{allow}) is calculated in accordance with SNI 1726:2019, where $\Delta_{allow} = 0.020 \times h_{story}$. For this building, $\Delta_{allow} = 8.50$ cm.

Figure 24. Floor displacement profiles in the X direction.

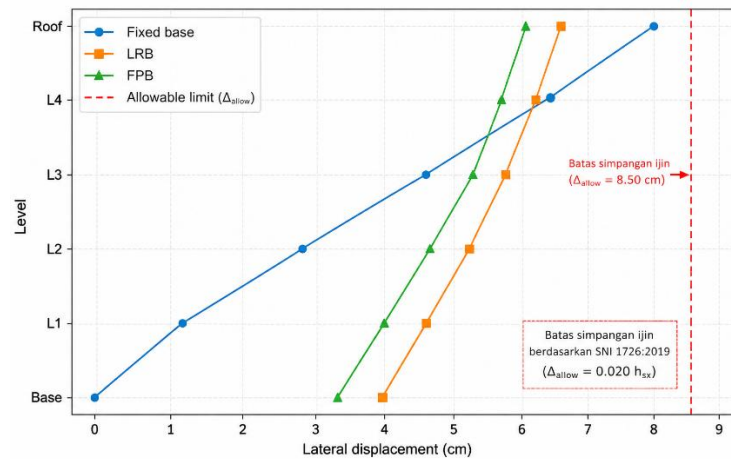


Figure 25. Floor displacement profiles in the Y direction.

Table 5. Roof-displacement comparison

Direction	Fixed-base roof (cm)	LRB roof (cm)	FPB roof (cm)	LRB reduction (%)	FPB reduction (%)
X	7.9838	6.8309	6.5484	14.44	17.98
Y	7.9551	6.5886	6.1652	17.18	22.50

3.4. Distribution of seismic force over the building height

The isolation systems reduced force demand over the full building height rather than only at the base. In the X direction, the shear at Level 4 decreased from 809.921 tonf for the fixed-base model to 218.237 tonf with LRB and 260.461 tonf with FPB. In the Y direction, the corresponding values were 827.205, 213.297, and 248.794 tonf. Similar reductions occurred at the roof and intermediate floors. This reduction is important for a hospital because lower story forces reduce the demand on columns, walls, beams, diaphragms, and connections, and may also reduce acceleration-sensitive nonstructural demand.

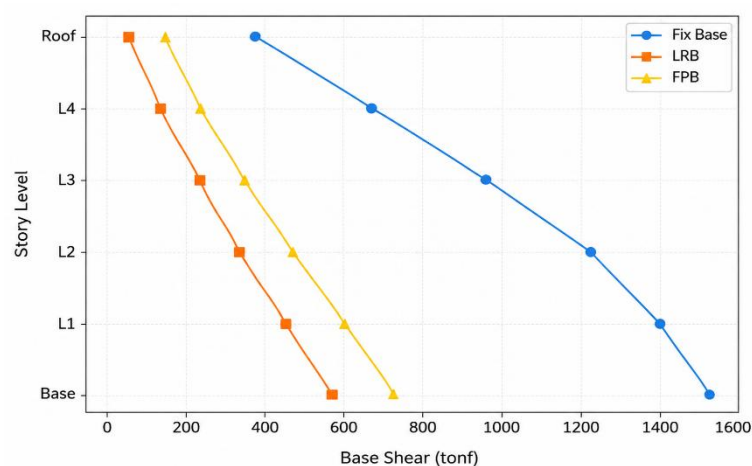


Figure 26. Floor shear force profiles in the X direction.

