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Performance of Elastomeric Base Isolated Medium-Rise Reinforced Concrete Building in High Seismic Region

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Abstract
High-risk natural catastrophes including earthquakes, floods, and landslides may result in fatalities, substantial economic losses, physical damage to already-existing structures. Damage to crucial facilities, such as hospitals, commercial buildings, and schools where the majority of people interact, may considerably demand the structural resilience against the possibility of seismic occurrences or exceeds. Due to its location above the plate boundary, Nepal may suffer catastrophic consequences if the integrity of its major systems breaks as a result of violent ground motion. So, it is imperative to build a robust main structure to continue providing services immediately following an earthquake. To determine the seismic performance of the isolation system in the Kathmandu Valley, a research of numerical finite element modeling of base isolation using nonlinear dynamic time history analysis, elastomeric rubber pad as an isolation system, has conducted. Moreover, the rubber pad base-isolation strategy is utilized to diminish or less transfer the input excitation to the superstructure by providing lateral flexibility. When employing the steel-laminated rubber bearing at the mid-height of the base column, it has been observed that the period is shifted by three times. When base-shear coefficient were 3.1 times lower than fixed base bare-frame, base-shear reduced by 50% as a result. It has been observed that the isolator or base-slab moved laterally during cyclic motion by more than 791 mm while considering ductility factor unity, which is larger than the anticipated roll-out displacement of 507 mm at MCE level excitation and a drift limit of more than permitted 2%. The location of the hinges, which are 284 mm more out of alignment due to greater flexibility, illustrates the effect that the residual displacement has on the structure. Therefore, it is advised to use an energy-dissipating dampers as a spring to return back its original position for the immediate function.

Keywords
Important Structure, Rubber Bearing Isolator, Nonlinear Time History, Response and Deformation, Immediate Occupancy

1. Introduction

At the point where the Indian Plate and the Eurasian Plate meet, Nepal is located in an area that is seismically active. There have already been several quakes here, all of varying sizes. As a result, buildings constructed there are extremely susceptible to earthquakes. Recently, many facilities were damaged by the 2015 Gorkha earthquake, and many lives were lost. Deaths were not brought on by earthquakes, but rather by the destruction of fragile structures during violent ground motion. This damage to essential services such as hospitals, banks, shopping complexes, colleges and schools, where most people interact, can undermine the demand for structural resistance to seismic hazards [1], as Nepal lies above a plate boundary that could have fatal consequences for its heartland, system and integrity; as a result, such a system may collapse under high seismic demand. The country is often exposed to seismic disasters, so there is a very important need to create a resilient basic structure (critical infrastructure) to provide service immediately after an earthquake. A basic isolation system could be the solution to the necessary flexibility-enhancing intervention.

In retrospect, several structures were built using foundation isolation, including Pasadena City Hall, San Francisco City Hall, the Salt Lake City and County Building, and LA City Hall, among others. Following the installation of isolation, it has been discovered that visco-elastic elements of various types below the ground floor level reduce base shear and regulate roof displacement of the structure during seismic excitation as the structure's natural period lengthens [2]. When it comes to the earthquake-resistant design of the structure, "Seismic performance of base-isolated commonly built medium rise building" is primarily a crucial thing to study and a long-anticipated concern for the public, the government, and other stakeholders. The institutional or commercial structure is where many people and their belongings are placed; in essence, a strong earthquake may have been set off there, causing great agony both during the day and at night. Urban, institutional, and commercial buildings are often built for use in everyday company operations and official delivery [1]. The term “Commonly build medium-rise building” was used in this study to refer to a type of medium-rise building that is typically used to house important infrastructure, such as a hospital, commercial bank, college, school, office for the government, or a telecommunications company.

Moreover, base isolation is a structural component that is often built at the bottom of the footing, below the base slab, which is immediately below the raft (mat) foundation and above the pile cap, if combination raft-pile is required for sandy soils and soft soil [3]. By enabling the deck to move laterally, a neoprene elastomeric Poly Tetra Fluro Ethylene (PTFE) rubber pad has traditionally been employed in the bridge system to reduce the live load effect to the pier. The performance of the neoprene elastomer and high damping rubber bearing (HDRB) base isolation is currently being studied by a large number of researchers [4] and other seismic resistant design experts [5] and professionals [6].

Therefore, numerous base-isolation methods are used in buildings and bridges [7]; the most common ones include neoprene elastomeric isolators, slide isolation systems, high damping rubber bearings, and friction pendulum isolators, among others. In this study, bearing isolators are employed at the mid-height of the foundation columns, and they are typically formed of steel-laminated elastomeric rubber and high damping rubber bearing. The system became more flexible and resilient for seismic interaction because the elastomer's capacity to move laterally and the qualities of rubber, where vertical stiffness and strength of the laminated steel plate-neoprene PTFEs; mostly utilized as a bearing pad in the buildings and bridges, are available in considerably better manufacturing quality (Sai Rubber Industry, New Delhi India, 2022).

2. Significance and Objective of Study

The recent devastating earthquake, 2015 Gorkha, 7.8 Mw, major shocks and aftershocks [8], destroyed the structural and non-structural components including building content of many medium-rise structures in hilly regions, particularly in the Kathmandu valley in Kuleshwor, Chabahil, and Samakhusi county. As a result, lateral displacement of semi-commercial buildings causes a tilting effect, significant damage to structural and non-structural components, particularly infill walls in medium-rise structures, and lateral displacement of non-structural components. The National Reconstruction Authorities and the National Planning Commission, Government of Nepal evaluated the damage to the structures after the 2015 Gorkha Earthquake and suggested that many semi-commercial buildings need to be modified [8, 1]. As a result, recently, government structures, educational facilities, and medical facilities have undergone renovations; three examples include Khesar Mahal, Supreme Court of Nepal and Singha-Darbar. Additionally, the cost of the retrofit is significantly higher than that of the standard isolation installations.

In addition, there is a 2 % possibility that the disaster may materialize or exceed the projected maximum earthquake that may take place in 2475 years. This implies that a catastrophe of this size might occur even years before the predicted date. Since technology is so important in today's world, most essential infrastructures must function in such conditions. The goals of this study are to swiftly ascertain the occupancy-based level of regularly built medium-rise reinforced concrete structure as well as to evaluate the seismic performance of base-isolated reinforced concrete building.

