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Original Article

Seismic Performance between the Diagrid Structural System and the Dual Structural System for Important Buildings

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Abstract - *The objective of the research is to evaluate the seismic performance of the Diagrid structural system and the Dual structural system for important buildings in the city of Huancayo. The damage to these buildings caused by frequent seismic events is becoming an increasingly serious and recurring problem, with repairs becoming more and more expensive. In response to this problem, the implementation of new structural systems such as the Diagrid Structural System has been proposed for integration into Peruvian regulations, as these systems are known for their ability to combine structural efficiency with aesthetics. At the same time, this Diagrid System will be compared through a linear seismic analysis with the Dual System to demonstrate which one has better seismic performance according to the following indicators: Vibration Periods, Displacements, Inter-story drifts, Shear Force, Axial Force, and Bending Moment. It was concluded that the Diagrid Structural System performed better seismically than the Dual System, mainly because it reduced vibration periods by up to 50%, displacements by 46.85% and inter-story drifts by 40.54%.*

Keywords - *Diagrid, Dual, Resistance, Seismic performance, Important buildings.*

1. Introduction and Background

In recent years, informal construction has become increasingly common in several Peruvian cities, mainly due to the lack of professional technical supervision and limited access to qualified engineering guidance during the building process. This situation has led to the development of structures with low seismic performance and reduced safety margins, especially in high-risk seismic zones. At the same time, there remains limited awareness and implementation of modern structural systems that have been successfully developed and adopted in other countries to improve building resilience and efficiency.

In Peru, the most used systems for medium- and high-rise buildings are still the Dual and the Moment Frame systems; such traditional approaches, however, are often associated with higher construction costs, architectural constraints, and lateral stiffness that is not enough when comparing these systems with more modern alternatives such as the Diagrid Structural System. Therefore, the encouragement of further research into the adoption of modern structural configurations becomes necessary to mitigate the risks associated with informal construction and to improve the structural safety and sustainability of the Peruvian scenario. Moreover, the Peruvian government's resistance to adopting and implementing new structural systems further aggravates the problem, especially considering the country's high seismic vulnerability due to its location within the Pacific Ring of Fire.

The problem or gap is clear; there is an important development of new and better structural systems in other countries, but in Peru, there is still no research or practical assessment considering the conditions that exist here and how those systems will behave when facing an earthquake. In this context, several developed countries in Asia, Europe, and North America have already incorporated structures with aerodynamic shapes and unobstructed façades, giving rise to the so-called Diagrid system, as shown in Figure 1.

According to Palacio-Betancur A. [1], since 2020, the number of Diagrid-type structures has increased exponentially worldwide. In the case of the structural inefficiency of conventional buildings in Peru, it was decided to seek the implementation of the Diagrid Structural System in Peruvian regulations, since this system, according to Moon, K [2], is more efficient at the structural level and is appropriate for application in essential structures that house many people, such as health centres, schools, shopping centres, etc. This research also seeks to demonstrate that the

Diagrid System has better seismic performance than the Dual System in a computer simulation of a seismic event.

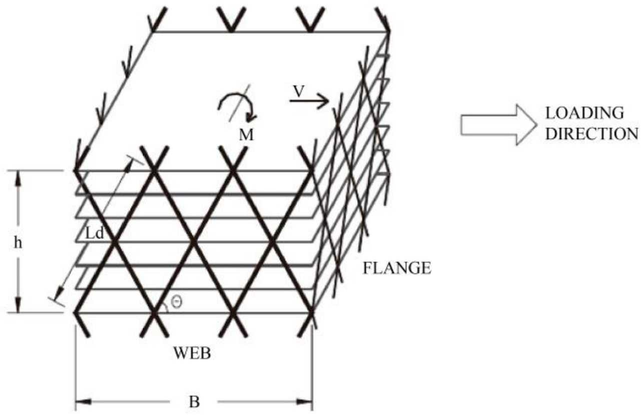

Fig. 1 Diagrid structural system

Among the studies related to the structural performance of the Diagrid system is a paper by Kim, J. & Lee, S. [3] in South Korea, who analyzed the seismic behavior of reinforced concrete Diagrid structures under lateral loads using numerical models and laboratory tests, concluding that Diagrid systems exhibit high torsional stiffness and are viable alternatives for buildings in areas of high seismic activity.

Another study conducted by Tomei V., Imbimbo M., Mele E. [4] in Italy, who developed optimization methodologies for the design of reinforced concrete diagrid structures considering structural efficiency and cost reduction, concluded that the use of optimization algorithms allows the weight of the structure to be reduced without compromising its strength, making concrete diagrids competitive with other structural solutions in tall buildings.

