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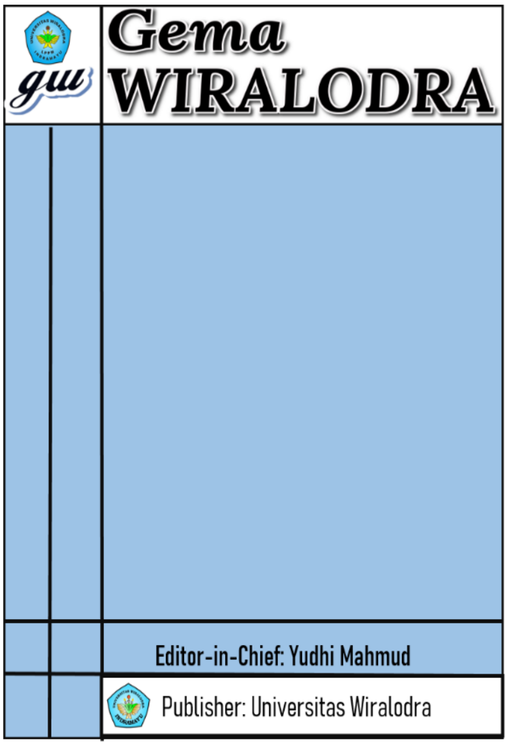

Seismic performance analysis of building structures using high damping rubber bearings

Veron Bella Anggara[a], Rosidawani[b], Hanafiah[c], Siti Aisyah Nurjannah[d], Andri Setiawan[e]

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Original Article

Seismic performance analysis of building structures using high damping rubber bearings

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Abstract
The problem in this study is how the performance of building structures that have horizontal irregularities using fixed base structures and High Damping Rubber Bearing (HDRB) basic isolated structures. As well as how the performance of building structures compares with horizontal irregularities using HDRB compared to fixed base structures. The purpose of the study was to analyze the effect of the performance of reinforced concrete building structures with horizontal irregularities using fixed base structures and HDRB type basic isolation structures, as well as analyze the comparison of structural performance responses when seismic forces occur on a fixed base and base isolation structures using HDRB in terms of natural periods, shape modes, mass participation, basic shear forces (base shear), story drift, horizontal irregularity, and the influence of the p-delta. This research method is to carry out equivalent static analysis at the initial stage of analysis to obtain minimum force values in the dynamic analysis of the response spectrum in accordance with the provisions of SNI 1726:2019 with the help of Etabs software version V.19. After obtaining the force in the response spectrum analysis results, proceed with designing the structural element reinforcement. Then final stage analysis with non-linear time history analysis (NLTHA) to assess the performance of the building structure. The dynamic analysis of the spectrum response uses spectrum response data for the city of Bengkulu taken from RSA 2021. Meanwhile, the NLTHA analysis uses 7 pairs of horizontal acceleration components selected and matched from individual recordings of MCER ground motion events.The results of this study show that the performance of building structures that have horizontal irregularities with HDRB has better performance than fixed base structures. Comparison of the structure's performance response during seismic forces from several parameters such as natural period, mode shapes, mass participation, base shear, story drift, horizontal irregularity, and p-delta influence. Based on the parameters of the performance of the structure, it proves that the performance of building structures with HDRB has better performance than fixed base. Based on the results of research HDRB can improve the performance of structures that have horizontal irregularities.
Keywords: Horizontal Irregularity, HDRB, *Fixed Base*, Structure Performance, NLTHA

1. Introduction
In this research study, it is discusses the effect of the performance of building structures that have irregularities in terms of the shape of the building plan or known as structures with horizontal irregularities, in Figure 1. Building structures that have horizontal irregularities can cause torsional dominant behavior in the structure when exposed to seismic forces. According to Bhasker & Menon (2020), buildings with horizontal irregularities may cause torque effects. When a structure undergoes seismic excitation, it undergoes not on (ly translational force but also floor rotation. The non-uniform distribution of displacement in load-bearing elements caused by floor rotation causes the ductility of the structure to be reduced, which can cause premature collapse in the building.

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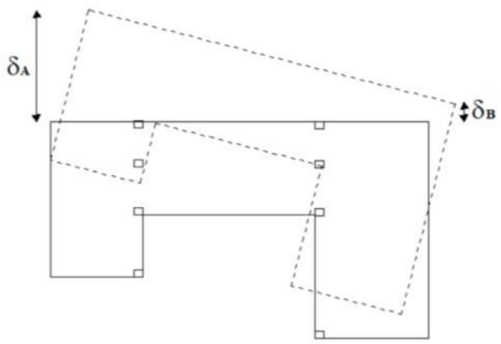
Potential hazards due to total collapse of buildings caused by earthquakes in buildings with horizontal irregularities must certainly be mitigated. As is known that Indonesia is an area that often experiences major earthquakes. Like the earthquake that occurred in Bengkulu Province in 2007 which caused extensive damage, 52,923 housing units were damaged (Suzetta, 2007).

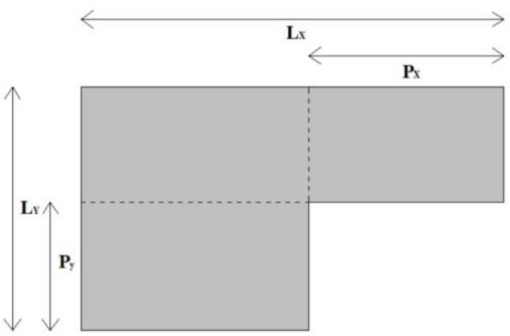
Therefore, research that discusses the influence of horizontal irregularities of buildings on earthquake-prone areas is important. Various attempts to improve *Performance* structures during an earthquake have been widely carried out such as with the mechanism of a double structure system, *strong column and weak beam*and *seismic device* (*Seismic Control System*) (Suhendro, 2022). But as the results of the study (Rahmantyo & Andayani, 2019) shows that the best structural performance is still a structure with a square-shaped symmetrical floor plan even though it has used the system *strong column and weak beam* and sliding walls. The concept of a seismic isolation system is how to design buildings in such a way that buildings can be isolated from the ground so that earthquake movements that occur are not continued to the buildings above or at least have been greatly reduced. Reduced or loss of earthquake force transferred from the ground in buildings accommodated by *base isolation*, Simply make an isolated building like not experiencing earthquake force (Minal, et al., 2015). The way basic insulation works is different from structural systems *Damping* and *resistant*. The idea of basic insulation is not to reduce the period of the structure but to extend the natural period of the structure, *displacement* will go up but since there is an insulator device then *displacement* will go down. The basic concept of isolation is to reduce the force that enters the structure during an earthquake. When the natural period value of the structure is elongated, the acceleration value entering the structure will be smaller (Gunawan, 2022).