3. Methodology

The following subsections provide illustrations of the building's mass necessities for the isolation-design, acceptance standards, and the utilized systematic procedure.

3.1 Building Weight (Lumped mass)

Table 1: Lumped Story Mass of 7 Stories Reinforced Concrete Building including Lower Basement in Gravity Direction

S.N	Story	Uz	S.N	Story	Uz
9	Top	46767.91	4	2nd	455851.1
8	6th	324743.1	3	1st	456631.7
7	5th	449951.6	2	GF	508848.3
6	4th	452072	1	Basement -1	1078262
5	3rd	454444.8		Total	4227572

The weight of 1078262 Kg was added to the superstructure's mass of 3149310 Kg to get the 4227572 Kg total mass of the isolated building [Table 1]. The parameters of high damping rubber or elastomeric rubber have been determined based on total mass, structural arrangement, hazards level, damping reduction factor, spectrum acceleration, and assumed shifted time. So, for an isolated building's shape factor, vertical frequency, stiffness, and period shifting, story mass is crucial.

3.2 Design of Isolator

Building weight, shape factor, vertical frequency, building arrangement, size, damping reduction factor, spectral acceleration at natural period, shifting period, bearing detail, torsion allowance, composite damping, stiffness (composite linear, rubber nonlinear, huge vertical linear), design displacement, and level of excitation are all factors that affect isolator design. The statistics that follow in table 2 shows how bearing isolators were designed in detail [9].

3.2.1 Isolator Properties and Acceptance Criteria

The steel-laminated elastomeric and high damping rubber bearing design was designed in accordance with the recommendations in James M. Kelly's book [7], FEMA 273, and IBC 2000. The following tables 3, 4 and 5 provide a list of the designed properties that finite element software requires.

Table 2: Design of elastomeric isolator bearing

Parameter	Value
Isolator effective height (mm)	300
Isolator diameter (mm)	600
Area of rubber (m^2)	0.283
Shape Factor	10
Vertical Frequency (Hz)	8.21
End plate thickness (mm)	25
Steel shims thickness (mm)	3
Each layer rubber thickness (mm)	16.46
Number of layers	13
Total Design displacement DBE (mm)	361.9
Total Design displacement MCE (mm)	507
Buckling Load safety Factor for type A bearing	6.895
Buckling Load safety Factor for type B bearing	5.63
Max Rollout Displacement (mm)	520
Buckling Load (KN)	0.98
Composite Damping (%)	9.18
Time Period (Sec)	2.68
Global Overturning and uplift, additional load (MN)	1
Pressure Raised due to additional load (Mpa)	3.55 & 4.94
Safety Against uplift	2.39

The section characteristics for isolator as link is stated in Table 2,3 and 4 based on the aforementioned design properties [7].

Table 3: Finite element input: ETABS inbuilt rubber isolators

ETABS input	Bearing type 1	Bearing type 2
KV (U1), KN/m	11251769.89	11251769.89
K eff. linear, KN/m (U2 & U3)	1405.46	2529.82
K eff -nonlinear, KN/m	33449.84	33449.84
Effective damping, KN-m-rad	2162.48	2162.48
Yield Strength, KN	32.99	32.99

Table 4: Equivalent Bilinear model Input: for viscoelastic material

Parameter	Bearing type 1	Bearing type 2
K1, KN/mm	140545.56	252982.01
Qd, KN/mm	2968.81	2968.81
Dy, m	0.00023	0.00013
Yield Strength (K1*Dy), KN	32.99	32.99

Table 5: For high damping rubber bearing isolator (HDRB)

Direction	Effective Stiffness (KN/m)	Damping (KN-s-m)
Vertical (U1)	14644589.1	3341.52
Bi-direction X and Y (U2 & U3)	2014.36	3341.52
Isolator effective height (mm)	300	-
Isolator diameter (mm)	600	-
Added elastic stiffness (Mpa)	9.73	-

3.2.2 Criteria for structural and deformation parameters

Coda compliance is 2% at MCE level and 1% at DBE level excitation for the drift to occupancy-based level (FEMA 273, IBC 2000, and ASCE 41-16/17).

3.3 Employed a systematic approach

By carefully reading through and evaluating the many articles, extensive study on connected topics was carried out. The isolated base building was designed [Figure 1, 2, 3 and 4] and studied using a reinforced concrete structure with predetermined dimensions, a certain floor height, and a predetermined number of stories. The ETABS V.20 & V.21 software [10]is used to simulate and analyze the sample building using finite element modeling. The numerical model was utilized to conduct seismic coefficient, response spectrum, and non-linear time history evaluations throughout the inquiry. To study seismic performance and explain the findings, building performance response factors of fixed base and isolated base buildings were employed.

4. Finite Element Analysis

The following subsections describe the building's configuration, synthesized ground motion, spectral matching, and rubber bearing isolator modeling using finite element software (ETABS V.20 and V.21).

4.1 Modelling of Building and Configuration

Building modeling with EATBS V.20 and 21 are shown in the figures 2, 3 and 4, along with tabulated properties in the table 6.

