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A comparative study of dynamic performance the shear-wall and bracing shapes on the tall building in seismic area

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Abstract: The solution to overcome earthquake loads in the seismic regions is to use resisting systems such as shear walls and braces. It can be used as an alternative design for resisting systems of tall buildings. The main purpose of this research is to compare the performance of tall buildings with resisting systems of partial shear walls and a variety of brace shapes in the seismic area of Malang City, Indonesia, by using the partial shear wall against braces of reinforced concrete in the shapes of V, inverted V (Λ) and X (on two floors). The mechanical properties of the materials utilized in the models are determined from laboratory testing results. They consist of 30 MPa compressive strength concrete, 250 MPa yield strength steel, and 410 MPa ultimate strength steel. To overcome the lack of bracing, position the braces on the outer side of the building and the number resisting. The several outputs reviewed are stiffness, displacement, drift, ductility, vibration period, and natural frequency. In this study, structural analysis using SAP 2000 v.20 software is used in the four models of the eight-story existing structure in Malang City. The results showed that the inverted V (Λ) reinforced concrete brace is the most suitable design as an alternative design for the building, compared to the partial shear wall and the other bracing shapes. The results of the study that in the X-direction the stiffness, displacement, drift, ductility, vibration period, and natural frequency respectively as follows 4.92865E+12 N/mm, 144.53 mm, 127.73 mm, 0.339, 1.12 s and 0.893 Hz. Whereas the displacement and drift in the Y-direction are 127.97 mm and 113.63mm. For practical implication, using a fully shear wall and the inverted V(Λ) brace creates a better performance of the structure in seismic areas.

Keywords: *Dynamic performance, Numerical modeling, Shear-Wall; bracing, Structural stability, Tall building.*

1. Introduction

Earthquakes are caused by vibrations that shock the earth's crust, potentially leading to damage to buildings [1-8]. Solutions to overcome this lateral load are inserting of diagonal structural elements such braces, shear walls, or by changing the relationship between structural elements [9-12]. Several investigations and studies have been conducted in Indonesia concerning the impact of earthquakes [13-15] to discover the answer for repairing damages [16, 17].

A shear wall is a structural element that provides support by resisting lateral forces like strong winds and seismic activity such as earthquakes or explosions. Shear force in civil engineering is the force that acts perpendicular to structural elements like beams and columns, leading to twisting and bending. A shear wall is a component designed to withstand horizontal forces, specifically those in line with the wall's surface. The shear wall counters the loads from cantilever action on slender walls with higher

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flexural deformation. In order to effectively work, shear walls must extend from the top to the bottom of the building to allow sliding past one another. Several research and studies were investigated due the using shear-wall in the high-rise building, [18-24].

Diagonal braces offer an alternative method of stiffening building structures, increasing rigidity, resisting lateral loads, enhancing ductility and strength, and minimizing energy from vibrations [25-27]. Typically, tall buildings respond differently to earthquake tremors in contrast to buildings with fewer levels. The building's mass, ground acceleration, foundation type, and structural dynamic characteristics all play a role in determining the level of inertia forces produced during an earthquake. Several researchers have also investigated how steel frames respond to seismic forces when equipped with different bracing systems, [28, 29] using numerical analysis [14, 27, 30-33].

Braces come in different shapes and positions, their utilization is tailored to the specific design and how they affect the structural behavior in response to loads on skyscrapers. Multiple previous research studies have integrated the functions of the bracings and dampers to reduce the impacts of earthquakes, [15, 34].

Indonesia is surrounded by volcanoes so it is vulnerable to earthquakes hazard, [35]. Some investigations have been studied in Indonesia regarding the earthquake effects, [26, 36].

In this study, analyzed the structural performance of the use of shear walls and braces V, inverted V (Λ) and X (on two floors) against earthquake loads applied to the nine-story building in Malang City of Indonesia. To increase the stiffness of the braces so that they are equivalent to the stiffness of the shear wall, the number of braces is added and placed on the outer part of the building. Researchers want to know the comparison of the performance of the structure is rigidity, period of vibration, base sheer force of the building, lateral deviation (displacement), and drift caused by the use of shear walls against reinforced concrete braces and whether the braces can be used as alternative reinforcement in tall buildings.

2. Materials and Method

In this paper, the investigation looks into specific an eight-story rectangular office building with a plan layout and size 78.00 m × 28.00 m. The story heights are: 3.50 m for basement; 5.50 m for first floor; 4.00 m for fourth, fifth, and sixth floors; 5.00 m for seventh floor. Figure 1 displays the site layout of the existing building of Malang, Indonesia.

2.1. Materials

Laboratory testing results are the source of input materials for modeling structures. Various mechanical properties of the materials utilized in this study are identified through laboratory testing, shown in Table 1.

Table 1.
Mechanical characteristics of the materials.

Properties	Concrete	Steel
Compressive strength, (f_c)	30 MPa	-
Yield strength, (f_y)	-	250 MPa
Ultimate strength, (f_u)	-	410 MPa
Modulus of elasticity, (E)	25742.96 MPa	21000000 MPa

2.2. Structure Analysis

The method of structural analysis involves analyzing the design of buildings that already exist. Creating columns and beams that are compatible with the existing measurements, followed by calculating the earthquake reinforcement dimensions using reinforced concrete braces measuring 40 cm x 75 cm. Determination of structural loading such as dead, live, rain, wind, and earthquake loads. Next, the research involves conducting structural modeling to elucidate the investigation on bracing

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structures in an 8-story building in Malang City, Indonesia. Next, by comparing the outcomes of the examination carried out with SAP 2000 v.20. The analysis utilizes the structural stiffness, structural vibration period, building's natural frequency, lateral displacement, and story drift deviation for the results. The steps for analyzing the structure are outlined in Figure 2.

