Seismic Behavior of Building Structures using Time History Analysis (Case Study: RSPAL Surabaya)

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Abstract

It is important to consider earthquake-resistant building construction in Indonesia due to its vulnerability to earthquakes. Ground acceleration directly affects structures. High-rise buildings in high seismic zones require special planning and review to remain safe during earthquakes. Structural analysis for earthquakes can be divided into two methods: static and dynamic analysis. In dynamic analysis, there are two main approaches: response spectrum analysis and time history analysis. Understanding building structure behavior involves applying forces to the structure. One example is the complex force of earthquakes, which have irregular characteristics and random timing. To simplify the influence of earthquake forces, spectrum response and time history analyses are conducted. In time history analysis, earthquake forces from previous events are adjusted to fit design loads. A study aimed to analyze the behavior of existing buildings, such as the RPAL Surabaya Inpatient Building, using the Specific Moment Resisting Frame (SRPMK) system with the Time History method. This study was conducted in Surabaya, and scaling processes were applied to Load Cases in each Time History, derived from scale factor calculations. The most critical inter-story drift from time history analysis was during the Tabas earthquake, where the total displacement did not meet requirements.

Keywords: *structure behavior, seismic analysis, time history, smrf.*

1. Introduction

Earthquakes have shown that many buildings in Indonesia suffer damage ranging from minor to severe, even collapsing. This is due to Indonesia being located in a tectonic zone, where three major and nine minor tectonic plates meet within its territory. Most earthquake casualties result from people being trapped under collapsed buildings because these structures cannot withstand the tremors. It's crucial to consider constructing earthquake-resistant buildings in Indonesia due to the country's vulnerability to earthquakes [1][2][3]. Earthquake acceleration at the ground surface is a direct factor that influences the structure [4][5]. High-rise buildings located in high seismic zones require special planning and scrutiny to remain safe while withstanding earthquake forces[6].

Analysis of structures against earthquakes can be divided into two methods, namely static analysis and dynamic analysis. In dynamic analysis, there are two main approaches, namely response spectrum analysis and time history analysis [7][8]. One way to understand the behavior of building structures is by applying forces to the structure. One example of a complex force is seismic force, which has irregular characteristics and random timing. To simplify the impact of seismic forces, it can be done through spectrum response analysis and time history [9]. The seismic force input is derived from previous earthquakes and adjusted to the design load. [10]. Due to the difficulty in predicting ground movements caused by earthquakes in a particular area, earthquake representations in the form of ground movement simulations are used as input. Each simulation provides information about structural behavior, including lateral displacement (drift), displacement, and base shear force. [2].

The aim of this research is to conduct a study on the behavior of the existing building at RPAL Surabaya Inpatient Ward, where the structural system is a special moment frame system (SRPMK) using the Time History method. The research utilizes earthquake recordings adjusted to the design response spectrum in Surabaya city. To understand the structure behavior, the reference used is SNI 1726-2019, along with the assistance of structural modeling software.

2. Method

The reference in this study is the Time History analysis procedure, and the structural loading provisions is [11] (Procedures for Earthquake Resistance Planning for Building Structures, both Building and Non-Building Structures). Also utilizing structural modeling software for structural analysis.

(1). Building Data

Structural analysis requires existing building structure data, including general building information, planning drawings (Figure 1 and Figure 2), and soil data.

Building General Data:

Building Name	: RSPAL Surabaya
Location	: Jl. Gadung No 1, Surabaya, East Java
Function	: Hospital
Number of Floors	: 4 floors + Helipad
Building Height	: 21.05 meters
Structure Material	: Composite Structure
Structure System	: Special Moment Resisting Frame (SMRF)