Heshmati M., Khatami A., Shakib H. [5] assessed the structural efficiency and sustainability of reinforced concrete diagrid systems in comparison with conventional ones by considering different factors like material usage and carbon footprint, amount of load-bearing capacity, performance under dynamic loads, etc. They found that reinforced concrete diagrid systems proved to be more efficient in terms of material use and had a lower environmental impact compared to conventional structures, not to mention providing better performance against wind and seismic loads.

More recently, Yousefi et al. [6] investigated the seismic performance of steel Diagrid systems under near-fault ground motions, focusing on the vertical component of earthquakes. Their results showed that Diagrid systems guarantee adequate energy dissipation and deformation control even for high seismic demands, proving to be robust in critical seismic zones. Likewise, Zhang et al. [7] suggested a Diagrid core–tube structural system with replaceable coupling beams for seismic resilience and sustainability. Their study revealed that this hybrid system was quite effective in improving energy dissipation capacity, reducing residual deformation, and prolonging the service life of high-rise structures with high efficiency in material use.

Despite these valuable contributions, a certain shortage still persists with respect to the number of comparative studies being done to specifically address the seismic performance of Diagrid and Dual structural systems under consistent conditions. This research proposes a new comparative methodology that uses Linear Analysis to assess the seismic performance of both the Diagrid Structural System and the Dual Structural System. Compared with previous literature reviews, which focused on individual system performance analysis, this work will directly compare their behavior under identical analytical conditions. The comparison of key performance indicators involves vibration periods, displacements, inter-story drifts, shear force, axial force, and bending moment. It is expected that the results will prove the better seismic performance of the Diagrid Structural System and its higher structural efficiency when compared to the Dual System. Besides, the present research emphasizes the potential of the Diagrid System for incorporation into the Peruvian National Building Code to reduce the vulnerability of buildings against earthquakes.

2. Materials and Methods

The seismic performance between the Diagrid Structural System and the Dual Structural System presents a scientific research methodology, a type of applied research, a descriptive level of research, and a non-experimental research design. First, the research area was determined. In this case, a 1,000 m² plot on Luther King Street, located in the "Los Jardines de la Justicia" neighborhood, which belongs to the district of Huancayo, was chosen as the sample, as shown in Figure 2. The study was conducted in this location because, according to the Municipality of Huancayo [8], the upper area of the District of Huancayo has an Urban Development Plan in place for the development and growth of medium- and high-rise buildings.


Fig. 2 Location of the study area

2.1. Materials

2.1.1. Soil

In the structural analysis of buildings, soil is an important factor that influences the design of foundations and seismic response [9]. For the study, three soil samples were extracted using hand tools and airtight bags for their care and transport to the laboratory. To determine the soil profile classification, a direct shear test was first performed in accordance with ASTM D3080 [10] to obtain the specific weight, soil cohesion, and friction angle, as shown in Table 1. Next, the allowable bearing capacity was found according to Terzaghi's theory (1), which is shown in Table 2, respectively.

Table 1. Mechanical properties of soil

Mechanical Properties		Soil		
		N° 1	**N° 2**	**N° 3**
Specific Weight	**g/cm3**	1.67	1.68	1.66
Soil Cohesion	**kg/cm2**	0.30	0.28	0.31
Angle of Friction	°	12.30	15.36	12.20

$$q_{adm} = \frac{1}{S.F.}\left(1.3CN_c + \gamma_1 D_f N_q + 0.4B\gamma_2 N_y\right) \qquad (1)$$

q_{adm} = Allowable bearing capacity (kg/cm²)
C = Cohesion (kg/cm²)
γ_1 = Specific weight of the soil above the foundation level
γ_2 = Specific weight of the soil under the foundation level
D_f = Foundation depth
B = Foundation width
N_c, N_q, N_y= Terzaghi's load capacity factor
S.F. = Safety factor

Table 2. Soil bearing capacity

Allowable bearing capacity		Soil		
		N° 1	**N° 2**	**N° 3**
Square Foundation	**kg/cm²**	1.49	1.56	1.45

According to the results in Table 2, the most unfavorable value for the soil's bearing capacity is 1.45 kg/cm2. Therefore, according to the classification in the Soil Manual [11], the soil corresponds to the intermediate type with an "S2" profile.