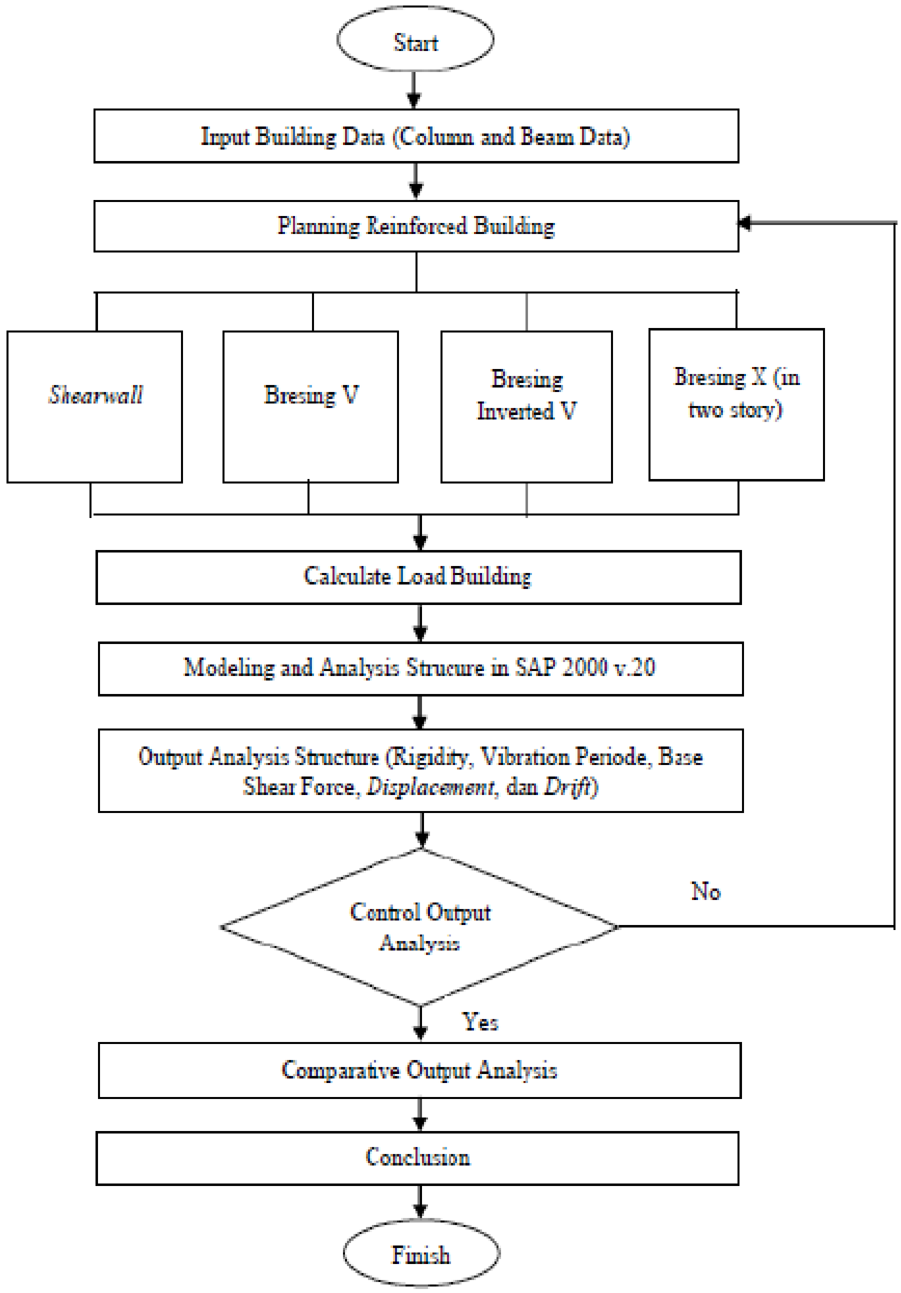

Figure 1.
Research flow diagram of research.

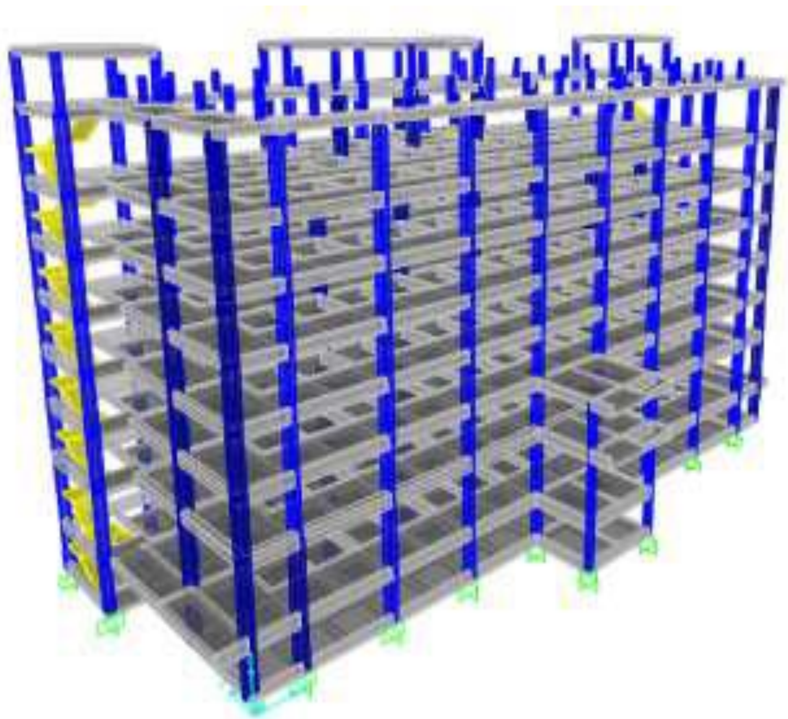

Figure 2.
Building frame structure modeling.

a. Loading on Tall Buildings

When planning a tall building, a consultant design must pay attention to the loads that will occur on the building. To determine the load used, it can be estimated using established regulations. The loads that occur can come from loads from the building (vertical loads) and loads that do not originate from the building (horizontal loads). The design of the structure should ensure that its strength either matches or surpasses the impact of loaded combinations, [10, 35].

A vertical load is a force that moves in the direction of the Earth's gravity. This load is caused by the weight of the building, including fixed and moving loads. The vertical force acting is affected by the size of the building; the larger the building, the stronger the vertical load and conversely. Vertical forces are separated into multiple loads, such as: dead load and live load.

The horizontal loads such as earthquake load and wind load are forces that act sideways on the structure, stemming from external factors. The load significantly affects the building's collapse, so when designing tall buildings, it is important to consider the load design for horizontal forces.

b. Drift Story

Drift is a measure of deviation between floor *x* and floor *x-1*. The deviation at the mass center above the designated level should be subtracted from the deviation below it to determine the difference in design levels (Δ). When using design allowable stresses, (Δ) must be calculated using the specified design seismic forces without adjusting for design allowable stresses. The drift value between levels (Δ_a) should not surpass the permitted deviation. Drift can be defined as:

$$\Delta x = (\delta ex - \delta ex - 1)\, Cd/Ie \quad (1)$$

where:

Δ_x - displacement deviation between floors.

Δ_{ex} - displacement at a location on floor x.

δ_{ex-1} - displacement at the location on floor x-1.
C_d - amplification factor of displacement.
I_e - earthquake priority factor.

c. Stiffness
c.1. Static Stiffness

When a structure is subjected to a static load, it undergoes displacement that looks like a wave with a particular peak, hence it is known as a displacement wave. The wave displacement in structures caused by static loads is not cyclic, therefore it is categorized as impulsive vibration rather than periodic vibration. The application of load affects the static stiffness of a structure (K), while the stiffness of a point (k) is impacted by the load's location and orientation, resulting in varying stiffness values with different positions and directions. The equation below illustrates the relationship among the load, stiffness, and displacement of a structure:

$$[K]\{U\} = \{P\} \qquad (2)$$

where:
$[K]$ - Stiffness matrix by considering the influence of boundary conditions.
$\{U\}$ - Displacement vector.
$\{P\}$ - Load vector.

c.2. Dynamic Stiffness

In addition to mass, stiffness is another dynamic feature of structures. The self-characteristic is the unique relationship between the mass and stiffness of a structure under dynamic loads. This distinctive connection dictates the construction's angular frequency and vibration period. Every mass (m), damping (c), stiffness (k), and external force (P) are assumed to be concentrated in one fission element and are represented by the equation:

$$m_i\ddot{u}_i + c_i\dot{u}_i + k_iu_i = P_i(t) \qquad (3)$$

where:
m - Total mass
$\ddot{u}$ - Acceleration of movement
$\dot{u}$ - Speed of movement
u - Displacement of movement
k - Stiffness
P - Load

d. Ductility

Ductility is the ability of a structure to undergo significant deformations at high amplitudes in the inelastic range without losing a significant amount of strength. Flexible structures are able to absorb a significant amount of energy while undergoing deformations. The ductility factor of 1μ is the ratio of the maximum displacement to the yield displacement (u_{max}/u_y) or ultimate drift to the yield drift (θ_{max}/θ_y). This indicates that a μ value nearing 1 lead to a resilient reaction, whereas a μ value distant from 1 lead to a non-resilient reaction.

$$\mu = \frac{\Delta_{max}}{\Delta_y} = \frac{\theta_{max}}{\theta_y} \qquad (4)$$

2.3. Dynamic Response Earthquake Load Analysis

Examining the structural movement of a structure in Malang City by using seismic data obtained from the Ministry of Public Works and Human Settlements website in Indonesia in 2021, which includes different values such as S_s = 0.621 g and S_1 = 0.390 g. The structure is situated in East Java's Malang City and rests on soil of moderate quality.