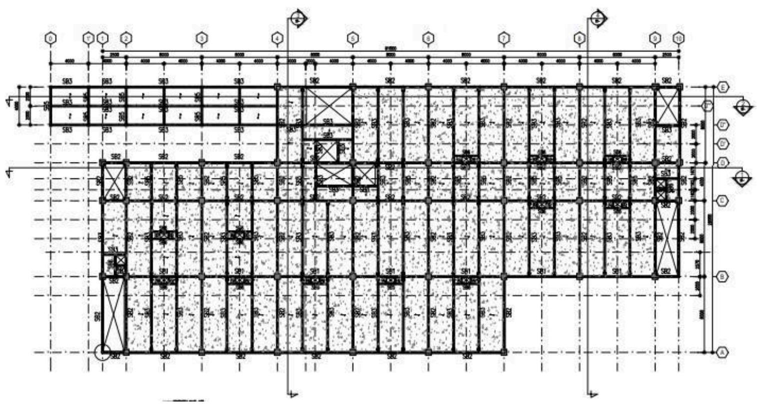


Figure 1. Layout of Existing Building

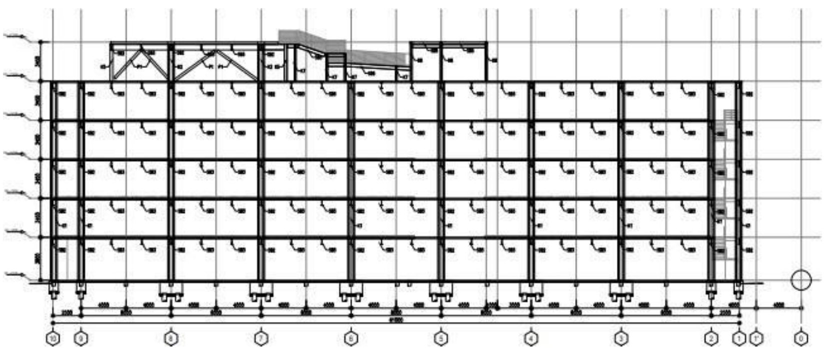


Figure 2. Long Section of Existing Building

(2). Loading Analysis

The load analysis in this study includes dead loads, live loads, and earthquake loads adjusted to the applicable loading regulations. Live load is a load that can change or move with the use of building spaces, which are not part of the building's structural construction. All live loads have the ability to shift or change position. Reference [11] is used to determine the minimum loads in building planning. Dead load is the weight of all permanent building components, including additional elements inseparable from the structure. This is regulated by standard [11] to establish minimum loads in building planning for both buildings and other structures. Earthquake load refers to the force applied to the structure as a result of ground movement caused by earthquakes, whether tectonic or volcanic, impacting the structural integrity. The guidelines used in planning earthquake resistance for building and non-building structures is [11]. In modeling, earthquake loads are analyzed in three-dimensional dynamic analysis according to[11].

(3). Structural Behavior Control

In this study, several controls will be conducted on the behavior of the structure, including inter-story drift, mass participation, shear force control, dual system control, and particularly time history analysis. In Section 11.1.1 [11] nonlinear time history analysis can be used as required to demonstrate the strength, stiffness, and ductility in resisting maximum earthquake shaking (MCER). Time history analysis uses earthquake records downloaded from the PEER database (The Pacific Earthquake Engineering Research), headquartered at the University of California at Berkeley. It has a collection of more than 10,000 strong motion ground motion records consisting of 173 different earthquake data and can be accessed publicly online. The time period of the structure is determined by equations (1) and (2), while the inter-story drift is shown in equation (3).

$$Ta = Ct.\ hn^{x} \quad (1)$$

$$Tmax = Cu.\ Ta \quad (2)$$

$$\delta x = \frac{Cd.\delta xe}{Ie} \quad (3)$$

3. Results and Discussion

The structure of the RSPAL Inpatient Hospital in Surabaya is modeled in 3D using structural modeling software, and it consists of a composite steel and concrete moment frame structure. The modeled structure comprises 4 floors + 1 roof deck + Helipad, with a height of 21.05 meters. This program will assist in structural calculations according to the requirements of SNI 1726-2019. The 3D structural modeling can be seen in Figure 3. Material quality for the RSPAL building structure:

Steel Grade (fy) : Wiremesh (500 Mpa)
Concrete Grade (fc') : Column (30 MPa), Beam (25 Mpa)

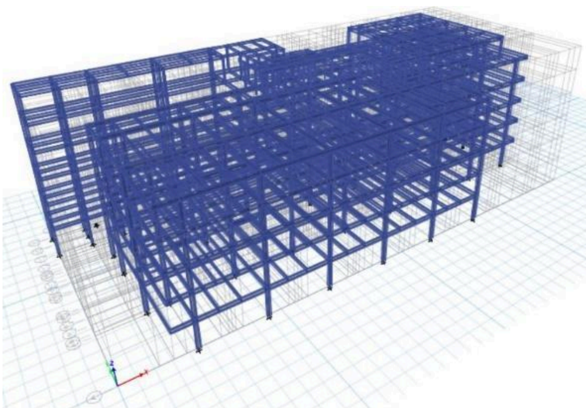


Figure 3. 3D Building Structural Modeling

(1). Load Analysis

In structural analysis, there must be accurate calculations for the loads acting on the building structure. Load analysis on the structure includes seismic loads, which refer to [12] and live and dead loads referring to [11].