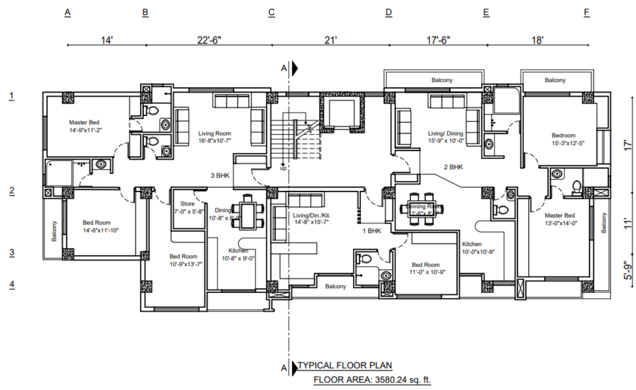


Figure 1: A Typical Plan of the Building

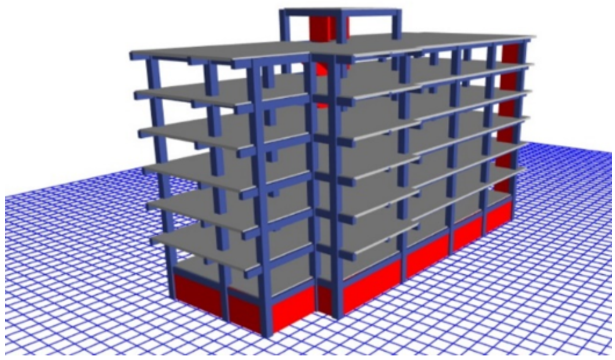


Figure 2: Finite Element Model of Fixed Base (bare-frame) Building

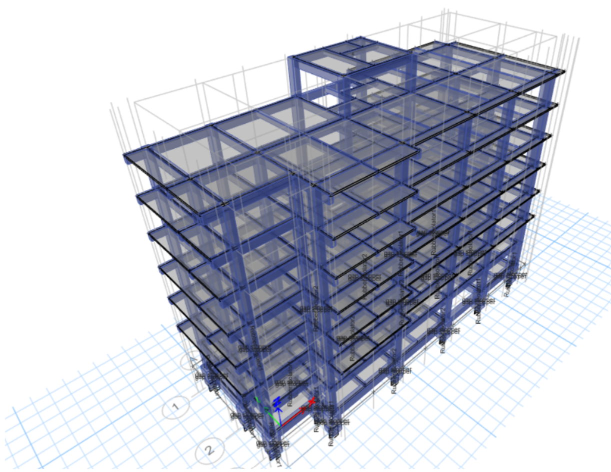


Figure 3: Finite Element Model of Base-Isolated Building

Table 6: Building Configuration

Parameters	Value / Description	Units
Beam Superstructure1_P	304.8 x 406.4	mm
Beam Superstructure2_S	230 x 350	mm
Base Beam 3_BS	406.7 x 508	mm
Column 1	508 x 508	mm
Column 2	558.8 x 588.8	mm
Column 3	609.6 x 812.8	mm
Base Column 4	900 x 900	mm
Slab	127	mm
Base Slab	254	mm
Bay size and length	attached plan	-
Live Load	2,3,6	KN/m^2
Floor Finish	1.1, 1.25, 1.5	KN/m^2
Wall, P Wall	12, 8, 6, 4	KN/m^2
Steel Grade	500 HYSD	Mpa
Concrete Grade	25, 30	KN/m^3
Rubber Isolator sizing	300 ht. x 600 dia.	mm
Shear Modulus of Rubber	0.7 & 1.02	Mpa
Importance Factor	1.5 (NBC105:2020)	-
Seismic Zone	Kathmandu Valley, Z = 0.35, PGA for 475 year return period @ 10% probability of exceedance in 50 years	-
Building Type	Medium-Rise - School College, Hospital, Bank, Supermarket etc.	-
Damping Ratio	5%, 10%	-
Structural Type	RC Moment Resisting Frame	-
Response reduction ductility factor	4 (Reinforced Concrete Frame) and 2 for isolation system	-
Over Strength Factor	1.5	-
Soil Type	D (very soft)	-

4.2 Modeling of Isolator

The model is constructed using linkages with visco-elastic material properties. The proposed 20 isolators are set up in a way that places 6 of one kind in the middle position or bays and 14 of another type in the outside column. The elastic-perfectly plastic (multi-linear plastic model) and bi-linear modeling [figure 5] are used. Rubber and HDRB's built-in function are utilized for the bi-linear oscillator [Figure 5] when the properties are entered. For the multi-linear plastic model, a backbone curve with force-deformation was included. The multi-linear plastic model was employed to validate the period shifting, damping, responsiveness, and deformation parameters of the bi-linear model. Stopper is also provided 800 mm apart from center of bearing or column to limit the movement of bearing. Nonlinear parameters [Figure 6] such as hinges, local nonlinear link and modal ritz vector are also utilized during analysis. [10].