Figure 1

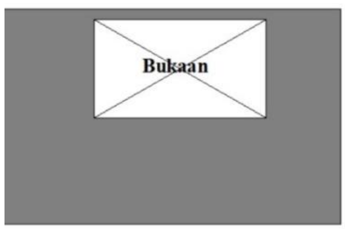
Horizontal irregularities of type 1a and 1b, type 2 and type 3



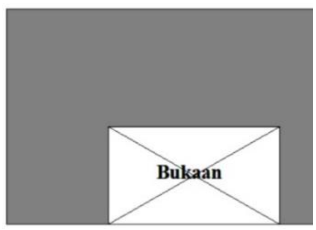
1(a)



1(b)



1(c)



One type of seismic insulator that is widely used around the world is *High Damping Rubber Bearing* abbreviated as HDRB. HDRB behavior has very interesting features for earthquake protection. HDRB has high rigidity and damping at low shear strain, minimizing response under laydown and wind loads. HDRB, which has a low shear stiffness value, also has adequate damping capacity in level shift designs. When HDRB experiences increased stiffness and attenuation at higher displacement amplitudes, it can limit displacement under

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large earthquakes (Oliveto, et al., 2019). The effects of torque experienced on structures that have irregularities can be overcome by placement *Base* The right insulator (Shiravand, et al., 2022).

Several previous studies that have examined horizontal irregularities in fixed structures include; Divya & Murali (2022) who researched structures with irregular configurations that would provide the best performance under lateral loads. Then Khanal & Chaulagain (2020), examined the influence of the configuration of plan angle irregularities using spectrum response analysis. Several other researchers have also discussed the effect of base isolation on buildings, including; (Islam, 2019) examined the feasibility of using HDRB devices on the structural basis of buildings. Then Murota et al. (2020) discussed the feasibility of a seismic HDRB isolation system for residential buildings in Turkey and also carried out analytical studies, full-scale HDR dynamic loading tests. Than Imran et al. (2021) discusses comparing the seismic performance of conventional buildings with a fixed base with DCFP-based buildings under the same scenario of ground motion using the latest Indonesian building and seismic codes. Researchers from Italy Cancellara & Angelis (2019) have discussed the dynamic behavior of basic isolated multi-storey structures characterized by irregularities in plan. The HDRB isolator is adopted and placed in parallel with the friction sliding isolator.

Based on descriptions from literature studies and previous research, this research will discuss the influence of horizontal irregularities in building structures with High Damping Rubber Bearing HDRB in detail using Indonesian code regulations. The research that will be discussed has differences with previous research, including; Divya & Murali (2022) research, 2022, they compared the influence of buildings that have horizontal and vertical irregularities using shear walls and without shear walls affect structural performance when lateral loads occur. Then Khanal & Chaulagain (2020) only evaluated the performance of buildings that have an L-shaped plan with varying plan angle configurations as well as the performance of the building structure in elastic conditions. Other research that has discussed HDRB has differences with this research, including; Than Islam (2019) only conducted research to evaluate the response of floors in earthquake-resistant buildings with HDRB. Then Murota et al. (2020) has different research because it examines the effect of applying HDRB to residential buildings and carries out full-scale dynamic HDRB tests using prototype testing methods at TSC2018. Then (Imran et al., 2021) has a different research because in that research they carried out a building evaluation using double concave friction pendulum type base isolation. Than Cancellara & Angelis (2019) conducted research that was different from the researchers' research because the research discussed the dynamic performance of buildings that have plan irregularities by placing HDRB insulators and friction shear insulators in parallel according to the Italian code.

The problem in this study is how the performance of building structures that have horizontal irregularities using *fixed base* structures and High Damping Rubber Bearing (HDRB) basic isolated structures. As well as how the performance of building structures compares with horizontal irregularities using HDRB compared to *fixed base structures.* The purpose of the study was to analyze the effect of the performance of reinforced concrete building structures with horizontal irregularities using fixed base structures and HDRB type basic isolation structures, as well as analyze the comparison of structural performance responses when seismic forces occur on a fixed *base and* base isolation *structures using HDRB in terms of natural periods*, shape modes, mass participation, basic shear forces (*base shear*), *story drift,* horizontal irregularity, and the influence of the p-delta.

Therefore, it is important to carry out this research to analyze the seismic performance of building structures using High Damping Rubber Bearings compared with fixed based structures in terms of parameters such as natural period, modal mass participation factor, base

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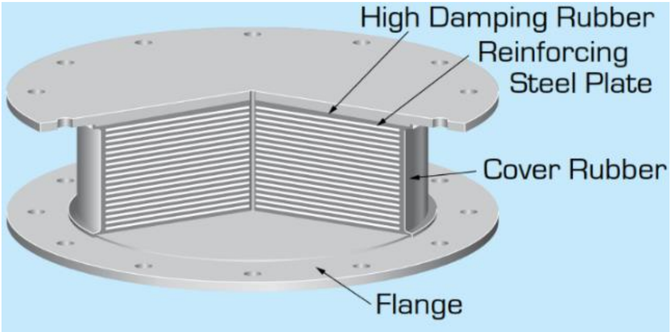
shear force, deviation between levels and horizontal irregularities. In addition, the performance of each type of structure is also analyzed.

High *Damping Rubber Bearing Explained*

According to Villaverde (2009), *High Damping Rubber Bearing* abbreviated HDRB is a laminated cushion made of intrinstic compound rubber that has a high damping ratio. HDRB is made from the addition of refined carbon exstra, oil, resin, or other fillers such as natural rubber. The effective attenuation of the HDRB insulator is 10 -20 % at 100% shear strain, In Figure 2 is the HDRB device.

Figure 2

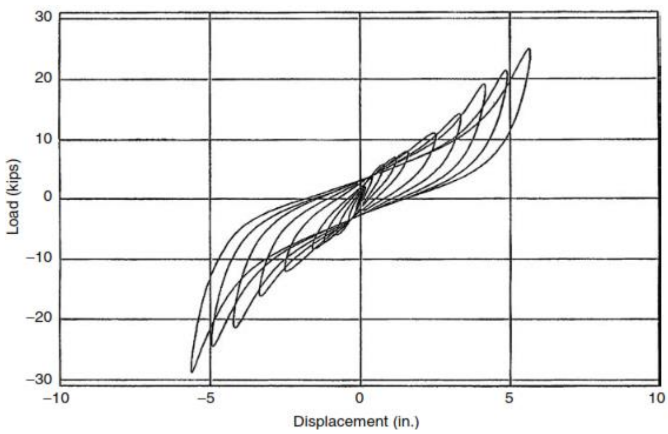
High damping rubber bearings Device Components



The deformation force-deformation behavior of high damping rubber pads at shear strains of less than 20% is characterized by high stiffness, as shown in Figure 2. When the shear strain reaches 20 and 120 %, the shear modulus is low and fairly constant. When the strain is large, the modulus will increase due to the crystallization process of the rubber strain. HDRB behavior generally exhibits high initial stiffness which is essential to accommodate forces from blowing winds and minor earthquakes in buildings without considerable friction (Villaverde, 2009). When the strain reaches 250 -300%, the horizontal stiffness will increase again due to the influence *hardening effects.*

Figure 2

Typical deformation-force characteristics of HDRB



2. Method

This research method is to analyze the structure of the building designed using Etabs software with static and dynamic methods. The description of the study model is in the form of a hospital building with a height between levels of all floors is 4 meters, the span of distance between columns is 8 meters located in Bengkulu City in moderate soil conditions.