2.1.2. Structural Engineering Software

Etabs 2021 is advanced software that can perform both linear and non-linear analyses. Linear analysis includes static seismic analysis (equivalent horizontal force method) and dynamic seismic analysis (spectral modal analysis and time history analysis). The advantages of the software include the calculation of Inter-story drifts, vibration periods, shear forces, axial forces, bending moments, lateral displacements, etc., complying with international standards such as ASCE 7-16 [12]. For this research, 3D modeling of the Dual Structural System and the Diagrid Structural System was performed to carry out the Structural Analysis and obtain results for measuring seismic performance.

2.2. Method of Analysis

To achieve the research objective, a linear seismic analysis was carried out in accordance with Peruvian Standard E.030 – Seismic Design [13], focusing on the evaluation of an 8-story reinforced concrete building designed for important uses such as commercial facilities, health centers, or educational institutions. The selected structure represents the typical mid-rise building configuration in urban areas of Peru, with an area of 876.16 m², a mezzanine height of 4.20 m, and typical floor dimensions of 29.6 m × 29.6 m. For the comparison, three analytical models were developed using finite element software (ETABS 19), two of them correspond to Diagrid configurations: Model A with diagonals modulated every two stories and Model B with diagonals every four stories, as shown in Figures 3 and 4. Meanwhile, the third model corresponds to a Dual Structural System that is composed of reinforced concrete shear walls and moment-resisting frames, as shown in Figure 5.

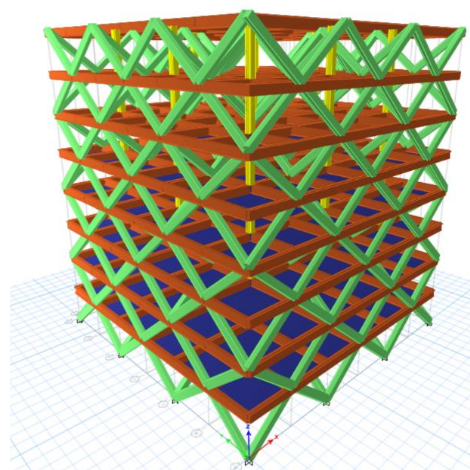

Fig. 3 Type A – Diagrid structural system

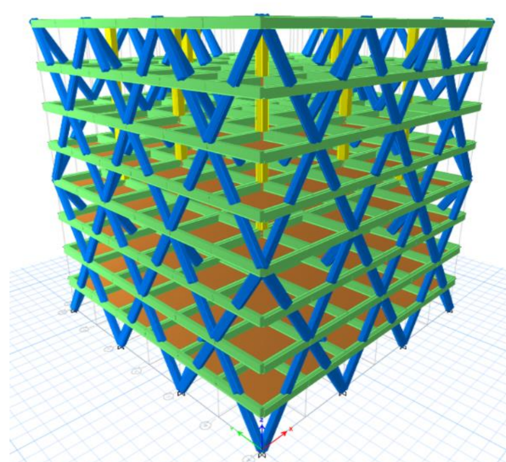

Fig. 4 Type B - Diagrid structural

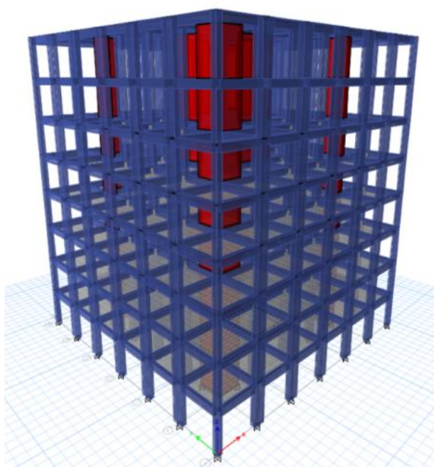

Fig. 5 Dual structural System

Material properties were assigned according to E.060 [14], while load combinations were defined based on the E.020 [15] and E.030 [13] standards. The seismic action was initially applied using the Equivalent Static Method and later validated with a Modal Response Spectrum Analysis, enabling the capture of the dynamic behavior of the structure in more detail. Finally, the obtained results are compared based on several KPIs, such as fundamental vibration periods, maximum displacements, inter-story drifts, base shear, axial forces, and bending moments. This holistic methodology has allowed establishing a coherent analytical framework that not only enhances the technical rigor but also the reliability of the comparison between the Diagrid and Dual structural systems.