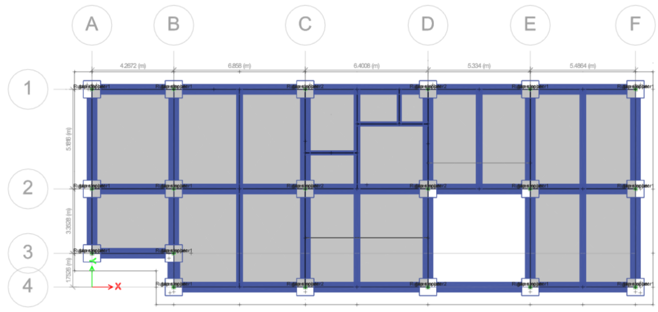


Figure 4: FEM model of added Base-Slab (Plan) for Isolated building

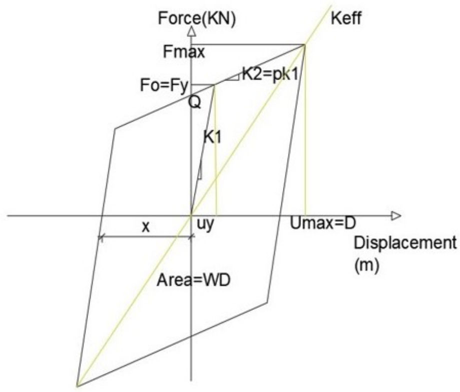


Figure 5: Idealized bi-linear hysteresis loop equivalent linear characteristics

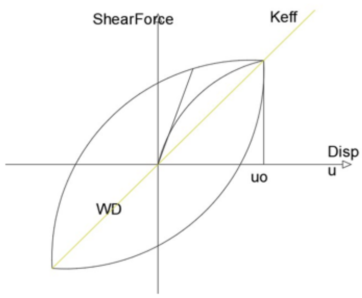


Figure 6: Nonlinear shear force-deformation cyclic behavior of rubber bearing

4.3 Selected Ground Motions and Spectral Matching

The results of time history analysis greatly depend on the choice of earthquake ground movements. Bi-direction (with vertical motions) 9 - pairs of earthquake recordings, including those from near-fault and far-field [subduction zone and oblique reversal fault] locations [Table 11], are examined [4]. The figure 10 includes a spectral matching in timeline domain of the selected earthquake (2015 Gorkha) with target spectrum (NBC 105:2020, soil type D) mentioned in figure 9 at MCE level shaking and figures 7, 8 and 11 indicates ground acceleration and frequency spectrum of 2015 Gorkha-Nepal earthquake respectively and Psuedo spectral acceleration (PSA) vs period of 2015 Gorkha synthesized ground-motion in u2 (NS) direction. The depth, acceleration, and near-far ranges of the field recordings used to depict the chosen ground movements. By using spectral matching techniques with the proper scaling procedures [NBC 105:2020 clause 9.3], the magnitude, frequency content, and length of the chosen seismic motions are all configurable and matched with the spectrum of soil type D-Kathmandu Valley. The synthesized ground-motions are applied to assess the structure's performance.

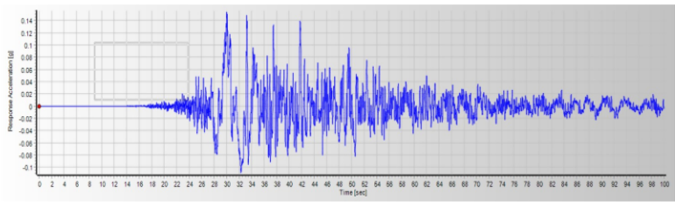


Figure 7: Recorded 2015 Gorkha earthquake in EW direction

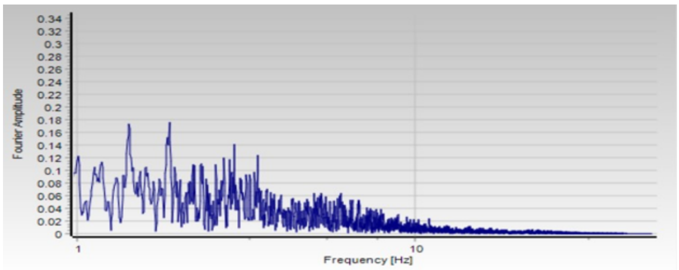


Figure 8: Frequency content of recorded 2015 Gorkha earthquake

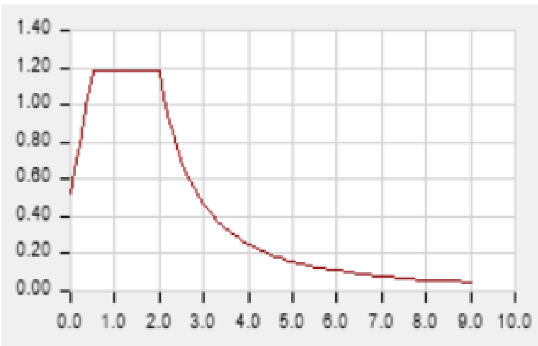


Figure 9: Target spectrum for DBE and MCE level excitation of horizontal Loading (NBC 105: 2020, clause 9.3; C(t) vs Period)

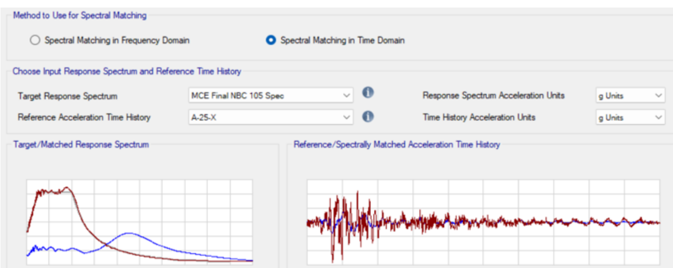


Figure 10: Spectral Matching with Target Spectrum to obtain synthesized ground-motion in u1 (EW) direction

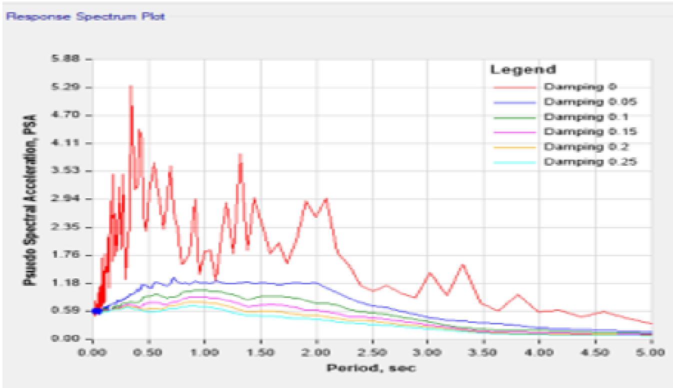


Figure 11: Psuedo spectral acceleration (PSA) vs period: response spectrum plot of synthesized ground-motion in u2 (NS) direction

5. Result and Discussion

5.1 Modal Analysis

Because the base-isolated building has steel-laminated elastomeric or HDRB isolated installation at mid-height of base column, the modal mass participation ratios of bare-frame [Table 7] and isolated base buildings [Table 8] demonstrate that almost 90% of the mass participated in the base-isolated building as opposed to fixed base building. It has also been noted that the fixed base bare frame building's vertical component makes it difficult to contribute 65 percent of the mass within a first mode or few modes.

Table 7: Modal Participating Mass Ratios of Fixed Base Bare Frame considering vertical component

Case	Mode	Period (sec)	UX	UY	RZ
Modal	1	1.006	0.6063	0.0774	0.0032
	2	0.993	0.0789	0.5332	0.0811
	3	0.829	0.0018	0.085	0.6059

Table 8: Modal Participating Mass Ratios for Base-Isolated Building

Case	Mode	Period (sec)	UX	UY	RZ
Modal	1	3.08	0.9709	0.0001	0.0011
	2	2.442	0.0002	0.8999	0.0624
	3	1.979	0.0009	0.0603	0.8857

To account for 3-dimensional ground shaking, an additional missing mass correction process is employed in the fixed base bare-frame building. But when a building was isolated, mass participated effortlessly.