(a). Dead Loads

Dead load, or dead load, is the total load of all components including columns, beams, and floor slabs. Dead load includes the self-weight of structural elements (DL) and additional dead load (SIDL). If all the self-weight of these structural elements has been automatically calculated in the structural modeling program. The details of the dead load on the structure can be seen in Table 1.

Table 1. Dead Load on the RSPAL Building Structure

Num	Materials	Loads (KN/m²)
1	Coloum Dead load	0,6191025
2	Beam Dead load	2,29585
3	Partitions	6
4	*Roof* Dak	0,981
5	Corridors	1,667
6	*Helipad & Walkway*	0,785
7	*Office*	1,471
8	Laboratorium	1,667
9	Patient room	1,667

(b). Live Loads

Live load is a load that varies or moves according to the usage of the building (space) and movable dead loads. This loading refers to [11] Table 4.3-1, based on the building being used as a hospital, shows the loading as indicated in Table 2.

Table 2. Live Load on the RSPAL Building Structure

No	Room Function	Loads (KN/m²)
1	Warehouse	3,923
2	*Helipad*	73,55
3	Corridor	3,83
4	*Office*	2,452
5	Operation Room	2,87
6	Patients Room	1,92
7	*Roof Tank*	4,903
8	*Roof Tank*	24,517
9	*Dack Roof*	0,981
10	Stairs	8
11	*Walk Way*	7,846

(c). Seismic Load

In the modeling, seismic loads are applied through three-dimensional dynamic analysis in accordance with [12]. The response spectrum is determined according to the Surabaya city earthquake. The earthquake response spectrum applied to the RSPAL building structure at the location is shown in Figure 4.

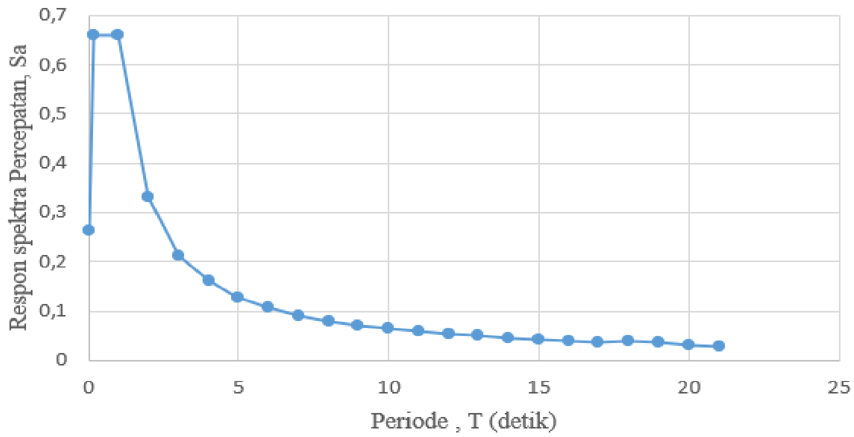


Figure 4. Seismic Response Spectrum for the Surabaya Region

(d). Loading Combinations
The loading combinations use ultimate load conditions, where the loads are multiplied by the scaling factor predetermined based on [12] Article 4.2.2. The basic loading combinations in the ultimate method are stated as follows:
1. 1,4D
2. 1,2D + 1,6L + 0,5 (Lr atau R)
3. 1,2D + 1,6 (Lr atau R) + (L atau 0,5W)
4. 1,2D + 1,0W + L + 0,5 (Lr atau R)
5. 0,9D +1,0W

The combination of loading affected by seismic loads should be considered with the basic load combinations and should not necessarily be considered simultaneously with wind loads. The loading combinations with the influence of seismic loads are as follows:
6. 1,2D + Ev + Eh + L
7. 0,9D – Ev +Eh

(2). Structural Behavior Control
(a). Mass Participation
According to [12] Article 7.9.1 states that the requirement for controlling mass participation is 100%, but the alternative obtained below 100% is a minimum of 90%. Mass participation from the analysis using the structural modeling program can be seen in Table 3.