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a. Equivalent Static Analysis

In structures, the nominal static equivalent base shear load occurs at the base level as per procedures for planning earthquake resistance in buildings and non-building structures [10]. Simultaneously, the formula must be used to calculate the horizontal force, F_x, caused by earthquakes on Every level:

$$F_x = C_{vc}V \quad (6)$$

$$C_{vx} = \frac{w_x h_x^k}{\sum_{i=1}^{n} w_i h_i^k} \quad (5)$$

where:

C_{vx} - Factor for vertical distribution.
V - The total sum of the horizontal forces at the base.
w_i - The weight of the building at level *i*.
w_x - The weight of the structure at stage *x*.
h_i - The distance from the base to level i is measured *i*.
h_x - The distance from the base to level *x*.
k - The exponent associated in T ≤ 0,5 seconds, then $k = 1$.
for structures that have T ≥ 2.5 seconds, then $k = 2$.
for structures that have T of 0.5 and 2.5 seconds, $k = 2$ or determined by linear interpolation.

b. Spectrum Response Analysis

The spectrum response illustrates how the vibration period (*T*) and maximum responses are correlated with damping ratio and specific earthquakes. If the code requires a design response spectrum but site-specific ground motion procedures are not used, a design response spectra curve must be created according to the guidelines in Figure 3.

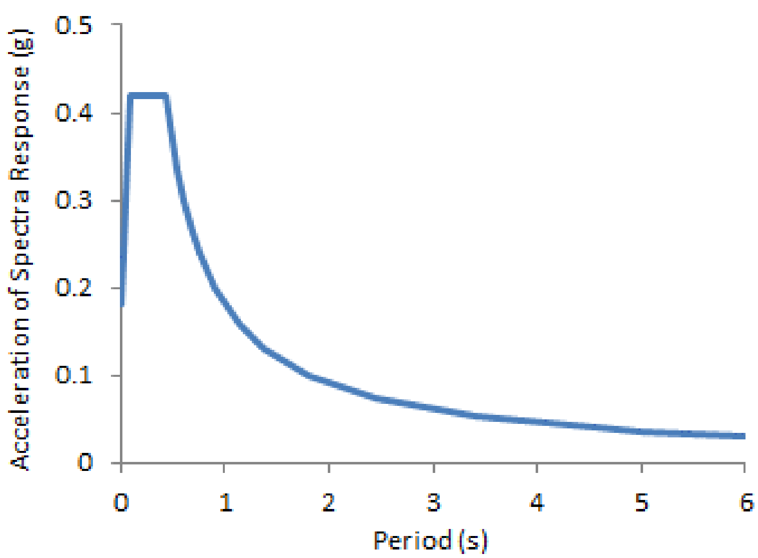

Figure 3.
Design of earthquake response spectrum.

1. For periods smaller than T_0, the design acceleration response spectrum, S_a, should be taken from the equation);

$$S_a = S_{DS}\left(0.4 + 0.6\frac{T}{T_o}\right) \quad (6)$$

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2. For a period, greater than or equal to a T_0 and less than or equal to a T_s, the design acceleration response spectra, the S_a, is the same as the S_{DS};
3. For periods greater than a T_s but less than or equal to a T_L, then a design acceleration spectral response, the S_a, is taken based on the formula:

$$S_a = \frac{S_{D1}}{T} \quad (7)$$

4. For a period, greater than a T_L, the formula for calculating the design acceleration spectral response, the S_a, is utilized:

$$S_a = \frac{D_{D1}T_L}{T^2} \quad (8)$$

Where;
S_{DS} - design acceleration of spectrum response at the short periods;
S_{D1} - design acceleration of spectrum response at first period;
T - period of the fundamental vibrations of a structure;

b.1. Vibration Periods

The time period T for one complete vibration cycle in the first mode is inversely related to the natural frequency. Structures that rely on mass and stiffness have an inherent tendency to vibrate on their own, without the need for external forces.

The structure's characteristics and deformation on supporting elements in calculations must be used to determine the building's fundamental period, T, in the specified direction. The value of T must not be higher than the product of the factor for the maximum limit on the calculated period (C_u) from Table 17 of SNI 1726, 2019, and an estimated fundamental period, T_a, determined based on 0. An alternative for conducting calculations to determine the fundamental period structure is to use the approach period, T_a, which is calculated based on 0. The value of T_a, signifying a period of approach in seconds, is specified in SNI 1726 of [10] in the following manner:

$$T_a = C_t h_n^x \quad (9)$$

where:
h_n - Calculated from a base foundation to a top-level of the structure
C_t - Showed from Table 18 SNI 1726, 2019
x - Determined from Table 18 SNI 1726, 2019
Maximum fundamental period ($T_{a,max}$) in seconds, formulated by the equation:

$$T_{a,max} = C_u T_a \quad (10)$$

where:
C_u - Seismic response coefficient

Analysis of vibration periods identifies two periods, T_a from manual examination and T_c. The comparison must be the basis for using the fundamental period (T) value in structural analysis:

$T_c > T_a C_u$ is used $T = T_a.C_u$ (11)
$T_c < T_c < T_a C_u$ is used $T = T_c$
$T_c < T_a$ is used $T = T_a$.

If the period is greater than T_{max}, it will be replaced with T_{max}. Alternatively, the initial period of approach (T_a) can be quickly calculated using the provided formula for structures with no more than 12 floors and a seismic resistance system of moment-resisting frames, where the typical floor height is at least 3 meters:

$$Ta = 0.1N \quad (12a)$$

where:
N = number of stories

A concrete shear walls with a height not exceeding 36.6 m, calculation of the estimated fundamental period, T_a, is permitted using a formula as follows:

$$T_a = \frac{0.00058}{\sqrt{C_w}} h_n \qquad (12b)$$

b.2. Natural Frequency

Each mode of the structure experiences a unique frequency and vibration mode shape caused by dynamic loads. According to Chopra (2014), the relationship between the natural period and natural frequency of a structural system in vibration modes is:

$$f_n = \frac{1}{T} = \frac{1}{2\pi}\sqrt{\frac{k}{m}} \qquad (13)$$

where:

f_n - Natural frequency
T - Vibration period
k - Stiffness
m - mass

3. Results and Discussion

The modeling analysis follows the site plan, incorporating different types of resisting systems like shear-wall, V-shaped bracing, inverted V (Λ), and X (on two floors). Figures 4 to 7 illustrate the layout and form of the shear-wall and bracing resisting system on building models. The SAP 2000 v.20 is utilized for modeling and evaluating the dynamic reaction under combined loads.

The data materials for the structure models come from the testing laboratory, Table 1.