The same characteristics were considered for all three models in terms of geographical location, soil type, use, importance, roofed area, floor plan dimensions, and elevation, as well as the same construction materials and load requirements. Table 3 shows the seismic parameters considered according to Standard E.030 [13] for Static and Dynamic Seismic Analysis, while Table 4 and Table 5 show the characteristics of the Dual Structural System and Diagrid, respectively.

Table 3. Seismic parameters

Seismic Parameters	
Zone (Z)	0.35
Use (U)	1.5
Soil (S)	1.15
Seismic Amplification (C)	2.5
Short Period (Tp)	0.6
Long Period (TL)	2
Seismic Reducer (R)	7

Table 4. Features of the dual structural system

Dual Structural System	
Columns (cm)	50 x 50
	50 x 100
Beams (cm)	35 x 70
Structural Wall (cm)	30
Slab (cm)	20
Dead Load (kg/m^2)	172
Live Load (kg/m^2)	300
f'c concrete (kg/cm^2)	210
f'y steel (kg/cm^2)	4200

Table 5. Features of the diagrid structural system

Diagrid Structural System		
	Type A	**Type B**
Columns (cm)	50 x 50	60 x 60
Beams (cm)	35 x 70	35 x 70
Diagonals (cm)	35 x 70	35 x 70
	35 x 60	35 x 60
	35 x 55	
Diagonal Angle (°)	41.18	60.25
Slab (cm)	20	20
Dead Load (kg/m^2)	172	172
Live Load (kg/m^2)	300	300
f'c concrete (kg/cm^2)	210	210
f'y steel (kg/cm^2)	4200	4200

Following the modeling and linear analysis of the Diagrid Structural System and the Dual Structural System in ETABS 2021, we proceeded to find the indicators to measure seismic performance, such as vibration periods, displacements, inter-story drifts, shear force, axial force, and bending moment.

2.2.1. Vibration Periods

According to Technical Standard E.030 [13] of the National Building Regulations, the vibration period is the time it takes for a structure to complete a cycle of free oscillation under the action of dynamic forces, expressed in seconds, and depends on the stiffness and mass characteristics of the structural system. Furthermore, for regular buildings, the maximum expected period (T) can be estimated approximately by dividing the number of floors by 10 (T = N/10), this being a fundamental parameter for determining the seismic response of the building and its interaction with the design spectrum.

2.2.2. Displacements

According to Technical Standard E.030 [13] of the National Building Regulations, displacements are the lateral deformations that a structure will undergo under the action of seismic forces; these are expressed in terms of distances (mm or cm) and must be limited to ensure stability and structural performance of the building. Maximum permissible displacement is taken as a percentage of the story height and is usually 0.7% of height for strong earthquakes, ensuring integrity and preventing damage to non-structural elements.

2.2.3. Inter-Story Drifts

According to the National Building Regulations, Technical Standard E.030 [13], inter-story drifts represent the relative lateral distortion between two consecutive levels of a structure, defined as the difference in horizontal displacements divided by the inter-story height, expressed as a percentage (%). This parameter must be controlled to ensure the overall stability of the building and limit damage to non-structural elements, with a maximum limit of 0.007 for concrete buildings, which corresponds to both structural systems in this case study.

2.2.4. Shear Force

According to Technical Standard E.030 [13] of the National Building Regulations, shear force is the total horizontal seismic action acting on the base of the structure, determined from spectral acceleration, the effective seismic weight of the building, zoning factors, soil, and importance. This force is distributed vertically according to the height and dynamic characteristics of the building, constituting a fundamental parameter for the design of elements resistant to lateral loads, where the standard requires that its calculation consider at least 80% of the static base shear in regular systems to ensure adequate performance in severe earthquakes.

2.2.5. Axial Force

According to Technical Standard E.030 [13] of the National Building Regulations, axial force is the internal load acting along the longitudinal axis of a structural element (such as columns or walls), generated mainly by gravitational loads (dead and live) and seismic effects, expressed in units of force (kN or tonf). This force must be considered in the design to ensure the stability and strength of the elements, verifying that they do not exceed their load-bearing capacity according to the materials and sections used, where Peruvian regulations require the inclusion of load combinations that consider both permanent and eventual stresses to ensure safe behavior under all anticipated load conditions.

2.2.6. Bending Moment

The bending moment, as defined in Technical Standard E. 030 [13] of the National Building Regulations, is the internal effect produced in a structural element (beams or columns) under transverse loads that tend to bend it; these generate compressive and tensile stresses in its extreme fibers, expressed in units of force per distance, (kN·m or tonf·m); this parameter is fundamental for seismic-resistant design, as it determines the capacity of elements to resist deformation under lateral and gravitational loads, where regulations require that its calculation consider ultimate load combinations, including the effects of seismic amplification and the redistribution of moments in hyperstatic structures, thus ensuring ductile and safe behavior in the event of severe seismic events.