Table 3. Modal Mass Participation Ratio

Case	Mode	Period	UX	UY	UZ	SumUX	SumUY	SumUZ
Modal	1	2,559	0,0000	0,1573	0	0,0000	0,1573	0
Modal	2	2,25	0	0,5448	0	0,0000	0,7021	0
Modal	3	2,018	0,0000	0,0021	0	0,0000	0,7042	0
Modal	4	1,843	0,001	0,0265	0	0,001	0,7307	0
Modal	5	1,778	0,0007	0,0679	0	0,0017	0,7986	0
Modal	6	1,664	0,0081	0,0000	0	0,0098	0,7986	0
Modal	7	1,646	1,646	0,0000	0	0,7395	0,7987	0
Modal	8	1,628	1,628	0,0001	0	0,7398	0,7988	0
Modal	9	1,557	1,557	0,0004	0	0,7412	0,7992	0
Modal	10	1,5	1,5	0,0038	0	0,8418	0,803	0
Modal	11	1,454	1,454	0,0178	0	0,9418	0,9208	0
Modal	12	1,445	1,445	0,0006	0	0,9421	0,9714	0

According to Table 3, the building structure achieves a minimum range of modal mass participation of over 90% in mode 11, with a total of 12 modes considered. This is consistent with [12] article 7.9.1.

(b). Time Period

Based on [12] Article 7.8.2 states that the fundamental period of the structure in the direction under consideration should be obtained using the structural properties and the deformation characteristics of the load-carrying elements tested in the analysis. The fundamental period of the structure should not exceed the product of coefficients for the upper limit on the calculated period. The analysis vibration time in the structural modeling is obtained as 2.127 seconds. The structural vibration time Mode 1 (Tc) is 2.127 seconds. The building structure is likely to experience movement every 2.127 seconds, as depicted in Figure 6. For the short fundamental period approach according to SNI 1726-2019, it is obtained using equation (1). The Inpatient Hospital (RSPAL) building structure in Surabaya is a composite structure with a special system. According to SNI 1726-2019 table 18, the value obtained is:

Ct = 0,0724
Hn = 21,05 m
X = 0,8
Ta = Ct . hnx
= 0,0724 . 21,05 0,8
= 0,8286 s

Cu values are obtained from SNI 1726-2019 table 17 with SD1 = 0.64, thus: Cu = 1.4, resulting in the value,

Tmax = Cu . Ta
= 1,4 . 0,8286
= 1,16 s < Tc (2,127 s)

From the calculation :
Ta (0,8286s) < Tmax (1,16s) < Tc (2,127s)
Thus, for the seismic response coefficient (Cs) using T = 1,16 detik

(c). Base Shear

The nominal seismic base shear values from the modeling results in the structural modeling application are as shown in Table 4.

Table 4. Base Shear

Output Case	Case Type	Step Type	FX	FY
RSPx	LinRespSpec	Max	11597,6436	35,8806
RSPy	LinRespSpec	Max	35,8806	9620,0149

Based on Table 4 The results of the response spectrum variation analysis (Vt) for the X and Y directions are as follows,

Vt X-direction = 11597,6436 Vt Y-direction = 9620,0149

To calculate the nominal seismic base shear value (V), you can follow these steps:

V = Cs . Wt
V = 0,0281 . 212611,69 = 5974,38 kN

Based on SNI 1726-2019 Article 7.9.2.5.1, for each ground motion analyzed, the maximum inelastic base shear forces, VIX and VIY, for the X and Y directions must be determined with:

• Vix = (VE. Ie) / Rx
= (5974,38 x 1,5) / 8
= 1120,19
• Viy = (VE. Ie) / Ry
= (5974,38 x 1,5) / 8
= 1120,19

Referring to SNI 1726-2019 Article 7.9.2.5.2, the base shear forces VX and VY for the X and Y directions must be calculated based on:

• ɲx = Vx / Vix ≥ 1,0

= 11597,6436 / 1120,19 ≥ 1,0
= 10,35 ≥ 1,0

• ɲy = Vy / Viy ≥ 1,0
= 9620,0149 / 1120,19 ≥ 1,0
= 8,58 ≥ 1,0

From the calculation results of ɲx and ɲy ≥ 1, it is confirmed to be satisfied.