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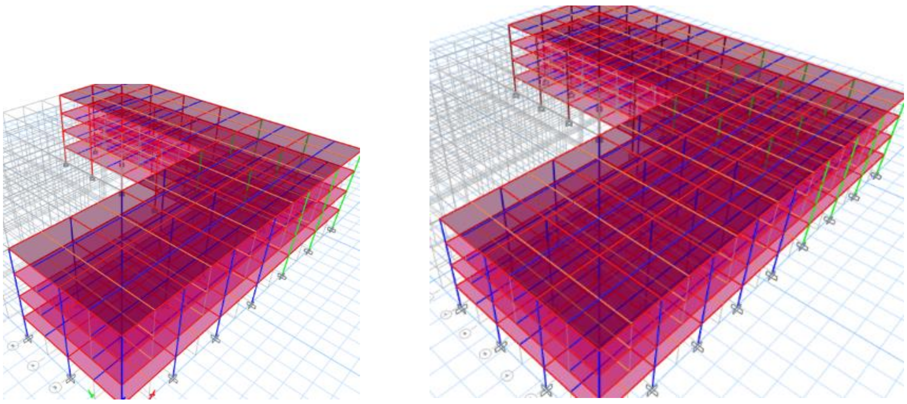
The floor plan and 3D view of the building are shown in Figure 4 and Figure 3. In general, research methods can be seen in Figure 6.

This study used 2 variations of buildings that have horizontal irregularities type 2 with a difference in angle ratio of 67% in building 1 and building 2 of 63%. Building models 1 and 2 are assumed to experience torsional irregularities 1a and 1b. Each model variation is made 2 types of building models as *fixed base* and *base isolation* buildings so that a total of 4 building models are analyzed, to clarify the division of the 4 building models described in Table 1.

Table 1
The design of the building to be analyzed

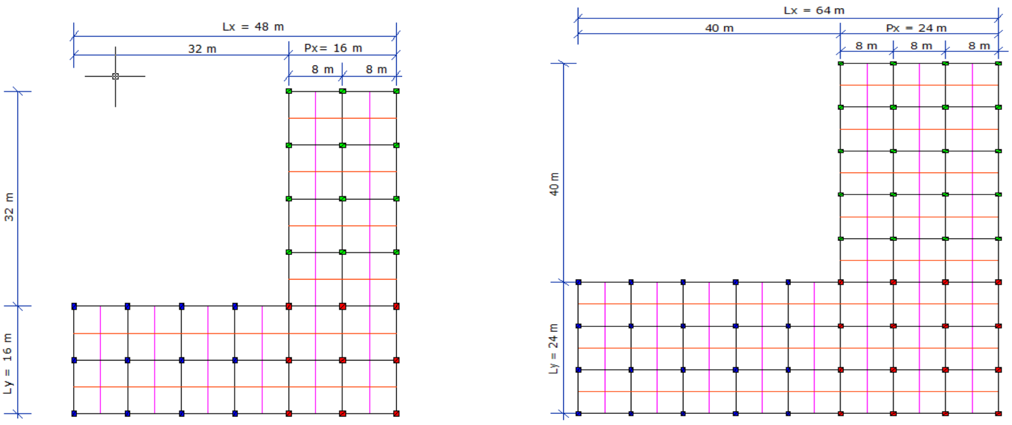
Building model 1- inner angle ratio 67 %	Building model 2 - inner angle ratio 63%
A-Fixed Base Design	B-Fixed Base Design
C-Base Isolation Design	D- Base Isolation Design

Figure 3
3D view of building 1 (3a) and building 2 (3b)



(3a) (3b)

Figure 4
Floor Plan 1- 4 model building 1 inner angle ratio 67% (4a) and building 2 ratio 62% (4b)



(4a) (4b)

The building structure uses reinforced with a compressive strength quality of concrete of 35 MPa. The quality of steel used as reinforcement has an Fy value of 420 MPa and has a modulus of elasticity value of 200,000 MPa. The standads used as provisions for designing reinforced concrete elements, determining earthquake loads and gravity are SNI 1726: 2019, SNI 2847: 2019, PPURG 1987, and SNI 1727: 2020. Spectral response data is data from Bengkulu City with soil conditions being sourced from data from the Directorate of

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Settlement and Housing Engineering, Ministry of Public Works and Public Housing taken from Web https://rsa.ciptakarya.pu.go.id/2021/ using RSA2019 application listed in Figure 5 and Table 2.

Figure 5

Bengkulu City Spectrum Response Curve

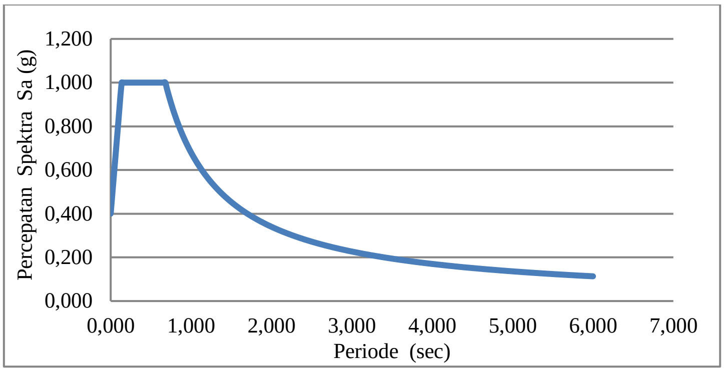

Figure 6

Research Flow Chart

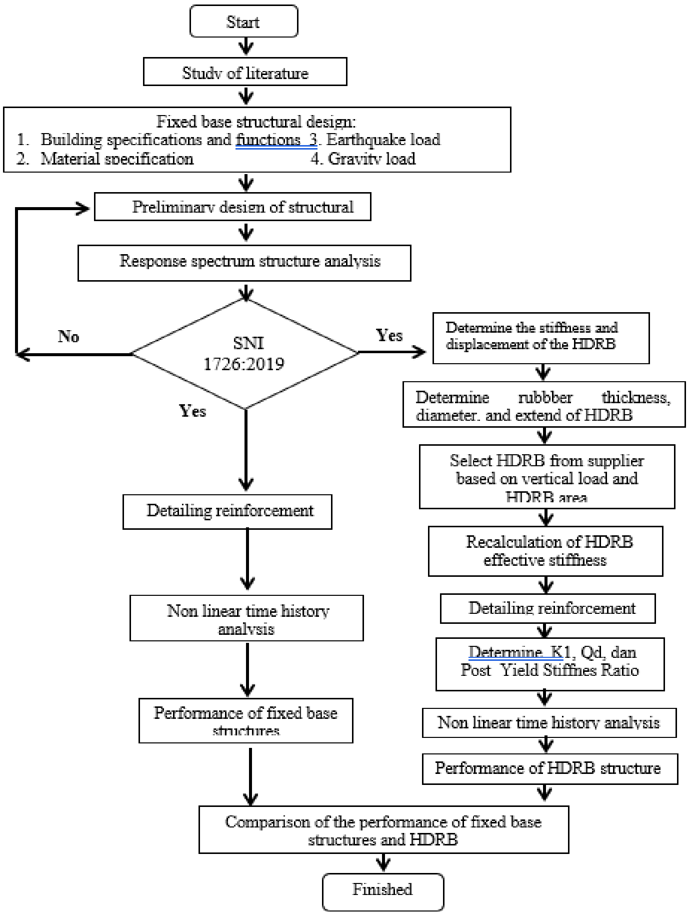

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Table 2
Bengkulu City spectral response data