3. Results and Discussion

The results obtained through static seismic analysis and dynamic seismic analysis, performed with Etabs 2021 software, are shown below. These include vibration period, displacements, inter-story drifts, shear force, axial force, and bending moments.

3.1. Vibration Period

The proposed models show shorter oscillation cycle times in their vibration modes compared to the conventional Dual system, reducing mode 1 by 19% in the Diagrid Type A structure and 24% in the Diagrid Type B structure. Mode 2 also shows a decrease of 17% in Model A and 24% in Model B. Mode 3 shows the greatest reduction in the proposed structures compared to the Dual model, with a 50% reduction in the Diagrid Type A structure and a 36.85% reduction in the Diagrid Type B structure. Table 6 presents the vibration periods obtained through computational analysis of the Dual Structural model, specifically Diagrid type A and Diagrid type B.

Table 6. Fundamental vibration period of the structure

System	Period		
	Mode 1 (Seg)	**Mode 2 (Seg)**	**Mode 3 (Seg)**
Dual Structure	0.547	0.539	0.464
Type A Diagrid Structure	0.447	0.447	0.227
Type B Diagrid Structure	0.412	0.410	0.293

The direction of rotation of the studied structures, as presented in Table 7, indicates that all three models exhibit vibration first in the Y direction, followed by the X direction, and finally in rotation. The latter remains below the 90% limit established by Technical Standard E.030 [13], classifying them as regular structures in the structural analysis.

Table 7. Direction of the fundamental vibration period

System	Period		
	Mode 1 (%)	**Mode 2 (%)**	**Mode 3 (%)**
Dual Structure	0.5259 (translation y)	0.5452 (translation x)	0.7305 (rotation)
Type A Diagrid Structure	0.361 (translation y)	0.361 (translation x)	0.8371 (rotation)
Type B Diagrid Structure	0.4135 (translation y)	0.4162 (translation x)	0.8259 (rotation)

The results in modes 1 and 2 of the Type A and B Diagrid structures show similar data, due to the symmetry in the structure in the X and Y directions, developing better behavior during earthquakes and avoiding the torsional effects of the structure [16].

The main reason for the shorter fundamental vibration period resulting from the Diagrid System compared to the conventional Dual System is due to its effective geometric configuration and its optimized structural behavior, given that the diagonal arrangement of the elements provides a continuous and direct load path, with a greater lateral stiffness and a lesser overall flexibility of the structure, which corresponds to shorter vibration periods. Furthermore, seismic forces can be distributed more uniformly along the structure, and local deformations can be minimized.

3.2. Displacements

The seismic displacements obtained from the computational analysis in the X-X and Y-Y directions are summarized in Tables 8 and 9, respectively. The results show that the Dual structure reaches a maximum displacement of 15.88 cm, the Type A Diagrid structure 9.76 cm, and the Type B Diagrid structure 8.44 cm. All these values fall within the limits established by the Peruvian Technical Standard E.030 [13] and the U.S. standard ASCE 7-16 [12].

Table 8. Seismic displacement in the X-X direction

Displacement in X-X Direction			
N° Floors	**Dual Structure (cm)**	**Type A Diagrid (cm)**	**Type B Diagrid (cm)**
8	15.7983	9.7676	8.4467
7	14.5819	8.5796	8.1501
6	12.9770	7.2408	6.8612
5	10.9704	5.8065	6.1010
4	8.6273	4.3911	4.5029
3	6.0716	2.9006	3.2272
2	3.4976	1.7635	1.9199
1	1.2338	0.6001	0.8752

Table 9. Seismic displacement in the Y-Y direction

Displacement in Y-Y Direction			
N° Floors	**Dual Structure (cm)**	**Type A Diagrid (cm)**	**Type B Diagrid (cm)**
8	15.8865	9.7608	8.4483
7	14.7320	8.5738	8.1538
6	13.1670	7.2356	6.8623
5	11.1788	5.8023	6.1005
4	8.8368	4.3880	4.5045
3	6.2612	2.8985	3.2314
2	3.6377	1.7624	1.9210
1	1.2920	0.6001	0.8736

The displacements of all floors in the X-X direction for the three developed models are illustrated in Figure 6. When compared with the conventional Dual structural model, the Type A Diagrid model exhibits a 38.17% reduction in displacement, while the Type B Diagrid model achieves a 46.53% reduction. Overall, the Diagrid structural systems demonstrate a displacement reduction exceeding 35% relative to the Dual structural system.