5.2 Time Period Shifting

It has been noted that the period of the isolated building shifted more than three times that of the fixed base bare-frame structure as a result of elastomeric rubber base isolation, presented in table 9 and Figure 12.

Table 9: Type of Model Used and Time Period

Type of Model Used	Time Period (sec)
Fixed Base Bare Frame (FBBF)	1.01
Isolated without Shear Wall	3.27
Isolated with Shear Wall as soil retainer	3.08

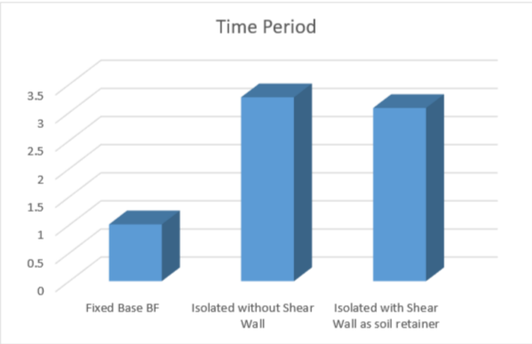


Figure 12: Comparison of Natural Period of Structures

5.3 Reduction of Base Shear and Base Shear Coefficient Cd(T)

Base-shear [Table 11] declined by 50% while the base-shear coefficient, Cd(t), decreased by 3.1 times. Because of the isolator rubber bearing, the structure period lengthens and transmits less seismic input [Figure 13 and 14].

Table 10: Base Shear Comparison

Type	Base Shear (KN)
Fixed Base	6434.38
Isolated base (5% damped)	3165.4

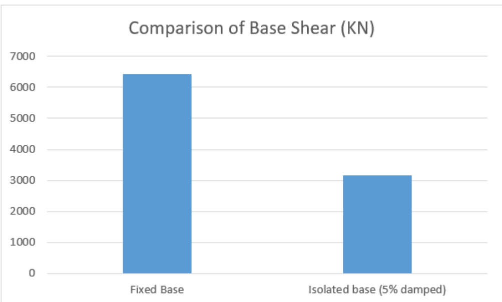


Figure 13: Base-Shear Comparison

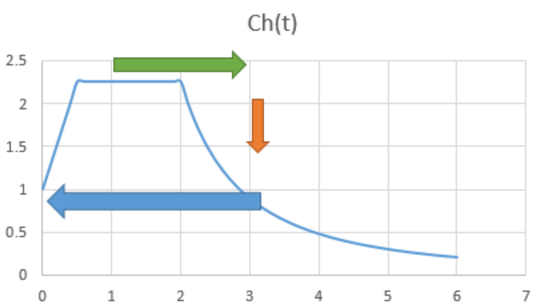


Figure 14: Reduction of Elastic Spectral Shape Factor (5% damped)

5.4 Story Response: Maximum Storey Displacement

The maximum story displacement of a fixed base bare frame building and a seven-story base-isolated reinforced concrete building are compared using the figures in the following subsection. It also shows the space requirements surrounding the building in strong ground motion and the response in near field motion.

5.4.1 Maximum Storey Displacement Response of 9 MCE level earthquakes

While taking into account the response reduction ductility factor as unity during nonlinear dynamic time history analysis, the maximum story displacement for a fixed base building is 735 mm at the sixth floor, but the maximum story displacement for a base-isolated building [Figure 15] is 1476 mm at the sixth floor, which is directly beneath the staircase cover. Roll-out displacement is 507 mm, but base-slab displacement is 791 mm. The rubber bearing slides laterally by around 284 mm despite having a stopper installed 810 mm from the bearing's center point.

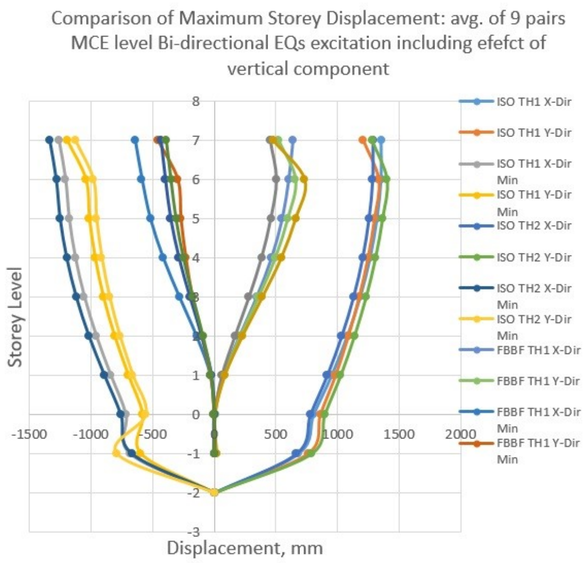


Figure 15: Maximum Storey Displacement Response of Fixed Base and Isolated Base of the Building

5.4.2 Space Requirement

When doing a nonlinear dynamic time history analysis, the space needed for the building all around it is 1.5 meters from the building when the response reduction ductility factor is taken into account as unity. The displacement of the top story increases to 1476 mm when the foundation slab shifts laterally by 791 mm. The top floor and base slab displacements differ by 685 mm [Figure 16]. The structure must be set up and regulated so that the base-isolated building displaces the roll-out plus an approximate equivalent fixed base for the superstructure. That is 507 mm + EQ ULS Fixed foundation, which indicates that the required roof displacement was 759 mm. Isolation bearing required an extra damper (spring) control mechanism as a result.