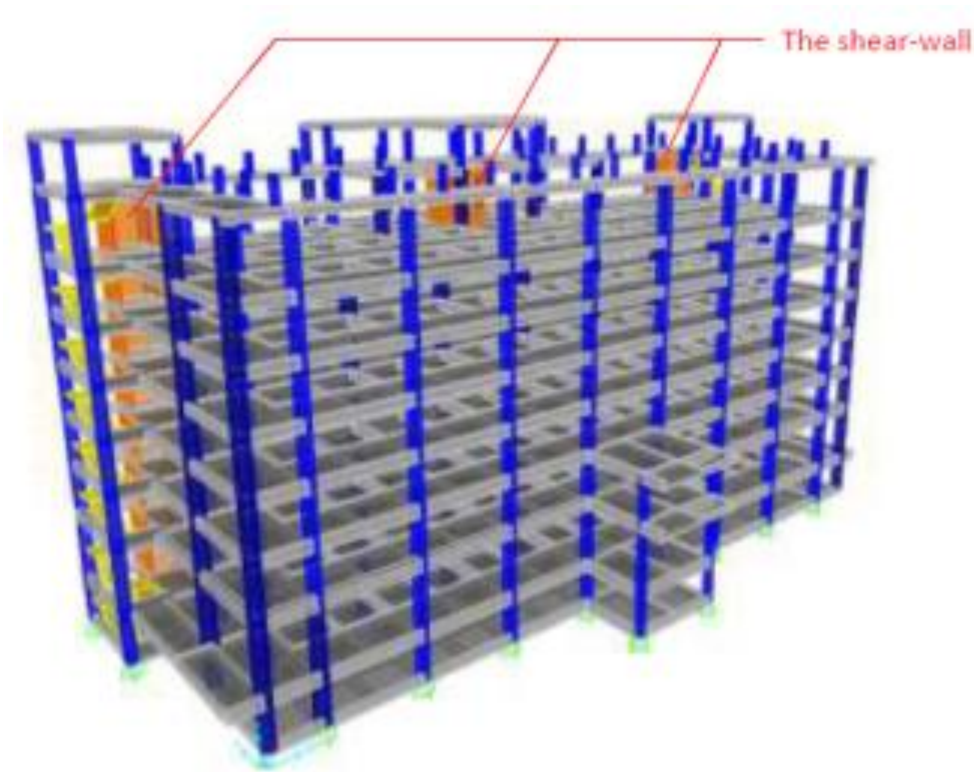

Figure 4.
The shear wall configuration on building.

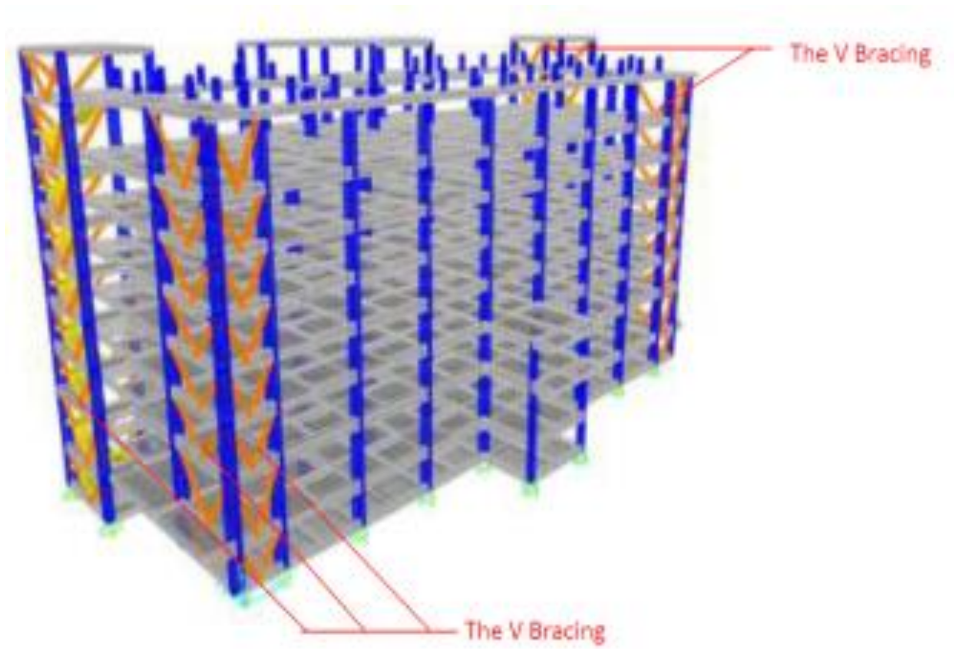

Figure 5.
The V bracing configuration on building.

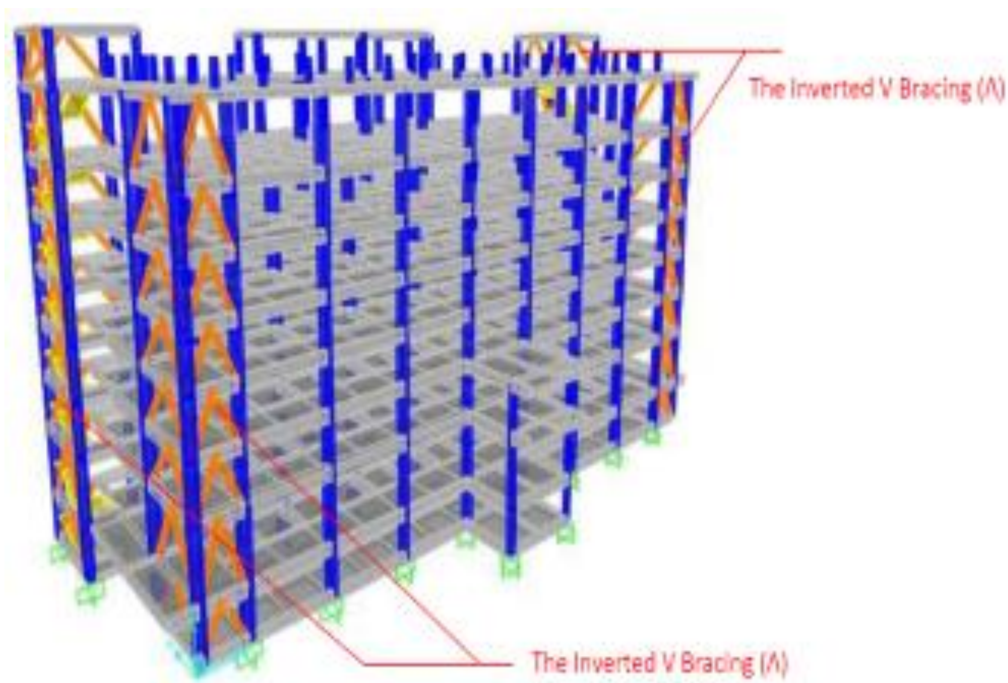

Figure 6.
The inverted V bracing (Λ) configuration on building.