No	Information	Notation	Value
1	Spectral acceleration of short-period design	S_S	1.5 g
2	Spectral acceleration design period 1 second	S_1	0.6 g
3	Site Coefficient	F_a	1
4	Site Coefficient	F_v	1.7
5	Short-period design acceleration	S_{DS}	1 g
6	Design acceleration period 1 second	S_{D1}	0.68 g
7		T_0	1.36 seconds
8		T_s	0.68 seconds
9	Long-period translational map	T_L	20 seconds
10	Building risk categories		IV
11	Earthquake primacy factors	I_e	1.5
12	Seismic design categories		D
13	Response Modification Coefficient	R	8
14	More Powerful Factor Systems	Ω0	3
15	Deflection Magnification Factor	Cd	5.5

Analysis Methods

In this study, the initial analysis method for *fixed base* and *base isolation structures* used equivalent lateral analysis to obtain minimum shear values in the dynamic analysis of spectrum responses. The final stage of analysis with the NLTHA method. Spectrum response analysis uses Bengkulu city spectrum response data taken from RSA 2021. While in non-linear analysis, time history uses 7 pairs of horizontal acceleration components, selected and matched from the recording of individual events of ground motion. Records of earthquake events are listed in Table 3.MCE_R

Table 3
Earthquake recording data used in the study

No	Earthquake name	Manitudo	Earthquake source mechanism
1	Iwate	6,1	Benioff
2	Nemuro	6,2	Benioff
3	Chile	8,81	Megathrust
4	Tokachi	6,6	Megathrust
5	Chi-Chi	6,2	Shallow Faults
6	Cristcruch	6,2	Shallow Faults
7	N Plam Springs	6,06	Shallow Faults

Fixed Base *Structure Analysis*

Fixed base analysis at the linear analysis stage begins by adjusting the function of the building intended as a hospital. Then the determination of the quality of concrete and steel materials has been explained in section 2.1. Furthermore, input was carried out in the Etbas application including earthquake loads and gravity loads the initial design of structural elements, namely beams, columns, and plates according to the limits of SNI 2847:2019.

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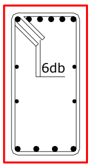
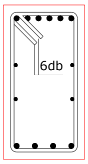
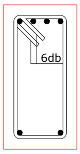
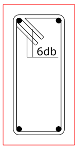
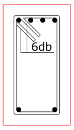
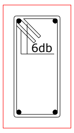
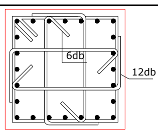
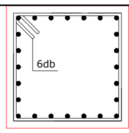
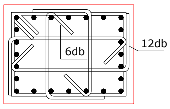
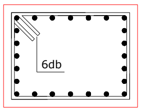
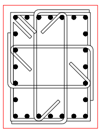
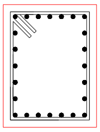
Table 4
SPRMK Beam Repetition

BEAM Type	Focus Area	Filed Area
B 45X85		
Top reinforcement	6D29	6D29
Bottom reinforcement	4D29	4D29
Waist reinforcement	4D19	4D19
Stirrup	2D19-150	2D19-180
B 28X55		
Top reinforcement	4D19	2D19
Bottom reinforcement	2D19	2D19
Stirrup	2D13-110	2D13-180
B 25X45		
Top reinforcement	4D16	4D16
Bottom reinforcement	2D16	2D16
Stirrup	2D10-90	2D10-180

Completed defining the building model according to the provisions of SNI 2847:2019 and SNI 1726:2019. The next step is to conduct *a running* analysis using the Etabs application. After all the design criteria for earthquake-resistant buildings have been in accordance with the provisions of SNI 1726:2019. The next step of analysis is to design reinforcement requirements for structural elements based on the inner forces of the Ethbas analysis. After the reinforcement design is completed, a final analysis is carried out with *non-linear analysis.* A resume of the results of linear analysis of structural elements and reinforcement is listed in Table 4 and Table 5.

Table 5
SPRMK Column Repetition

Column Type	Focus Area	Filed Area
K 85X85		
Longitudinal reinforcement	24D29	24D29
Transverse reinforcement	4D19-110	2D19-150
K 65X85		
Longitudinal reinforcement	24D29	24D29
Transverse reinforcement	4D19-100	2D19-150
K 85X65		
Longitudinal reinforcement	24D29	24D29
Transverse reinforcement	4D19-110	2D19-150

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Base Isolation Structure *Analysis*

Structural design and analysis with HDRB is a continuation of fixed base building design.The initial stage of HDRB device design is to determine some initial parameters for HDRB design according to SNI 1726: 2019 such as; response modification coefficient$R$, nurmeric coefficient of seismic force bearing system in isolation system, R_I, fixed base fundamental period, *effective seismic weight*, SM_I*and* effective seismic weight of structures above the surface of the isolation system W, W_S.

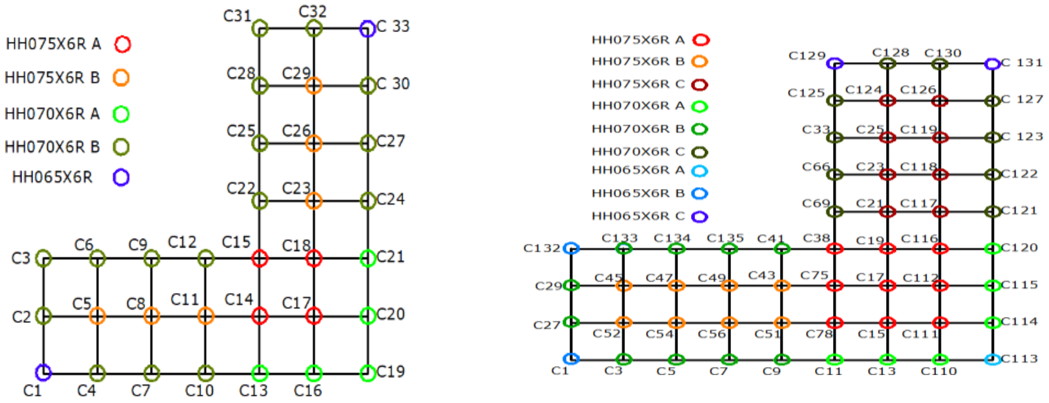
Other parameters in the iteration of designing HDRB according to the reference from (Kelly, 2001) and (Setiawan, 2014) Including; the heaviest point of gravity load on the bottom column with a combination of 1 LL+1 DL, effective damping, β_M, effective damping factor, initial period of HDRB, $B_M$initial effective stiffness of HDRB, and initial maximum displacement, D_M.