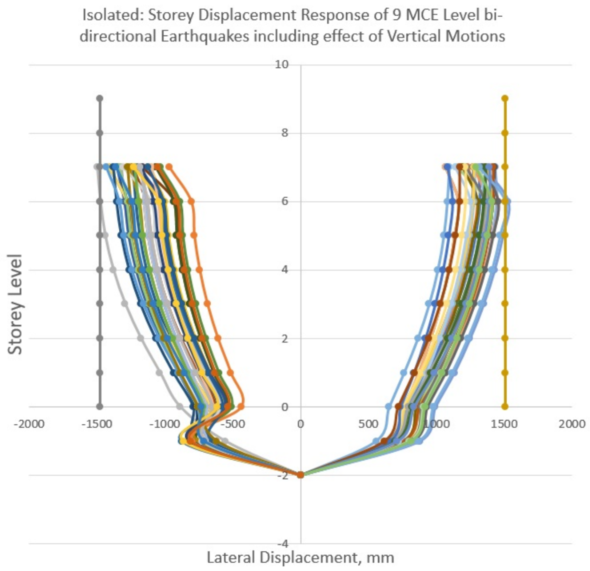


Figure 16: Storey Displacement Tracing at MCE Level Excitation enabling investigation of space requirement all around building

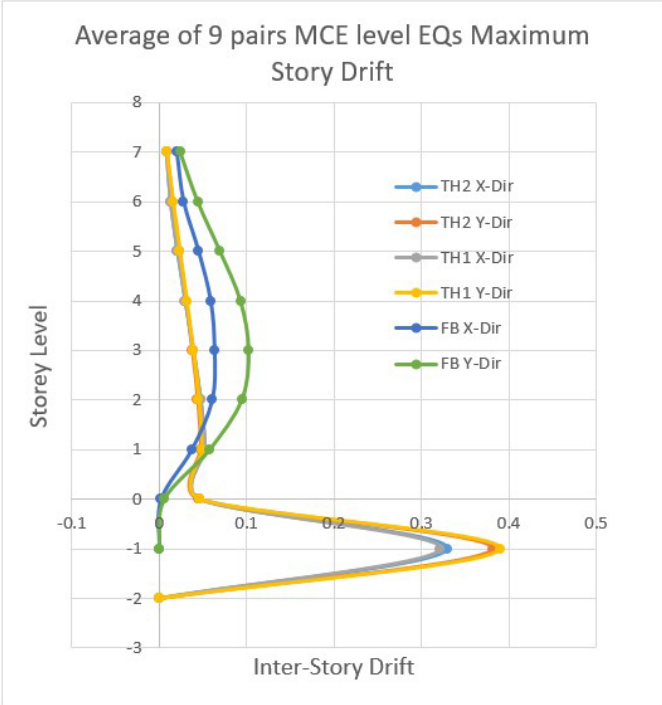


Figure 17: Inter-Story Drift Comparison of Fixed Base and Isolated Base

5.4.3 Near-Field Motions and Response

During time history analysis, 5 near field motions, including Kobe, Nortridge, Chi Chi, Elcentro, and Kocaeli, are employed, mentioned in table 7 [4]. It has been noted that bi-directional Kobe earthquakes cause increased roof displacement by 90 mm more than Imperial Valley El Centro motion. Additionally, far-field earthquakes like those in Alaska, Borrego Mountain, and Loma Parieta are analyzed [figure 16] and assigned an average reaction. It is thought that the 2015 earthquake in Gorkha was neither far-field nor near-field.

5.5 Story Response: Maximum Story Inter-Story Drift

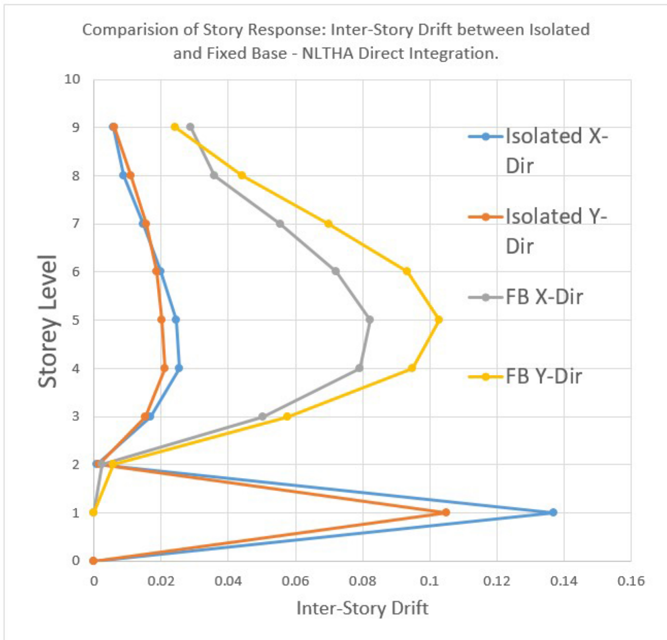
The following subsections compare and display the drift response of base-isolated buildings with and without a shear wall serving as a soil retainer in the basement.

5.5.1 Inter-Story Drift Response of 9 pairs at MCE level Ground Motions

When the ductility factor is set to unity during a nonlinear time history analysis, the base-isolated building's inter-story drift is reduced by half compared to a fixed base building [Figure 17], but the inter-story drift at the basement level increases. This is because rubber bearing isolators at the foundation level provide lateral flexibility. The increased amount of drift at basement level should be managed toward optimal provision by providing additional control devices such as dampers.

5.5.2 Drift comparison while constructing shear wall as soil retainer at foundation level

The base-isolated structure's drift concentrated at superstructure was mitigated by the shear wall's function as a soil retainer [figure 18]. The coda provision of 2% is exceeded by the drift limit at MCE level excitation. On the other hand, good concrete design may restrict the drift limit of permanent bases (Fixed Base Bare-Frame). Despite having a superstructure made of concrete that was properly designed



Shear wall as soil retainer and concrete design for super-structure.

Figure 18: MCE Level Story Drift Response of FB and Isolated Building with Shear Wall as Soil Retainer

(IS 456: 2000) for an isolated building, the drift could not be contained within 2% by only the rubber bearing isolators.

5.5.3 9 Pairs of MCE Level Earthquakes Response: Maximum Story Drift Tracing

Figure 19 of the base-isolated building depicts the drift response tracing of all 9 pairs of bi-directional MCE level excitation with a shear wall acting as a soil retainer at the basement level.