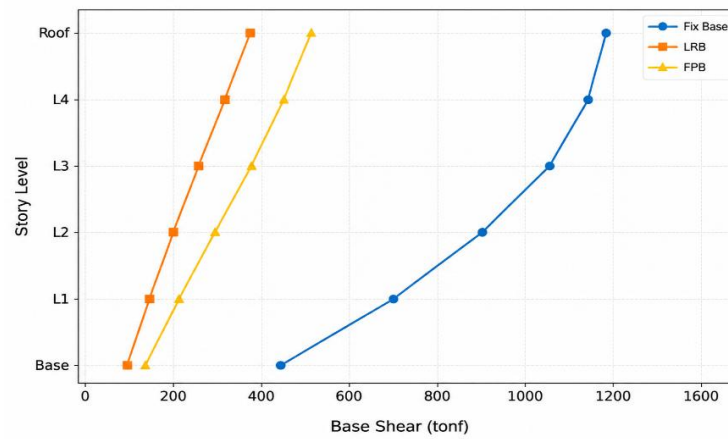


Figure 27. Floor shear force profiles in the Y direction.

Table 6. Story-shear distribution (tonf)

Level	Fixed base X	LRB X	FPB X	Fixed base Y	LRB Y	FPB Y
Penthouse	88.315	12.174	15.006	88.824	11.770	14.007
Roof	460.238	101.107	122.651	474.223	98.502	116.224
Level 4	809.921	218.237	260.461	827.205	213.297	248.794
Level 3	1053.992	313.101	368.429	1075.507	307.993	356.068
Level 2	1265.229	399.783	463.613	1289.168	396.394	454.316
Level 1	1406.711	480.644	550.568	1431.608	479.885	545.480
Isolation/Base	1491.823	589.019	667.530	1511.477	591.070	665.545

3.5. Comparative performance and device-selection implications

The comparison reveals a meaningful trade-off. LRB generated the longest period and the lowest base shear, while FPB generated the lowest roof displacement. Consequently, device selection depends on the governing performance objective. If the design is controlled by force demand in the superstructure or foundation, the LRB configuration is preferable. If displacement, clearance, or drift control is more critical, the FPB configuration offers an advantage. For the AMC hospital, both criteria are important because the structure must protect both load-bearing and nonstructural systems.

The results also demonstrate why a device should not be selected solely from generic claims about its mechanism. The actual response depends on the numerical values assigned to effective stiffness, yield strength, friction, and curvature. A stiffer FPB may limit displacement but transmit a larger force; a softer LRB may reduce force but require a larger isolation movement. A rational design should therefore evaluate at least base shear, isolation displacement, superstructure drift, floor acceleration, recentering capability, stability under axial load, and seismic-gap demand.

The current paper uses the global response indicators available from the thesis. Several limitations should be recognized. First, the manuscript reports governing design responses rather than a probabilistic distribution over individual records. Second, peak floor acceleration and residual displacement were not included in the present comparison. Third, the conclusions apply to the AMC geometry, mass, and selected isolator properties; changing these parameters could reverse the relative ranking. These limitations do not invalidate the project-based comparison but define the scope within which the results should be interpreted.

Table 7. Performance-based interpretation of the isolation-system comparison.

Performance criterion	Preferred system	Technical basis from the present models
Maximum period elongation	LRB	2.869 s compared with 2.588 s for FPB
Minimum base shear	LRB	Approximately 60.5-60.9% reduction
Minimum roof displacement	FPB	Approximately 18.0-22.5% reduction
Balanced hospital application	Project-specific	Selection should include equipment acceleration and isolation-gap checks

3.6. Required engineering checks for implementation

Although the global analysis demonstrates substantial benefits, implementation of either isolation system requires a set of device- and building-level checks. The maximum displacement at the isolation interface should be compared with the design displacement and maximum considered earthquake displacement specified by the governing standard. The required seismic gap must include the isolator displacement, torsional amplification, construction tolerance, and potential movement of adjacent structures. Utility connections crossing the isolation plane, including water, medical gas, electrical, drainage, and communication lines, should be detailed with sufficient flexibility.

For LRB, the design should verify average compressive stress, maximum shear strain, combined compression and shear stability, buckling capacity, tensile demand, lead-core heating, and the effects of aging and temperature on rubber properties. The vertical load distribution among bearings should be checked under gravity and overturning combinations because changes in axial load influence lateral stiffness and stability. Prototype and production tests should confirm the characteristic strength, post-yield stiffness, effective stiffness, damping, and displacement capacity used in the analysis.