After obtaining some previous parameters, the HDRB design continued by calculating the thickness of the rubber and the initial dimensions of HDRB. If the design results of the thick rubber and the initial dimensions of the HDRB do not match the capabilities of the HDRB unit, when supporting the load on it is referred to as *the Nominal Long Tern Column* listed on the HDRB brochure from Bridgestone. So the HDRB dimensions chosen are according to the ability *of the Nominal Long Tern Column* must be greater than the weight of the load that occurs at each column point that will be accommodated by each HDRB unit. After obtaining the type of HDRB used is listed in Table 6. Structural analysis with HDRB is followed by iterating by placing each type of HDRB as shown in Figure 7.

Table 6
Mechanical properties of each HDRB type

Mechanical Properties	Insulator Type Specifications								
	HH075 X6R A	HH075 X6R B	HH075 X6R C	HH070 X6R A	HH070 X6R B	HH070 X6R C	HH065 X6R A	HH065 X6R B	HH065 X6R C
Initial Stifness (kN/m)	6047,6	6954,9	6933,5	6052,4	6058,8	6040,1	5218,6	6224,1	5207
Characteristic Strength (kN)	173,2	173,5	172,5	150,8	151,1	150,3	130,1	130,3	129
Effective Stifness (kN/m)	1039,1	1039,9	1037,6	905,2	905,9	903,7	1039,1	781,2	779
Post Yield Stiffnes Ratio	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1

Figure 7
Typical HDRB installation layout of building 1 (7a) and building 2 (7b)



(7a) (7b)

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3. Results and Discussion

In this section, we will discuss the final results of the structural analysis obtained from the analysis of the response spectrum and NLTHA. The results of the comparison of the performance of *fixed base structures* and building structures with HDRB are discussed in detail in the following sections.

Structure Period

The fundamental periods of *fixed base* and HDRB structures to be compared are the result of the spectral response analysis shown in Table 7 and Figure 8.

Table 7

Resume period comparison of fixed base and HDRB structures

Building Model	Mode 1 (seconds)		Mode 2 (seconds)		Mode 2 (seconds)	
Building 1 *fixed base*	0,772	Translation X	0,769	Translation y	0,721	Z rotation
Building 2 *fixed base*	0,753	Translation X	0,749	Translation y	0,712	Z rotation
Building 1 HDRB	2,959	Translation X	2,958	Translation y	2,806	Z rotation
Building 2 HDRB	3,043	Translation X	3,039	Translation y	2,915	Z rotation

Figure 8

Period Comparison The structure of the 1st, 2nd and 3rd modes

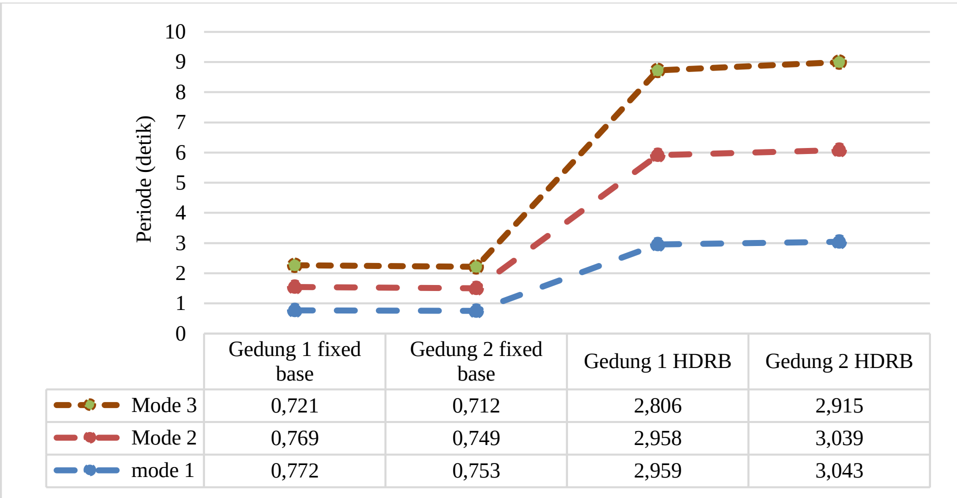

Figure 8 shows a comparative plot of period structures *fixed base* and HDRB. The period of structure with HDRB has a longer period compared to the period of structure *fixed base*. Extension of the HDRB structure period in modes 1, 2 and 3, three times larger compared to the period *fixed base*. The extension period is still in accordance with the range between 1.5 - 3.5 seconds from the period *fixed base* (Kelly, 2001).

Capital Mass Participation Factor

Capital Mass Participation Factor abbreviated MMPF for *fixed base* and isolated structures with HDRB obtained from spectrum response analysis. MMPF comparison resumes of *fixed base* structures and structures with HDRB are shown in Table 8 and Figure 9 as examples of MMPF comparison resumes are shown only in direction X.

From Table 8 it can be seen that structures with HDRB managed to increase MMPF above 90% in both buildings. This shows that the HDRB structure has succeeded in increasing the *mass pertiivation of* the structure which makes the basic shear force will be

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greater into the building structure which will be accommodated by the *assistance* of the HDRB.

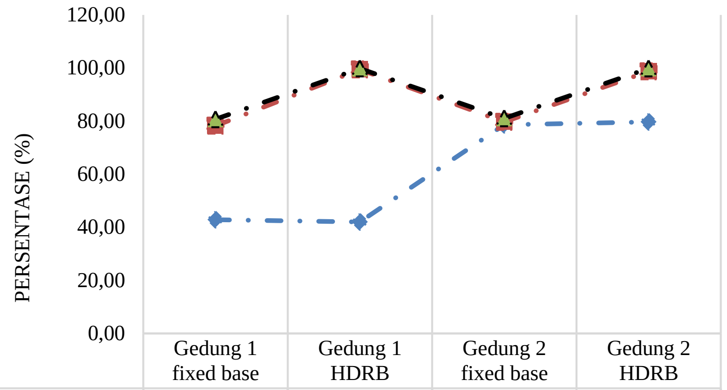
Table 8

MMPF resume, fixed base building structure and HDRB

Building Model	MMPF Mode 1 (%)	MMPF Mode 2 (%)	MMPF Mode 3 (%)
Building 1 *fixed base*	42,90	78,20	80,70
Building 2 *fixed base*	78,60	79,70	81,00
Building 1 HDRB	42,00	99,43	99,84
Building 2 HDRB	79,68	98,68	99,85

Figure 9

Comparison of MMPF Structures in Modes 1, 2 and 3



	Gedung 1 fixed base	Gedung 1 HDRB	Gedung 2 fixed base	Gedung 2 HDRB
MMPF Mode 1	42,90	42,00	78,60	79,68
MMPF Mode 2	78,20	99,43	79,70	98,68
MMPF Mode 3	80,70	99,84	81,00	99,85

Basic Sliding Styles

The basic shear force was obtained from NLTHA analysis, using a 2500-year-old MCER earthquake from 7 earthquake recording data that had been matched. The HDRB structure succeeded in reducing the base shear to be smaller than the fixed base shear, as in building 2 the reduction reached 83%. Table 9 and Figure 10 show the comparison of shear force reduction in building 1, while for building 2 is in Table 10 and Figure 11.