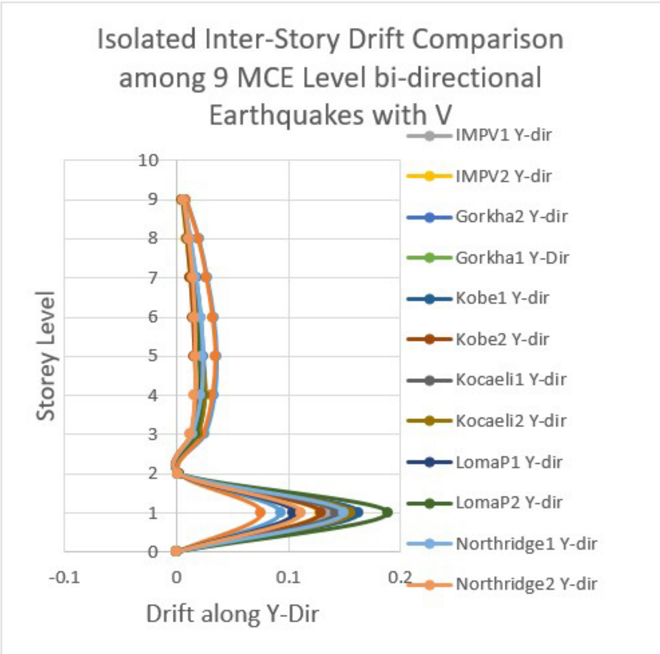


Figure 19: Maximum Story Drift Tracing

5.6 Energy Dissipation and Cyclic Hysteresis of Rubber Bearing

The subsection includes illustrations of cumulative energy content, energy dissipation, and hysteresis behavior of rubber bearing isolated building with elastomer as link element.

5.6.1 Cumulative Energy Component and Energy Dissipation

When modal damping is defined at 5% the analogous average damping ratio is 4.91, and the total damping increases to 9.91% as equivalent composite damping [Figure 20], according to the energy dissipation by damping observations. The 20 rubber bearings inserted at the midpoint of the base column have an average global damping of 83% by a 16.9% hysteretic damping, which provides extra damping in addition to modal damping. However, all energy in the bare-frame model was kinetic and potential [Figure 21]; these peeks are shown in the graphics that are linked to this paragraph.

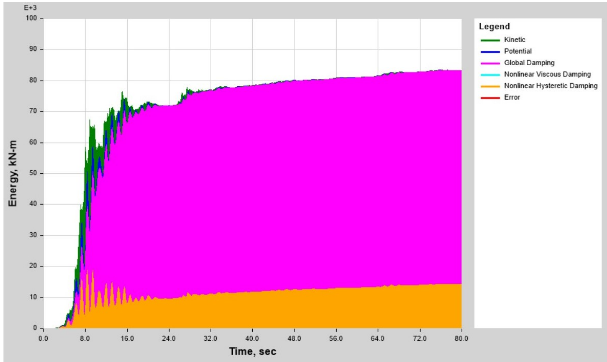


Figure 20: Culumative Energy Components of rubber bearing isolators

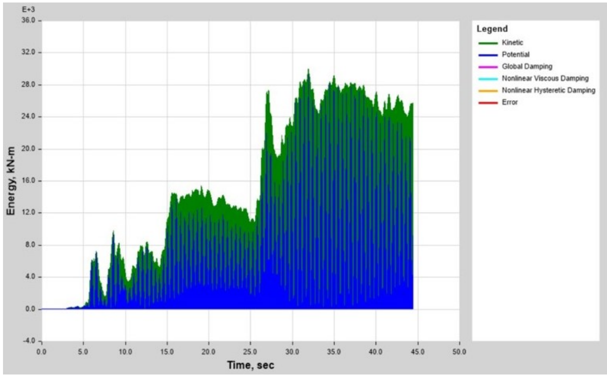


Figure 21: Cumulative Energy Components of bare-frame(FB) building

5.6.2 Observed Hysteresis Behaviour

The images illustrate the hysteretic behavior of rubber isolators for shear force (KN) vs deformation (mm) [Figure 23] and moment (KN-m) versus deformation (rad) [Figure 22]. The highest deformation has been observed to be 692 mm at a contact with a shear force of 2324 KN. Similarly, the rotation is 0.03504 rad when the moment is 710 KM-m.

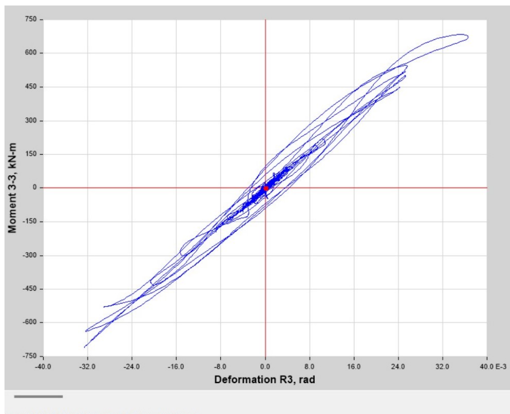


Figure 22: Moment Vs Deformation hysteresis of rubber bearing

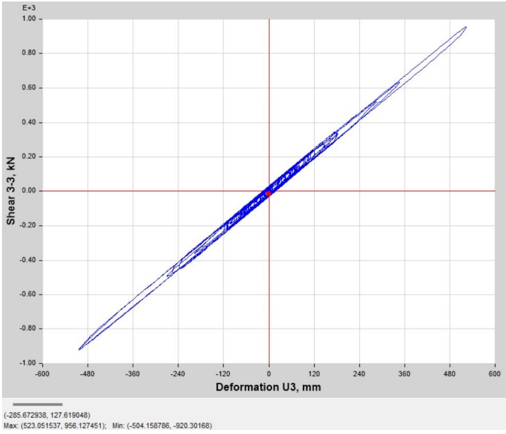


Figure 23: Shear Force Vs. Deformation hysteresis of rubber bearing

5.7 Story Shear

The fixed base bare-frame structure and the base-isolated building have comparable patterns of story shearing forces [Figure 25 and 24]. Despite offering lateral flexibility, the base-isolated building's story shear reduced by almost 1.5 times. When dealing with response reduction ductility factor as unity during nonlinear time history analysis, it has been shown that maximum story shear, 44803 KN of isolated building at basement-1 level when maximum story shear, 69283.4 KN of bare-frame at ground floor level. The figures display all of this information.