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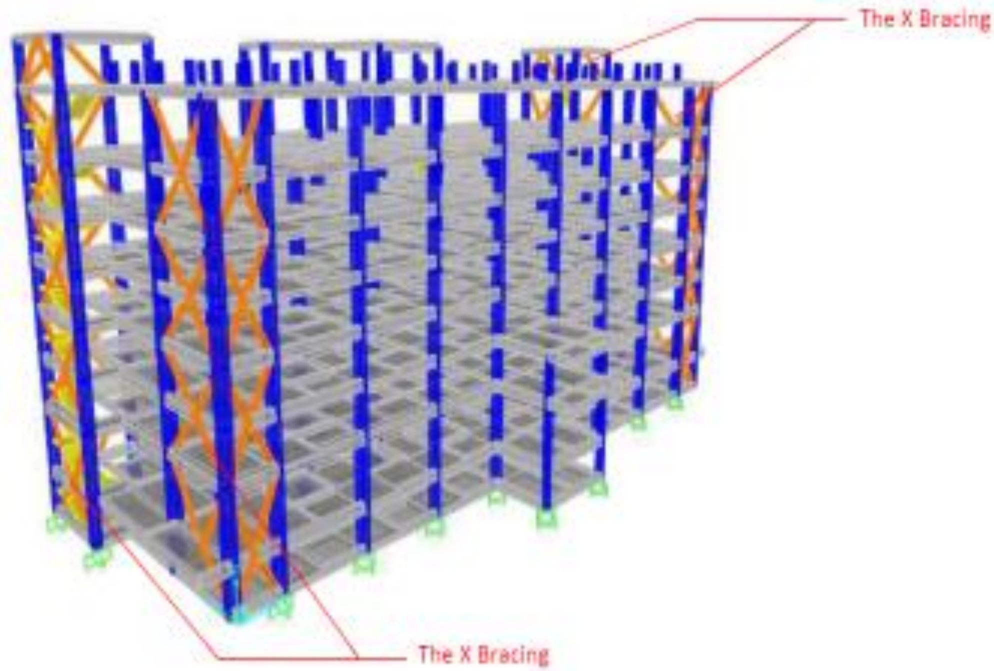

Figure 7.
The X bracing (In two floor) configuration on building.

3.1. Structure Performance

The calculation model was developed with the help of SAP 2000 software. An investigation was carried out on the modal response-spectra analysis under linear elastic assumptions to evaluate the effects of seismic activity. Certain results were derived concerning the stiffness of the structure, vibration period, natural frequency, and drift of the building through output analyses.

a. Structure Stiffness

Structural stiffness refers to a structure's ability to resist deformation. A sufficient amount of rigidity is required for a building to minimize its flexibility. The rigidity of a building is influenced by both the stiffness of the material and the size of structural elements. Some typical design flaws in buildings can include an irregular shape, weakened structural integrity on certain floors, concentrated weight distribution, or deficiencies in the lateral force-resisting system. Irregularities in the vertical direction are influenced by factors like strength, stiffness, geometry, and mass. Even though they are assessed individually, they are interconnected and can happen at the same time.

Experts who specialize in the seismic performance of buildings generally agree that the shape of a building has a notable effect on how it performs during earthquakes. This happens because of how the shapes and proportions of the building affect the distribution of earthquake forces within the structure. The way the shapes are arranged, the type of structural elements, how they are connected, and the materials used all have a substantial effect on the structural dynamics. Seismic criteria designed for buildings with regular features may not be appropriate for buildings with irregular characteristics like non-uniform floor plans or vertical interruptions. Hence, it is advised to refrain from constructing buildings with irregular characteristics. For instance, if the exterior walls on the first level of a building are removed, it will create an open first floor with the remaining columns capable of withstanding side forces.

Applying force to a structure determines its static stiffness, with the location and orientation of the force impacting stiffness at a specific point. Hence, the stiffness value fluctuates at different locations and angles. Simultaneously, when exposed to repetitive dynamic loads at particular velocities and accelerations, the material particles and the structure experience oscillations in both directions at a specific rate referred to as the natural frequency. The movement of atoms in materials and structures due to dynamic loads is characterized by continuous oscillation, as opposed to a sudden, one-time shift. Stiffness is also a dynamic characteristic of structures, in addition to weight. The unique bond between a structure's mass and stiffness due to dynamic loads is known as self-characteristic. This unique bond determines the frequency of angular structure and period of vibration. Table 2 and Figure 8 display the comparison of structural stiffness achieved through different resisting systems of shear-wall and bracing methods in this study.

Table 2.
Structure stiffness.

Resisting system	Stiffness (N/mm)
Shear-wall	2.97676E+12
V bracing	4.01509E+12
Inverted V bracing (Λ)	4.92865E+12
X bracing (On two floors)	4.5924E+12

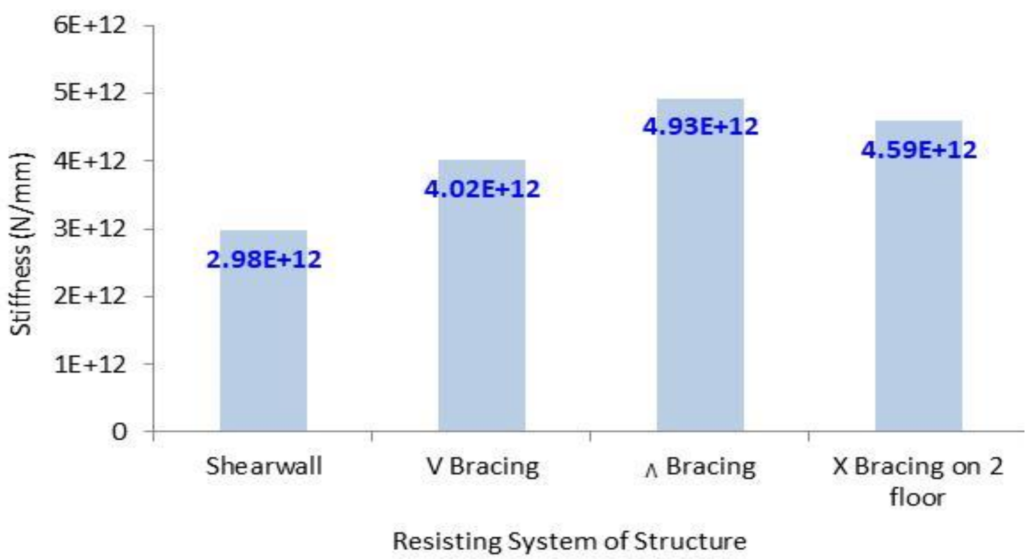

Figure 8.
Relationship between variety resisting systems of tall building and stiffness.

Figure 8 showed that the inverted V bracing has a highest performance on the structure stiffness. The shear-wall, the V braces, the inverted V braces (Λ), and the X braces have stiffness of 2.97676E+12, 4.01509E+12 N/mm, 4.92865E+12 N/mm, and 4.5924E+12 N/mm, respectively. nverted V bracing outperforms shear-wall by 39.6%, V bracing by 18.53%, and X bracing by 6.82% in terms of stiffness. The incomplete shear-wall stiffness was unable to provide as much stiffness as the fully covered one.

b. Displacement

Vibrations are linked to a building's response during an earthquake. A rise results in a rise in the stress that can cause columns and walls to buckle or collapse as the weight pushes down on a structural element that has been deflected or moved from its upright position by horizontal forces (*P-delta* effect). When flexible structures experience horizontal forces, the horizontal displacements cause extra overturning moments due to the displacement of the gravity load. Moreover, in addition to the

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overturning moments created by lateral force Vu, the secondary force must also be countered. More sideways growth will occur as a result of this increase in time. The increase in position change will lead to a further rise in transformation. In forms that are highly adaptable, collapse may occur as a result of instability. Recognizing the importance of *P–Δ* effects is essential in determining seismic design forces, especially for buildings in regions with mild to moderate seismicity. In regions prone to frequent earthquakes, the lateral forces in building design will be significantly higher. Therefore, in numerous instances, particularly in regions experiencing considerable seismic design force.