(d). Story Drift

Based on [12] Article 7.8.6 The determination of design inter-story drift shall be calculated as the difference in displacement at the center of mass above and below the reviewed level. Inter-story drift in the x-direction (δx) shall be determined after obtaining the value of δx obtained from the output of the structural modeling program in accordance with equation (3).

Cd = 5,5 (SNI 1726 – 2019 Table 12)
δx = Story drift in the x-floor
Ie = 1,0 (SNI 1726 – 2019 Table 4)

The design combination loads for short-term inter-story drift (Δ) must not exceed the allowable inter-story drift (Δall) as regulated in SNI 1726-2019 Article 7.12.1 for reinforced concrete structures. The allowable inter-story drift is limited to:

Δall = 0,020.hsx

For example Δall in the mz floor :

Δall = 0,020.hsx
= 0,020.3800
= 76 mm

For the calculation of inter-story drift with allowable deflection, please refer to Table 5 and Table 6.

Table 5. Inter-story Drift in the X Direction

Story	Elv	hsx	□ex	□x	Δx	Δall	Descriptions
Helipad	21,05	3450	62,029	227,4397	35,449	69	OK
Atap	17,6	3450	52,361	191,9903	44,194	69	OK
Lantai 4	14,15	3450	40,308	169,796	34,148	69	OK
Lantai 3	10,7	3450	30,995	120,9817	39,428	69	OK
Lantai 2	7,25	3450	20,242	81,554	37,319	69	OK
Lantai 1	3,8	3800	10,064	36,90133	36,901	76	OK
Lantai Dasar	0	0	0	0	0	0	OK

From Table 5, the checking of inter-story drift occurring in the inter-floor drift in the x-direction can be categorized as safe because the story drift value does not exceed the allowable limit.

Table 6. Inter-story Drift in the Y Direction

Story	Elv	hsx	□ex	□x	Δx	Δall	Descriptions
Helipad	21,05	3450	55,261	283,2903	28,717	69	OK
Atap	17,6	3450	47,429	247,2397	32,545	69	OK
Lantai 4	14,15	3450	38,553	203,6943	27,544	69	OK
Lantai 3	10,7	3450	31,041	146,817	28,780	69	OK
Lantai 2	7,25	3450	23,192	92,37067	42,636	69	OK
Lantai 1	3,8	3800	11,564	42,40133	42,401	76	OK
Lantai Dasar	0	0	0	0	0	0	OK

From Table 6, the inter-story drift check for the inter-floor drift in the Y direction is categorized as safe because the story drift values do not exceed the permissible limit. Figure 5 depicts the inter-story drift diagram for the X and Y directions. Knowing that the results of the inter-story drift check for the earthquake response spectrum forces in the X and Y directions can be categorized as safe because the story drift results do not exceed the permissible limit.

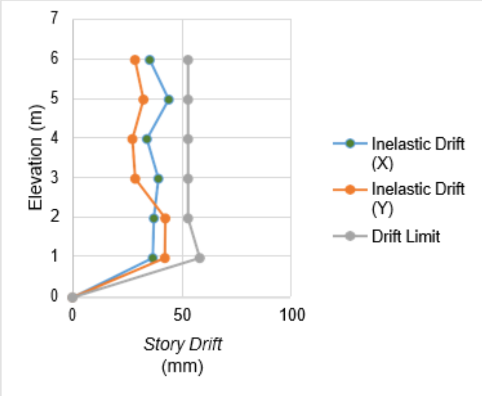


Figure 5. Diagram of *Story Drift Respons Spectrum* X and Y Direction.

(3). *Time History Analysis*

The time history analysis is input using earthquake data recordings obtained from the PEER website. After obtaining SE soil data (Soft Soil), the initial step in processing the Time History data is to access https://ngawest2.berkeley.edu/ with several steps to obtain the data. 11 earthquake recordings are used for the time history analysis, as shown in Table 7.