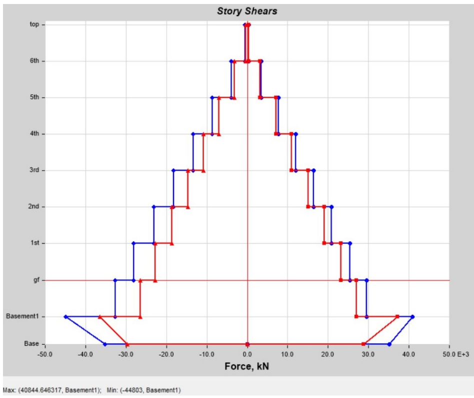


Figure 24: Maximum Story Shear Response of Base-Isolated Building

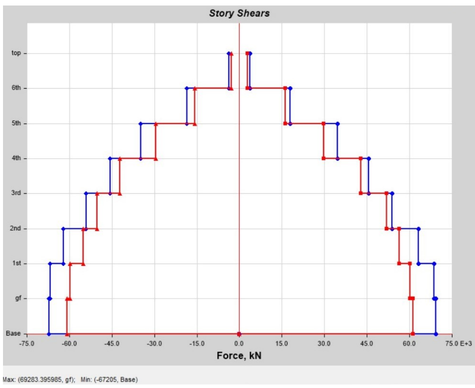


Figure 25: Maximum Storey Shear Response of Bare-Frame (FB) Building

Table 11: Selected Earthquakes List

S.N	Earthquake and Year	Station	Mw, Depth (KM)	EW-U1(g), NS-U2(g), UD-U3(g)
1	Gorkha, 2015	KATNP (85KM)	7.8, 18.5	0.158, 0.165, 0.187
2	Imperial Valley-09, 1940	EL-Centro	6.9, 16	0.214, 0.348, 0.21
3	Northridge (near fault 12.9 KM), 1994	White Oak Cov.	6.7, 17.5	0.477, 0.364, 0.8
4	Loma Parieta, California, 1989	A. Dam (L Abut)	7, 17.5	0.27, 0.388, 0.186
5	Kobe, Japan, 1995	Abeno (23.6 KM)	6.9, 17.9	0.235, 0.222, 0.134
6	Izmit-Kocaeli, Turkey, 1999	Yarima Petkim	7.4, 15	0.23, 0.322, 0.24
7	Denali Alaska, USA (far-field 258.6 KM), 2002	TAPS Pump Station 12	7.9, 4.9	0.035, 0.04, 0.024
8	Borrego Mountain (far-field 208.2 KM), 1968	LA - H. FF	6.5, 8	0.012, 0.013, 0.005
9	CHI CHI, Taiwan (Near-field), 1999	TCU 116 (12.5 KM)	7.6, 6.8	0.189, 0.122, 0.135

6. Conclusion

A structural innovation in the construction of medium-rise building that transfers ground motion as input to the superstructure with the exception of roll-out is the use of elastomeric rubber isolation at the mid height of the foundation column. The following findings are drawn from a study of numerical model comparison of isolated building and fixed base bare-frame building:

- The natural period of the building shifted by three times more than a fixed foundation bare building by giving the base of the structure lateral flexibility.
- Base-isolated building has a higher level of mass participation than fixed base bare-frame structure.
- In base-isolated buildings, base shear is reduced by half while Cd(T) is 3.1 times lower than that of the fixed base buildings.
- When the response reduction ductility factor is assumed to be one, the isolated building's roof displacement

exceeds then the fixed base building by 741 mm. The displacement of the foundation slab or bearing isolator is 791 mm, which is more than the roll-out displacement of 507 mm. This implies that the rubber bearing isolators might not be enough for stability and restoring to its original position for immediately occupy without considering additional control mechanism.

- At MCE level excitation's, the drift limit has been seen to be greater than 2%.
- The rubber bearing provides 4.1% more equivalent average damping than modal damping, and this is because the rubber's visco-elastic component exhibits hysteresis.
- The base-isolated building's pattern of story shearing force is identical in shape to that of the fixed base. Despite giving the structure lateral flexibility, the story shear was decreased by half compared to a fixed base building.

However, base-isolated buildings' stability could not be guaranteed without the placement of additional energy dissipation control mechanisms, such as dampers and springs. The reason for this is that at MCE level ground excitation, the inter-story drift limit should be under 2% and base-slab or rubber bearing movement should be controlled within roll-out limits. It is recommended to examine and investigate the performance of base-isolated building with a damper system and bearing isolator in high seismic regions.

Acknowledgments

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References

[1] Nepal, National Planning Commission, Government of Nepal. *Nepal Post Disaster Need Assessment.*

[2] Nirmal George Chinju Joseph. Effect of soil structure interaction on frames with different base conditions. 2015.

[3] Michael Craig Griffith. Experimental evaluation of seismic isolation for medium-rise structure subject to uplift, uc berkeley. 1988.

[4] Fabio Mazza and Vulcano Alfonso. Base-isolation techniques for the seismic protection of rc framed structures subjected to near-fault ground motions, vol 3, 13th world conferrence on earthquake engineering. 2004.

[5] A Dushimimana, F Nzamurambaho, E Shyaka, and AA Niyonsenga. Optimum performance of isolation system for medium rise buildings subject to long period ground motions. 2018.

[6] Srijit Bandyopadhyay, YM Parulekar, Aniruddha Sengupta, and J Chattopadhyay. Structure soil structure interaction of conventional and base-isolated building subjected to real earthquake. In *Structures*, volume 32, pages 474–493. Elsevier, 2021.

[7] James M. Kelly Farzad Naeim. *Design of Seismic Isolated Structures: From Theory to Practice.* John Wiley & Sons Inc., 1st edition, 1999.

[8] Katsuichiro Goda, Takashi Kiyota, Rama Mohan Pokhrel, Gabriele Chiaro, Toshihiko Katagiri, Keshab Sharma, and Sean Wilkinson. The 2015 gorkha nepal earthquake: insights from earthquake damage survey. 2015.

[9] New Zealand, Holmes Consulting Group Ltd. *Base Isolation of Structure: Design Guidelines, 2001.*

[10] Computer and Structures, Inc. *CSI Analysis Reference Manual for SAP2000, ETABS, SAFE and CSiBridge, 2017.*