Figures 9 and 10 display the movement of every structural resistance system in both the X and Y axes. In the X direction, the displacements of the structure are 134.05 mm, 157.5 mm, 144.53 mm, and 148.2 mm for V bracing, inverted V bracing, and X bracing. In the vertical direction, their lengths are 236.83 mm, 90.36 mm, 108.86 mm, and 104.36 mm.

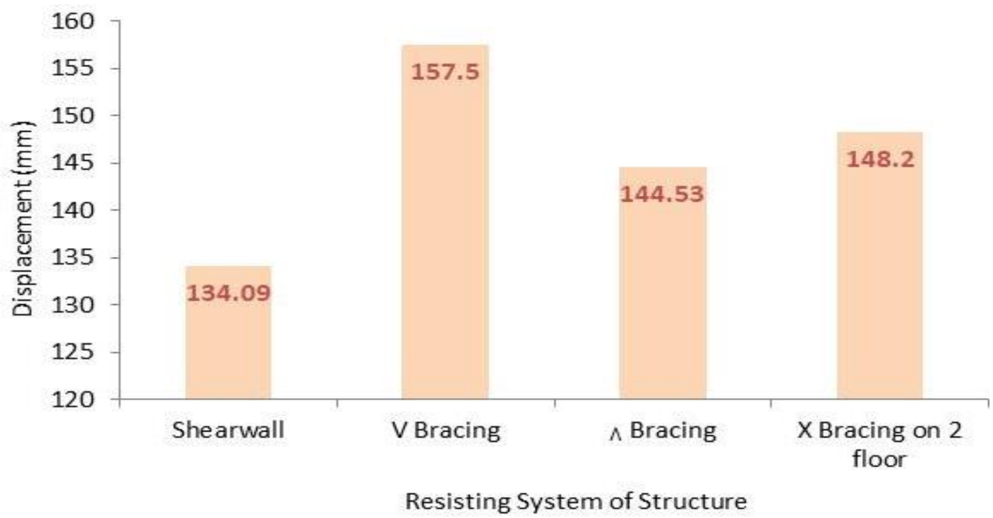

Figure 9.
Displacement of structures in X direction using various resisting systems of structure.

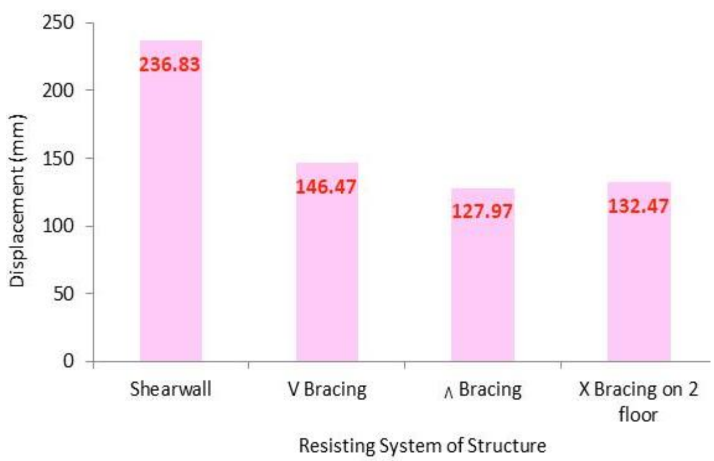

Figure 10.
Displacement of structures in Y- direction using various resisting systems of structure.

c. Drift

Drift is frequently described as the horizontal movement of one level compared to the level underneath. It is important to have drift control in order to minimize damage to indoor walls, elevators, stairs, glass, and exterior cladding systems. Restrictions in stress or strength management may not consistently offer sufficient control of displacement, particularly for tall buildings with flexible moment-resisting frames or slender shear walls. The total displacement of a point relative to the base determines the overall building drift. Different buildings or parts of a building may not respond similarly, potentially resulting in them colliding with one another. In a major earthquake, the columns in the structure stay intact as the floors move due to the beams bending permanently. The movement could be significant and result in harm to components firmly fastened to the structure of the building. Fragile partitions, staircases, plumbing, outer walls, and other elements that span multiple floors are examples of elements susceptible to damage. Hence, in spite of significant non-structural damage inside and outside, a moment-frame building will remain structurally stable. Some buildings may not see improvements from this system unless particular mitigation tactics are implemented.

Table 3.
Drift deviations in X direction.

Story	Shear wall	V bracing (mm)	Λ bracing (mm)	X bracing (mm)
Basement	0	0	0	0
1	6.27	8.53	6.33	5.33
2	23.61	31.07	25.00	29.43
3	38.35	48.23	40.53	43.67
4	54.41	66.40	66.4	61.90
5	70.88	84.83	84.83	78.63
6	87.08	102.83	92.43	96.20
7	102.45	119.90	108.67	112.27
8	121.26	140.33	127.73	131.77

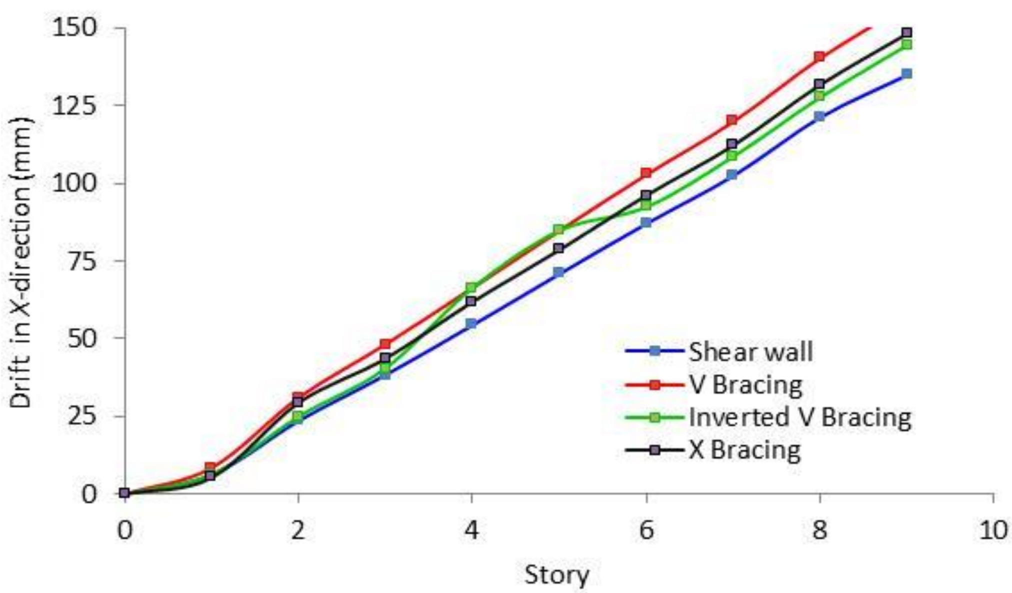

Figure 11.
Drift versus story along the X-axis.