For FPB, the design should verify contact pressure, slider stability, friction variability, velocity and pressure dependence, recentering capacity, uplift, and displacement capacity. The coefficient of friction used in analysis should account for upper- and lower-bound properties rather than a single nominal value. The curvature radius and friction coefficient jointly determine the effective period and force transmitted to the superstructure; consequently, both parameters should be treated as design variables during optimization.

At the building level, the final evaluation should include peak floor acceleration and floor response spectra because acceleration-sensitive equipment is critical in hospitals. Residual displacement, pounding risk, diaphragm forces, collector actions, and the performance of stairs and ramps crossing the isolation interface should also be assessed. These checks complement the comparative results reported here and prevent selection based only on base shear or roof displacement.

Table 8. Additional verification required before implementation

Design level	LRB verification	FPB verification	Building-system verification
Service/operational	Rubber aging and vertical stiffness	Sliding surface condition and recentering	Utility flexibility and operational clearance
Design earthquake	Shear strain, compression, and hysteretic properties	Friction bounds, contact pressure, and displacement	Drift, floor acceleration, diaphragm forces

Maximum considered earthquake	Buckling, tension, and ultimate displacement	Uplift, stability, and ultimate travel	Pounding, residual offset, and seismic gap
Quality assurance	Prototype and production bearing tests	Prototype sliding and friction tests	Installation survey and inspection plan

3.7. Relation to previous studies

The trends obtained for the AMC building agree with the general conclusion of previous Indonesian studies that isolation increases the natural period and reduces story shear and superstructure deformation [5]-[18]. However, the relative ranking of LRB and FPB differs among studies. Research on bridges and light-rail structures has often reported greater reductions from friction-pendulum devices, whereas the present hospital model produced lower base shear with LRB. This difference is technically reasonable because bridge mass distribution, pier flexibility, bearing axial load, and selected friction parameters differ substantially from those of a medium-rise reinforced-concrete hospital.

The present results are also consistent with studies showing that isolated structures may have greater movement at the isolation level while developing a more uniform displacement profile over the superstructure. Therefore, comparisons should distinguish total displacement, isolation displacement, and interstory drift. Reporting only one of these quantities can lead to an incorrect conclusion about the effectiveness of an isolation system. In the AMC models, the shift of deformation toward the isolation plane is visible in the relatively flat floor-displacement profiles of both isolated configurations.

A practical contribution of this study is the simultaneous presentation of force and displacement criteria for the same project. The LRB system would be selected from a force-minimization perspective, while the FPB system would be selected from a displacement-minimization perspective. This explicitly demonstrates the need for a multi-criteria decision process. For an essential facility, the final weighting should reflect structural safety, protection of medical equipment, continuity of utilities, inspection and replacement requirements, procurement, and lifecycle cost.

Table 9. Comparison of the present findings with the general literature trend

Study emphasis	Common finding in prior studies	Finding for AMC hospital
Period	Isolation lengthens the structural period	LRB: +87.76%; FPB: +69.37%
Force demand	Isolation reduces base and story shear	LRB produced the lowest base shear
Deformation	Superstructure deformation generally decreases	FPB produced the lowest roof displacement
Device ranking	Dependent on structure and device parameters	No universal winner; criterion-dependent selection

4. Conclusions

The seismic response of the Anutapura Medical Center hospital building was evaluated for fixed-base, lead rubber bearing, and friction pendulum bearing support systems. Both isolation systems substantially modified the dynamic characteristics and reduced the demand transferred to the superstructure. LRB increased the fundamental period from 1.528 s to 2.869 s and reduced the base shear by 60.51% in the X direction and 60.89% in the Y direction. FPB increased the period to 2.588 s and reduced the base shear by 55.25% and 55.97%. In contrast, FPB provided the better displacement control, reducing roof displacement by 17.98% in X and 22.50% in Y, compared with 14.44% and 17.18% for LRB. The comparison therefore does not support a single universally superior device. For the selected hospital model, LRB is preferable when minimizing seismic force demand is the primary objective, whereas FPB is preferable when controlling displacement is

more important. Final selection for an essential facility should combine these results with isolator displacement capacity, seismic-gap requirements, floor acceleration, residual displacement, axial stability, maintenance, and lifecycle considerations.

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