Table 9

Reduction of Basic Shear Force of Building Structure 1

Ground Motion	Fixed Base X (kN)	HDRB X (kN)	Fixed Base Y (kN)	HDRB Y (kN)
Chi-Chi	38279,96	6814,60	38065,47	6467,87
Cristcruch	36224,26	6390,60	37152,55	5427,78
N. Plam Springs	37837,85	6525,70	23938,34	5509,20
Iwate	36250,21	6067,90	40057,01	6862,12
Nemuro	38212,40	6266,60	38926,58	6612,34
Tokachi	174,56	661,50	44981,74	7888,56
Chile	41625,21	11556,20	39188,12	7043,04
	REDUKSI	81%	REDUKSI	82%

The reduction in structural shear force with HDRB is due to a significant extension of the natural period of the structure with HDRB, this is because the structure becomes more flexible and will experience a smaller earthquake acceleration. Smaller earthquake acceleration in structures with HDRB is the cause of reduced base shear forces in isolated structures (Setiawan, 2014).

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Table 10
Reduction of Basic Shear Force of Building Structure 2

Ground Motion	Fixed Base X (kN)	HDRB X (kN)	Fixed Base Y (kN)	HDRB Y (kN)
Chi-Chi	72204,68	12375,28	65069,13	10987,16
Cristcruch	68195,93	12495,62	66678,21	8892,70
N. Plam Springs	71950,89	11679,64	49890,39	9726,89
Iwate	65793,02	11402,19	75661,53	11754,84
Nemuro	71252,00	11624,90	72615,37	11319,26
Tokachi	31,04	1290,57	85678,68	14681,76
Chile	79009,45	21416,70	72095,81	12969,52
	REDUKSI	81%	REDUKSI	83%

Figure 10
Basic Sliding Comparison Fixed base structure of building 1

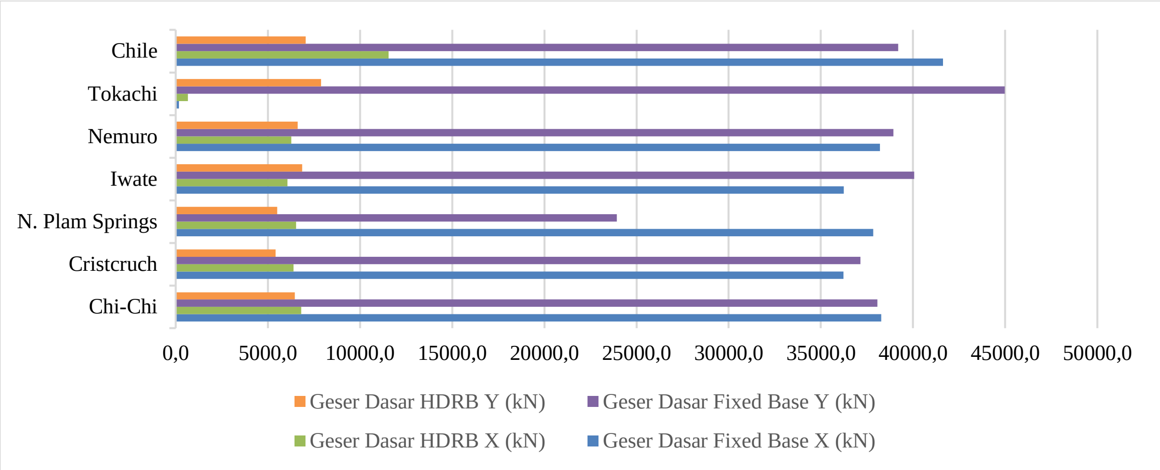
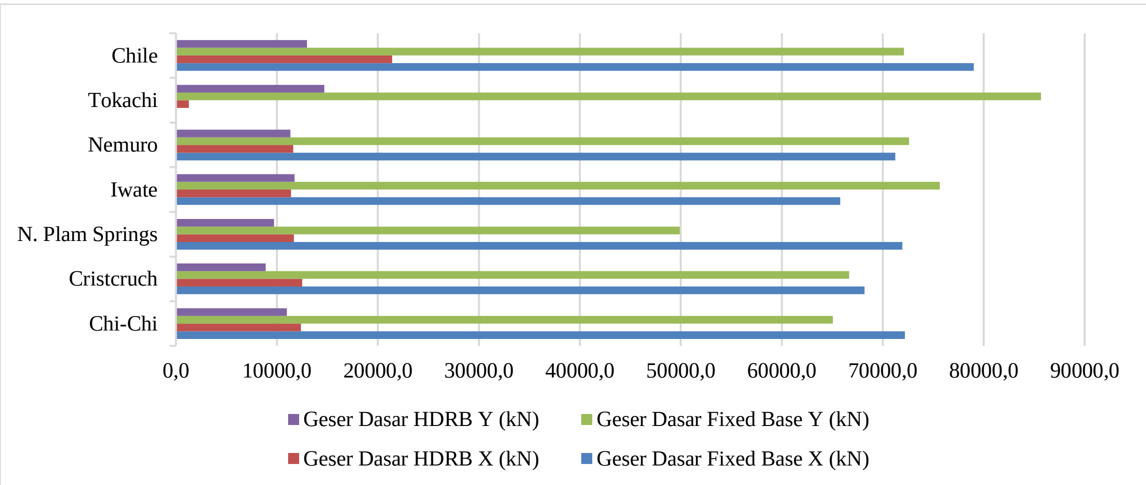


Figure 11.
Comparison of Basic Sliding Fixed base structure of building 2



Inter Story Drift

Building structures with HDRB are checked for inter story drift and global acceptance criteria to assess structural performance from NLTHA analysis. The value of s*tory drift* to

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assess *global acceptance criteria* is the average value of 7 earthquake histories of 2500 years. *Fixed base story drift* is shown in Table 11 and Figure 12 for building 1 and building 2 in Table 12 and Figure 13.

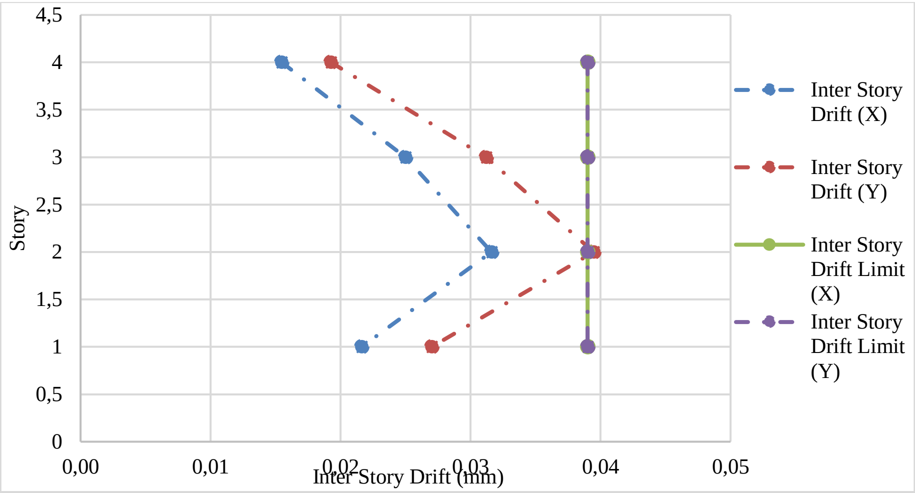
Table 11

Inter story drift Building 1 fixed base

Inter Story Drift X	Inter Story Drift Y	Inter Story Drift Limit X	Inter Story Drift Limit Y
0,015468	0,0192606	0,039	0,039
0,024989	0,0312088	0,039	0,039
0,031610	0,0394717	0,039	0,039
0,021623	0,0270083	0,039	0,039

Figure 12

Checking the Inter Story Drift of Building 1 fixed base



The deviation between levels of building 1 *fixed base* has a deviation value between levels exceeding the *story drift* permit on the 3rd floor shown in Figure 13. Meanwhile, in building 2 *fixed base*, all intersections between floors are still in accordance with *the limits of story drift* permits.