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The drift in the X-direction indicates that the building with shear-walls experiences less drift than the building utilizing reinforced concrete bracing such as V, inverted V (Λ), and X bracing (on two floors). The drift discrepancy between shear-wall and reinforced concrete bracing is 17.46%, 7.79%, and 10.52% in V, inverted V (Λ), and X bracing (on two floors). There is no drift on the basement floor, while drift ranges from 6.27 mm to 18.81 mm on floors 1 to 8 and the roof. This occurs because the shear-wall is more efficient (stiff) in resisting horizontal forces when compared to other reinforcements in the X direction. In the event of an earthquake, the building typically experiences a slight swaying motion. Meanwhile, the comparison of deviations between levels in the X direction can be seen in Table 3 and Figure 10. Comparing the Y-direction drift above reveals that the structure with inverted V bracing (Λ) experiences less drift than the structure with different braces. The drift discrepancy between shear-wall and reinforced concrete bracing in V, inverted V (Λ), and X form (on two levels) amount to 38.16%, 45.97%, and 44.07%. The displacement on different floors varies from 0.00mm in the basement to 17.13mm on the 8th floor and is 6.30mm, 14.73mm, 13.93mm, 15.27mm, 15.70mm, 15.43mm, 15.13mm, and 14.33mm on floors 1 to 7, and the roof, respectively. This is due to the fact that the inverted V-bracing (Λ) provides a stiffer structure compared to other reinforcements. Therefore, in the event of an earthquake, the building typically experiences a slight movement.

Table 4.
Drift deviations in Y direction.

Story	Shear wall	V bracing (mm)	Λ bracing (mm)	X bracing (mm)
Basement	0	0	0	0
1	10.19	7.67	6.3	4.97
2	42.17	27.53	21.03	24.83
3	69.01	42.9	34.97	37.57
4	96.95	59.93	50.23	53.87
5	126.24	77.10	65.93	68.93
6	154.95	94.27	81.37	84.77
7	183.96	111.20	96.50	100.17
8	218.79	130.83	113.63	117.80

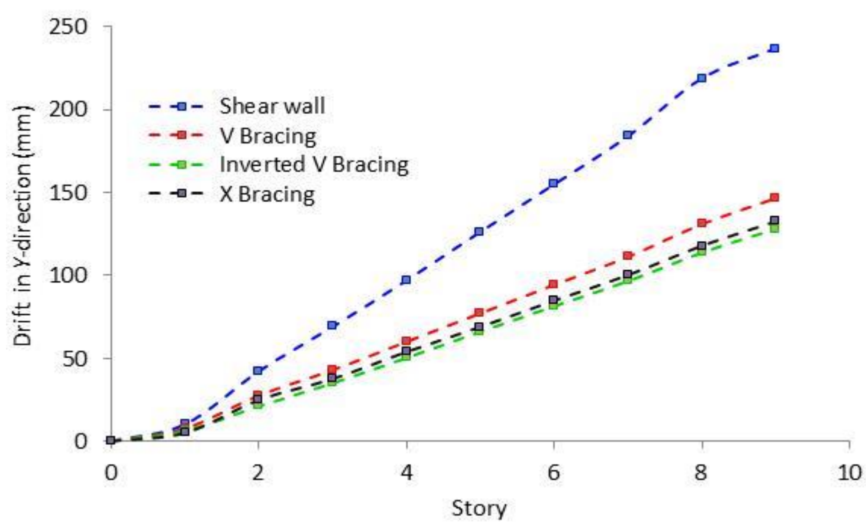

Figure 12.
Drift on Y-direction.

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d. Structure Ductility

Ductility is the structure's capacity to offer support in the non-elastic phase of reaction. It involves the capacity to endure significant distortions and the capability to soak up energy through hysteresis, essential features for a building's resilience in the face of a substantial earthquake. Ductility is calculated by comparison between displacement at ultimate stage (Δ_u) and displacement at initial yield (Δ_y). The ultimate displacement limit (Δ_u) usually corresponds to a specified limit for strength degradation, indicating the maximum ductility. Once reaching this threshold, structural collapse may not happen, but failure or significant inelastic deformations can still occur.

As the structure starts to warp and deform in a non-elastic way, the period of the structure's response appears to extend. Numerous buildings lead to a decrease in the need for strength. Moreover, the lack of flexibility leads to this outcome in a notable level of energy absorption, also referred to as hysteresis damping. The impact, that adequate stiffness can undergo large deformations without collapsing. Generated a force which is significantly lower than the maximum elastic seismic force allowed, while still meeting the anticipated performance criteria under the designated ground movements.

Table 4 displays the displacement values at the initial yield (Δy), ultimate stage (Δu), and ductility for different structural systems including shear-wall, V bracing, inverted V, and X shapes. A structure with V bracing exhibits greater ductility compared to one with inverted bracing (λ), X bracing (on two floors), and a shear wall. The ductility of structures with inverted V bracing is lesser compared to other types. A partially covered shear-wall does not perform as effectively as a fully covered one.

Table 5.
Ductility of structures using various bracing shape.

Bracing shape	Δ_y(mm)	Δ_u(mm)	Ductility (μ)
Shear wall	236.83	377.5	0.627
V bracing	146.47	377.50	2.58
Inverted V bracing (Λ)	127.97	377.50	2.95
X bracing (On two floors)	132.47	377.50	2.85

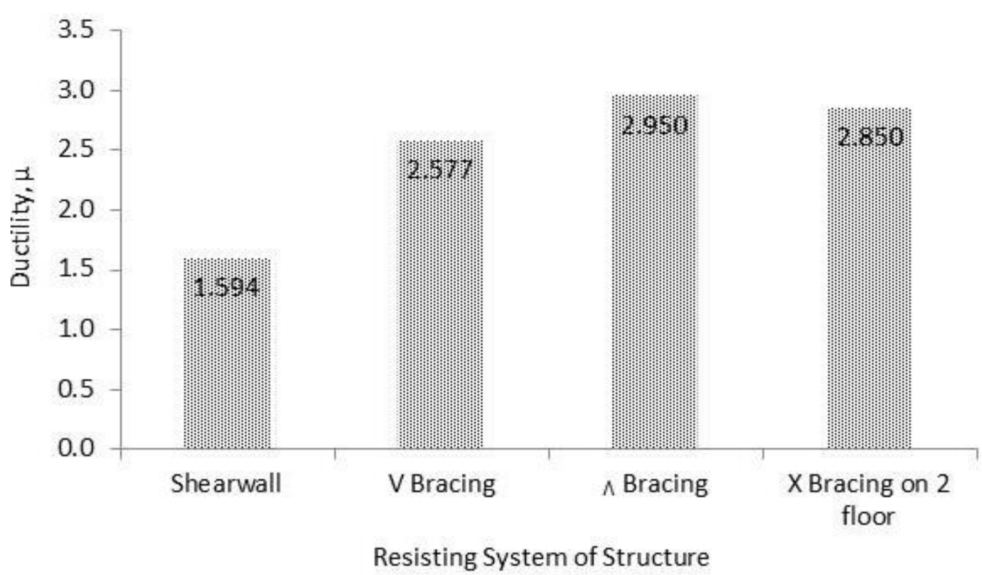

Figure 13.
Ductility of structures with various resisting systems of building.

3.2. *Dynamic Response of Structure*

a. *Vibration Period of Structure*

The dynamic parameters of a movement include the vibration period T and vibration mode. The period of vibration is the time permitted for a structure to perform one cycle of simple harmonic motion in one vibration mode. The dynamic parameters of a movement include the vibration period T and vibration mode. The period of vibration is the time permitted for a structure to perform one cycle of simple harmonic motion in one vibration mode. Meanwhile, what is meant by natural vibration mode is each characteristic form of displacement that occurs in a harmonic movement. A structure must have many degrees of freedom so that the system will have a solution which indicates the vibration mode of the system. A free vibration will occur in each mode with a certain frequency and vibration mode.