Table 7. Recapitulation of Eartquake Time History

Num	Earthquake	Years	Station	RS
1	Chi-Chi, Taiwan	1999	CHY028	7,26
2	Duzce, Turki	1999	Bolu	7,14
3	El mayor, Mexico	2010	El Centro	7,20
4	Friuli, Italy	1976	Forgaria Cornino	5,91
5	Imperial Valley	1940	El Centro	6,95
6	Kobe, Japan	1995	Takarazuka	6,90
7	Kocaeli, Turki	1999	Duzce	7,50
8	Loma Prieta	1989	LGPC	6,93
9	Northridge	1994	Beverly Hills	6,69
10	San fernando	1971	Pacoima Dam	6,61
11	Tabas, Iran	1978	Tabas	7,40

From Table 7, earthquake data in the form of X and Y direction accelerograms were obtained from the PEER website. The actual earthquake accelerogram response spectrum must be matched with the elastic design response spectrum. The accelerogram data from the PEER website is input into the application to obtain the elastic design response spectrum. With the help of the selected accelerogram program, it can be modified so that the elastic response spectrum matches (with a tolerance of 30%) the elastic design response spectrum.

Inputting 11 earthquake records in the X and Y directions into the application, adjusted for several parameters such as soil type and magnitude from previous earthquakes, further analysis can be conducted. As shown in Figure 6, the input for the Chi-Chi earthquake in the X direction is demonstrated.

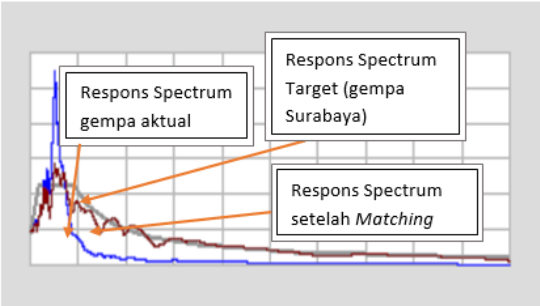


Figure 6. ***Chi-Chi X Matched to Respons Spectrum***

(a). *Base Shear*

The results of the analysis discussed in the time history analysis include the base shear and inter-story drift. The nominal base shear values resulting from the Time History analysis for the X and Y directions can be seen in Table 8.

Table 8. Base Shear from Time History Analysis

Output Case	Fx	Fy
Chi-Chi X	4634,53	1991,2
Chi-Chi Y	1581,2	4327,6
Duzce X	6339,23	3989,2
Duzce Y	1527,9	2636,10
El mayor X	1742,7	1916,4
El mayor Y	1607,8	2179,4
Friuli X	7841,95	3687,5
Friuli Y	3721,67	7811,2
Imperial Valley X	8569,2	3854,9
Imperial Valley Y	2716,9	9272,7
Kobe X	9151,2	2699,71
Kobe Y	3520,2	4725,4
Kocaeli X	1524,35	3513,2
Kocaeli Y	4514,2	1729,83
Loma Prieta X	9657,66	2885,21
Loma Prieta Y	2361,56	5563,98
Northridge X	1401,92	3641,66
Northridge Y	3495,81	9148,72
San fernando X	5031,27	2636,89
San fernando Y	2883,42	4303,7
Tabas X	1259,08	3701,27
Tabas Y	4383,46	9677,43

Referring to SNI 1726-2019 on 7.9.2.5.1, for each ground motion analyzed, the maximum inelastic base shear forces, VIX and VIY, for the X and Y directions, must be determined based on:

• Vix = (VE. Ie) / Rx
  = (5974,38 x 1,5) / 8
  = 1120,19

• Viy = (VE. Ie) / Ry
  = (5974,38 x 1,5) / 8
  = 1120,19

Based on SNI 1726-2019 on 7.9.2.5.2, the base shear forces VX and VY for the X and Y directions are calculated.

• ɲx = Vx / Vix ≥ 1,0
  = 7841,95 / 1120,19 ≥ 1,0
  = 7,05 ≥ 1,0

• ɲy = Vy / Viy ≥ 1,0
  = 3721,67 / 1120,19 ≥ 1,0
  = 3,32 ≥ 1,0

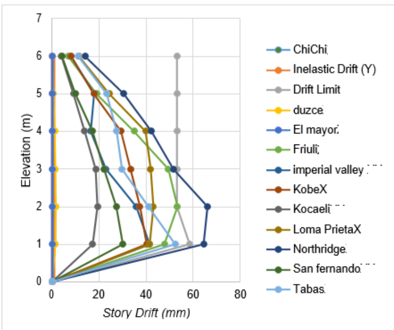
Based on the calculation results of the Chi-Chi earthquake force, ɲx and ɲy ≥ 1.0, indicating compliance. The recapitulation of base shear for each earthquake can be seen in Table 9. As shown in Table 9, the seismic base shear results from the calculations yield values of ɲx and ɲy greater than or equal to 1. Therefore, the earthquake forces meet the specified criteria.