Structures with HDRB have smaller inter-level deviations compared to fixed base structures, this can be seen in Figure 13 that in Building 1 which was originally *in a fixed* base condition *experienced inter-level deviations that exceeded* the limits of the story drist permit *on the 2nd floor but with HDRB installed the deviations between levels became in accordance with the limits*. Checking inter-level deviations for buildings with HDRB in accordance with article 11.4.1.2 SNI 1726:2019. So it can be concluded that the design of the structure with HDRB is in accordance with SNI 1726: 2019.

Table 12

Inter story drift Building 2 fixed base

Inter Story Drift X	Inter Story Drift Y	Inter Story Drift Limit X	Inter Story Drift Limit Y
0,0153	0,0188	0,039	0,039
0,0243	0,0298	0,039	0,039
0,0307	0,0375	0,039	0,039
0,0213	0,0261	0,039	0,039

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Figure 13.
Checking the Inter Story Drift of Building 2 fixed base

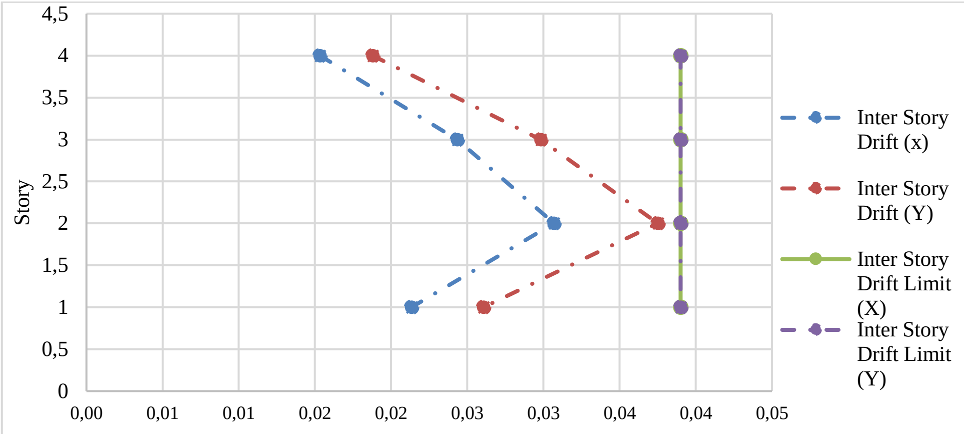

Table 13
Inter story drift Building 1 HDRB

Inter Story Drift X	Inter Story Drift Y	Inter Story Drift Limit X	Inter Story Drift Limit Y
0,0026	0,0033	0,039	0,039
0,0047	0,0058	0,039	0,039
0,0077	0,0098	0,039	0,039
0,0124	0,01566	0,039	0,039

Figure 14.
Checking the Inter Story Drift of Building 1 HDRB

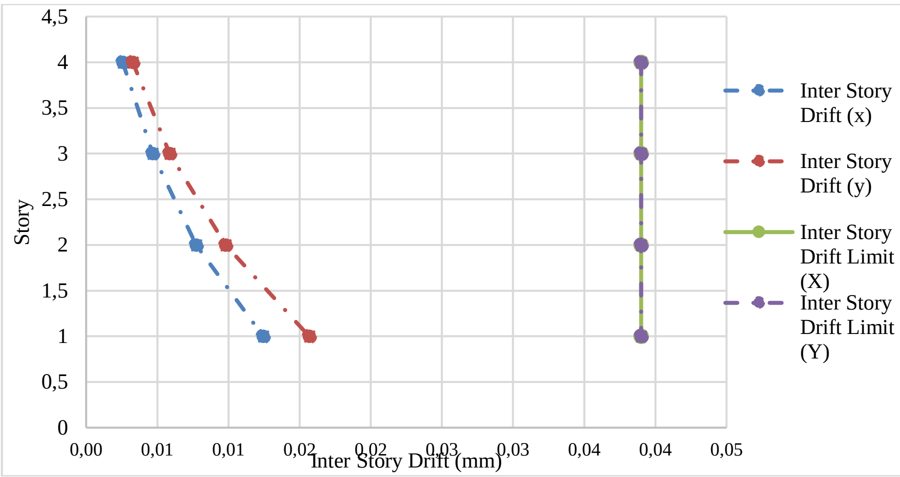

Table 14
Inter story drift Building 2 HDRB

Inter Story Drift X	Inter Story Drift Y	Inter Story Drift Limit X	Inter Story Drift Limit Y
0,0028	0,0035	0,039	0,039
0,0048	0,0059	0,039	0,039
0,0076	0,0087	0,039	0,039
0,0143	0,0127	0,039	0,039

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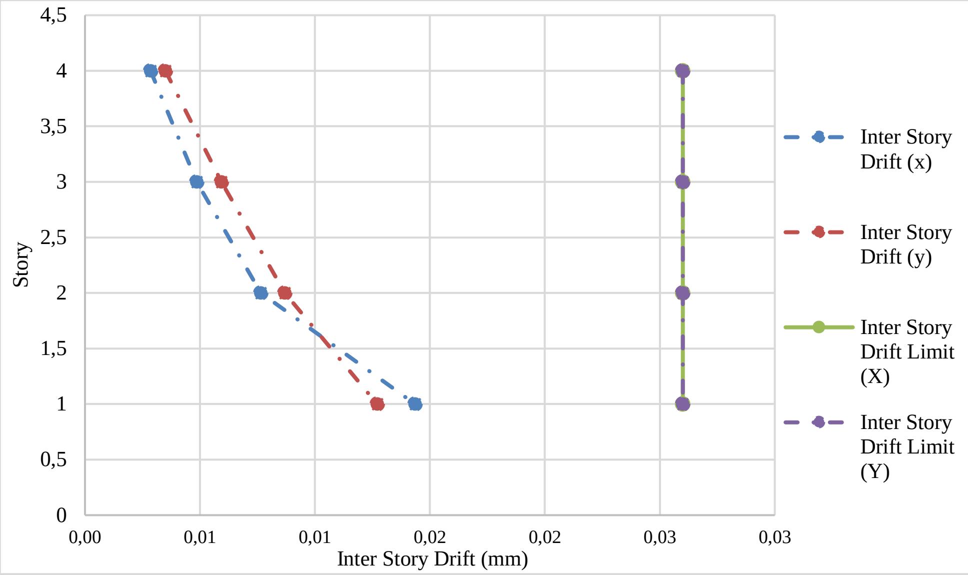
Figure 15.
Checking the Inter Story Drift of Building 2 HDRB



Global Acceptance Criteria

Another important parameter in NLTHA analysis is the assessment of the performance of the structure. The performance structure to be considered is *the global acceptance criteria* related to the value of the *story drift ratio*. The performance of structures as shown in Table 17 and Table 18 shows that structures isolated with HDRB have a smaller *story drift ratio* value than structures with HDRB. The best performance *of the fixed base structure is to achieve* the level of Immediate Operational damage abbreviated IO, but the *fixed base structure also experiences* a level of damage Collapse Prevention *abbreviated* CP on one of the floors in the Y direction of buildings 1 and 2.