The vibration period of a structure (T) is obtained by comparing the parameters T_a (minimum period), T_c (program analysis results) and $T_{a,max}$ (maximum vibration period). Then, a vibration period value for the structure is selected that is below the $T_{a,max}$ value, the maximum allowable limit for the structure. A comparison of the vibration period values for the structure can be viewed in Table 5 and Figure 14.

Table 6.
Vibration period and natural frequency of structures.

Resisting system	Vibration period (Second)	Natural frequency (Hz)
Shear wall	1.441	0.694
V bracing	1.240	0.806
Inverted V bracing (Λ)	1.120	0.893
X bracing (On two floors)	1.160	0.862

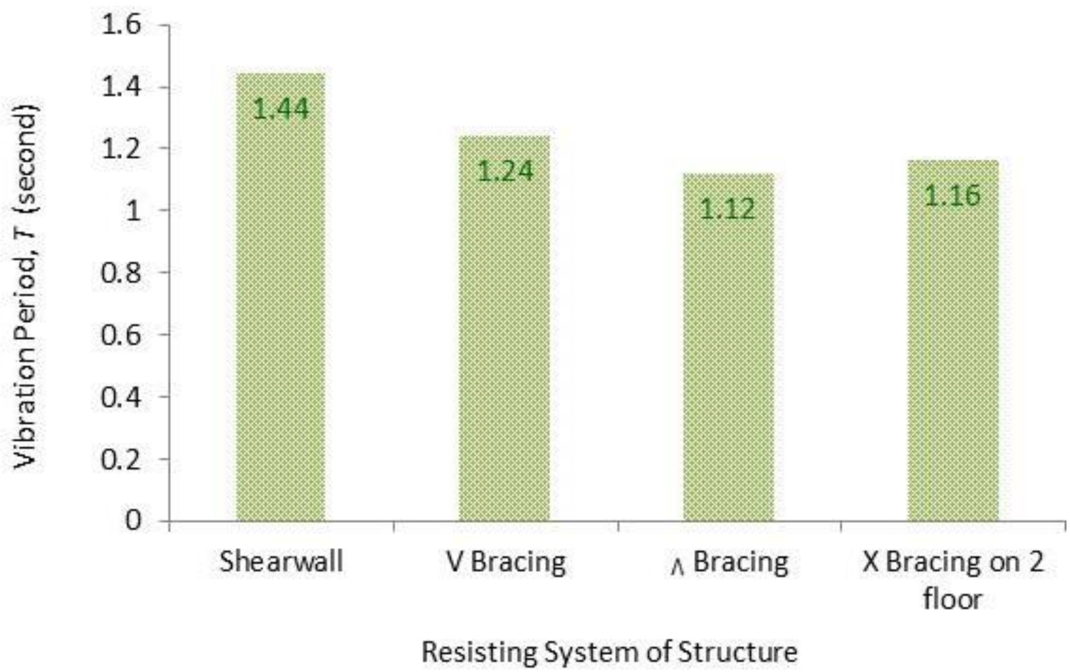

Figure 14.
Vibration period of structures.

The vibration periods obtained from models (T_c) utilizing shear wall, V-bracing, inverted-V (Λ) bracing, and X-bracing are 1.44 seconds, 1.24 seconds, 1.12 seconds, and 1.16 seconds. The inverted V-shaped brace (Λ) has the shortest vibration period of 1.12 seconds. The reason is that the stiffness analysis shows that a structure with an inverted V-shaped brace (Λ) is stiffer. Therefore, in the event of an earthquake, the building will likely oscillate briefly in comparison to structures using different types of support. Nevertheless, the vibration period values obtained in the three models exceed the maximum vibration period value ($T_{a,\ max}$). Therefore, the basic shear force analysis utilizes the $T_{a,\ max}$ value of 1,040 seconds for each model.

b. Natural Frequency

The number of cycles within a specific period determines the oscillation frequency. The system's natural frequency is the speed at which it vibrates independently if it continues to vibrate after a disturbance. Vibration in a system will result in natural frequencies being displayed by the n degrees. The system's dynamic characteristics are depicted by the frequency function, which is formed by measuring vibrations in a curve. The function is derived from the relationship between the Fourier transform of the input signal and the output signal. The input signal includes a force vector with both magnitude and direction, whereas the output signal comprises displacement, velocity, and acceleration.

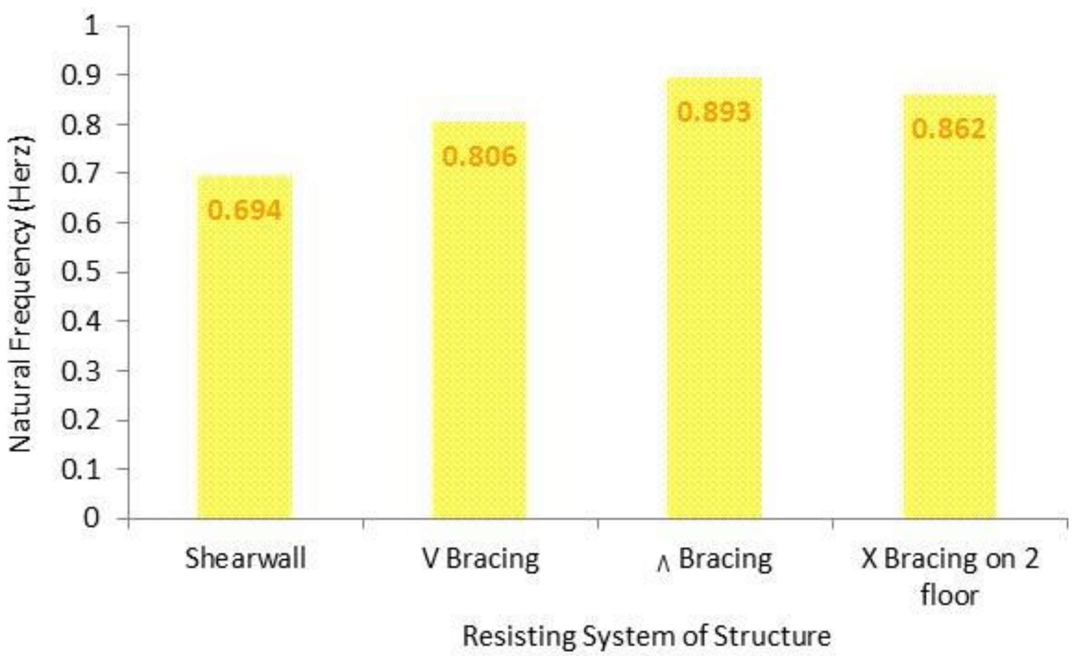

Figure 15.
Natural frequency of structures using various resisting systems of structure.

Furthermore, the natural frequency can be obtained for each model using the formula $1/T_c$. Table 6 and Figure 15. Table 6 shows that the inverted-V shaped reinforced concrete brace (Λ) has the largest natural frequency compared to other reinforcements, namely 0.893

4. Conclusion

From the analysis and discussion that has been carried out, it can be concluded that the most suitable structure as an alternative to partial shear wall is reinforced concrete braces form inverted V (Λ). However, reinforced concrete braces only improve performance in the Y direction. For this reason, reinforcement of reinforced concrete braces must be added in the X direction. The reinforcement can be placed in the middle of the span which aims to strengthen the structure. This is because the building structure has a long span in the X direction.

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