Table 9. Recapitulation of Base Shear from Time History Analysis

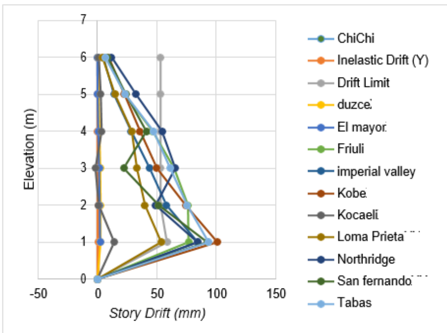
Output Case	FX	FY	ɲx	ɲy	ɲ ≥ 1,0
Chi-Chi X	4634,53	1991,2	4,13	1,77	OK
Chi-Chi Y	1581,2	4327,6	1,41	3,84	OK
Duzce X	6339,23	3989,2	5,65	3,56	OK
Duzce Y	1527,9	2636,10	1,36	2,35	OK
El mayor X	1742,7	1916,4	1,55	1,71	OK
El mayor Y	1607,8	2179,4	1,43	1,94	OK
Friuli X	7841,95	3687,5	7,05	3,22	OK
Friuli Y	3721,67	7811,2	3,32	3,32	OK
Imperial Valley X	8569,2	3854,9	7,64	3,44	OK
Imperial Valley Y	2716,9	9272,7	2,42	8,21	OK
Kobe X	9151,2	2699,71	7,16	2,41	OK
Kobe Y	3520,2	4725,4	3,14	4,21	OK
Kocaeli X	1524,35	3513,2	1,36	3,13	OK
Kocaeli Y	4514,2	1729,83	4,02	1,54	OK
Loma Prieta X	9657,66	2885,21	8,62	2,57	OK
Loma Prieta Y	2361,56	5563,98	2,10	4,96	OK
Northridge X	1401,92	3641,66	1,25	3,25	OK
Northridge Y	3495,81	9148,72	3,12	7,16	OK
San fernando X	5031,27	2636,89	4,49	2,35	OK
San fernando Y	2883,42	4303,7	2,57	3,84	OK
Tabas X	1259,08	3701,27	1,12	3,30	OK
Tabas Y	4383,46	9677,43	3,91	8,63	OK

(b). Story Drift

The inter-story drift values resulting from the time history analysis for the X and Y directions can be seen in Figure 9.



(a)



(b)

Figure 7. ***Story Drift For Earthquake X in The X Direction***

In Figure 7(a), the Story Drift graph for Earthquake X in the X direction shows that one earthquake exceeds the allowable limit, which is Northridge SR 6.69. Figure 7(b) depicts the Story Drift graph for Earthquake X in the Y direction, where several earthquakes exceed the allowable limit, including Northridge SR 6.69, Kobe SR 6.69, Friuli SR 6.5, Imperial Valley SR 6.95, and San Fernando SR 6.61.

4. Conclusions

Behavioral Structure Study is an evaluation of the behavior that occurs during the occupancy of the Inpatient Building of RSPAL using the time history method with 11 earthquake records that have been matched to the Surabaya earthquake response spectrum, the following are the conclusions from the analysis: Mass participation in the X direction is 74.18% and in the Y direction is 80.3%. These results indicate a combined distribution of variability. The time period from the analysis with the first mode in the application analysis yielded a value of Tc = 2.127 seconds. The largest base shear from linear time history for the X direction is 9657.66 kN for the Loma Prieta earthquake and 9677.43 kN for the Tabas earthquake in the Y direction. This study was conducted in the Surabaya area, and for each Time History Load Case, a Scaling process was also conducted, where these results were obtained from the calculation of the scaling factor values. The most critical inter-story drift from the time history analysis is for the Tabas earthquake, where the total displacement value does not yet meet the requirements.

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