Structures equipped with HDRB successfully improve structural performance to the *Operational* level to the OP level. As in buildings 1 and *2, the fixed base* in *story 2* originally had CP structure performance, but after the structure was installed HDRB insulator, its performance increased to OP. This shows that the planned HDRB type insulator succeeded in achieving OP structure performance as the results of previous studies.

Table 15
Global acceptance criteria building structure 1 fixed base

Story	*Story Drift Ratio*			
	X Direction	Explanation	Direction Y	Explanation
Story 4	0,42 %	IO	0,53 %	LS
Story 3	0,68 %	LS	0,85 %	LS
Story 2	0,86 %	LS	1,08 %	CP
Story 1	0,59 %	LS	0,74 %	LS

Table 16
Global acceptance criteria building structure 2 fixed base

Story	*Story Drift Ratio*			
	X Direction	Explanation	Direction Y	Explanation
Story 4	0,42 %	IO	0,51 %	LS
Story 3	0,66 %	LS	0,81 %	LS
Story 2	0,84 %	LS	1,02 %	CP
Story 1	0,58 %	LS	0,71 %	LS

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Table 17
Global acceptance criteria building structure 1 HDRB

Story	*Story Drift Ratio*			
	X Direction	Explanation	Direction Y	Explanation
Story 4	0,07 %	OP	0,09 %	OP
Story 3	0,13 %	OP	0,81 %	OP
Story 2	0,21 %	LS	1,02 %	LS
Story 1	0,34 %	LS	0,71 %	LS

Table 18
Global acceptance criteria building structure 2 HDRB

Story	*Story Drift Ratio*			
	X Direction	Explanation	Direction Y	Explanation
Story 4	0,07 %	OP	0,09 %	OP
Story 3	0,13 %	OP	0,81 %	OP
Story 2	0,21 %	LS	1,02 %	LS
Story 1	0,34 %	LS	0,71 %	LS

Horizontal irregularities

In this study, one of the parameters that must be checked is the horizontal irregularity of the structure. This section discusses only horizontal irregularities of types 1a and 1b relating to the *drift* values of the structure. The purpose of the discussion of horizontal irregularities of types 1a and 1b is to assess whether structures isolated with HDRB can make the value of the *drift* ratio at the most influential floor plan angle smaller than the results of fixed *base structures.*

Table 19
Horizontal Irregular 1a and 1b building 1 fixed base

Story	Δmax/ Δ avg >1.2 = 1a X	Δmax/ Δ avg >1.4 = 1b X	Δmax/ Δ avg >1.2 = 1a Y	Δmax/ Δ avg >1.4 = 1b Y
Story4	1,87	1,87	1,47	1,47
Story3	1,50	1,50	1,27	1,27
Story2	1,11	1,11	1,14	1,14
Story1	1,19	1,19	1,48	1,48

Table 20
Horizontal Irregular 1a and 1b building 2 fixed base

Story	Δmax/ Δ avg >1.2 = 1a X	Δmax/ Δ avg >1.4 = 1b X	Δmax/ Δ avg >1.2 = 1a Y	Δmax/ Δ avg >1.4 = 1b Y
Story4	2,38	2.38	1,10	1,10
Story3	1,46	1,46	1,06	1,06
Story2	1,01	1,01	1,07	1,07
Story1	0,27	1,27	1,16	1,16

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Table 21
Horizontal Irregular 1a and 1b building 1 HDRB

Story	Δmax/ Δ avg >1.2 = 1a X	Δmax/ Δ avg >1.4 = 1b X	Δmax/ Δ avg >1.2 = 1a Y	Δmax/ Δ avg >1.4 = 1b Y
Story4	1,29	1,29	1,05	1,05
Story3	1,22	1,22	1,02	1,02
Story2	1,16	1,16	1,08	1,08
Story1	1,11	1,11	1,13	1,13

Table 22
Horizontal Irregular 1a and 1b building 2 HDRB

Story	Δmax/ Δ avg >1.2 = 1a X	Δmax/ Δ avg >1.4 = 1b X	Δmax/ Δ avg >1.2 = 1a Y	Δmax/ Δ avg >1.4 = 1b Y
Story4	1,25	1,25	1,03	1,03
Story3	1,19	1,19	1,08	1,08
Story2	1,15	1,15	1,12	1,12
Story1	1,11	1,11	1,15	1,15

As shown in Table 21 and Table 22, structures with HDRB only experience irregularities 1a on the 3rd and 4th floors of building 1, while in building 2 only occur on the 4th floor. And the ratio value / on building structures with HDRB has a smaller value than $\Delta_{max}\Delta_{avg}$*fixed base.* This proves that structures equipped with HDRB insulators successfully reduce the torque that occurs in the structure. So as discussed in Subchapter 4.8 that structures with HDRB succeed in making the CM and CR values of the structure more crowded due to reduced torque and deviation differences from different building plan angles become smaller.

4. Conclusion

Performance Structures that have horizontal irregularities with HDRB have better performance compared to fixed base structures. This is evidenced by the value of global acceptance criteria, the structure with HDRB achieving operational performance while the fixed base structure only achieves life sefety performance. When compared with another parameter between the natural periods of the structure, MMPF, the base shear force shows that the response of structures that have horizontal irregularities with HDRB has better performance than fixed base structures.

Comparison of the performance response of fixed base structures and with HDRB when seismic forces occur from the following structural performance parameters: HDRB-equipped structures are able to extend the natural period of the structure by more than 3 times the period of fixed base structures as in building 1 of the extended period from 0.77 seconds to 2.96 seconds after HDRB insulators are installed. Structures with HDRB are capable of increasing MMPF in modes 1, 2, and 3. It can be seen that the mass participation of HDRB structures in mode 2 and mode 3 has reached more than 90%. The basic shear force that

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occurs in the fixed base structure has been reduced by HDRB insulators reaching more than 81%. Story drift from NLTHA analysis shows that the deviation between levels that occur in fixed base structures is successfully reduced in structures with HDRB. The results of the analysis show that the value of story drift structure with HDRB has a longer range to pass the limitation of story drift permission. Structures with HDRB have a smaller ratio value than $\Delta_{max}\Delta_{avg}$fixed base structures. So that making structures with HDRB in building 1 and building 2 does not experience type 1b irregularities and only experiences 1a irregularities on the 4th floor. This is different from fixed base structures that experience irregularities 1a and 1b in both buildings.

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