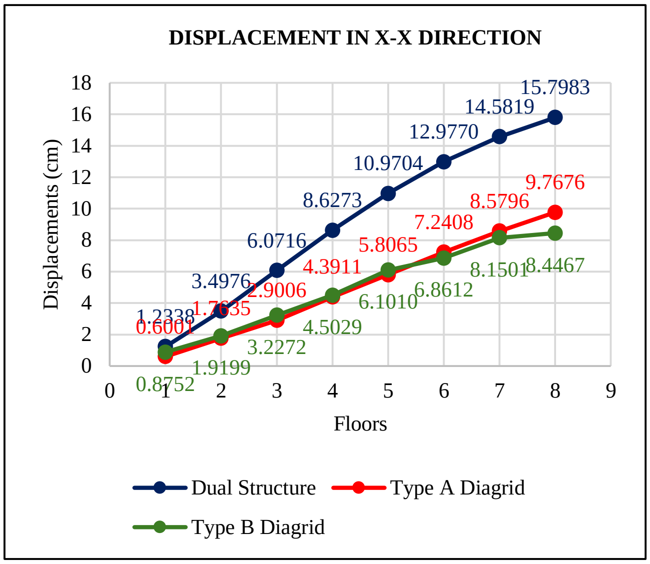

Fig. 6 Displacement per floor, X-X direction

Similarly, Figure 7 shows the displacements of all floors in the Y-Y direction of the three models developed. Compared to the conventional Dual structural model, the Type A Diagrid model shows a 38.54% reduction in displacement, while the Type B Diagrid model shows a 46.85% reduction, demonstrating the high efficiency of Diagrid structural systems compared to the Dual structural system.

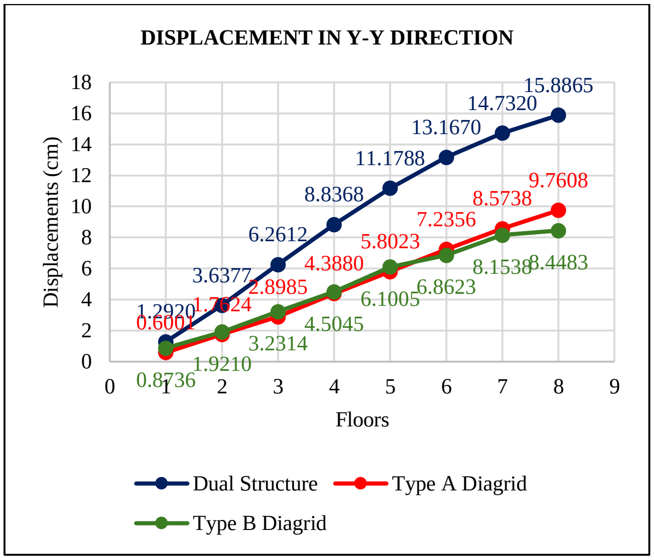

Fig. 7 Displacement per floor, Y-Y direction

It is evident that Diagrid structures offer greater control at all levels of the structure against displacement caused by seismic activity compared to Dual structures.

The considerable reduction in seismic displacements in both directions demonstrates that, in the Diagrid system, lateral stiffness is greater and load distribution is more effective compared to other systems. Indeed, the diagonal configuration allows for direct load paths, so bending and shear demands are transformed into axial forces, reducing lateral deformations along the height.

This explains the 35-45% reduction in displacement compared to the Dual system and confirms that the Diagrid system is more effective than traditional frame and wall systems for controlling seismic motion.

3.3. Inter-Story Drifts

In Table 10, inter-story drift results are shown for the conventional Dual model and the Diagrid Type A and Type B models in the X-X direction. On the third level, the Dual model has a relative lateral displacement of 0.612%, close to the limit set by Peruvian Technical Standard E.030 [13]. On the contrary, for the Diagrid model Type A, the maximum drift value was 0.359% on the fourth level, while the Diagrid model Type B had the maximum drift on the fifth level, reaching a value of 0.389%.

Table 10. Inter-story drifts in the X-X direction

Inter-story drifts in the X-X direction			
Number of Floors	Dual Structure	Type A Diagrid	Type B Diagrid
	Inelastic drift Δ (%)	Inelastic drift Δ (%)	Inelastic drift Δ (%)
8	0.289	0.284	0.102
7	0.382	0.341	0.329
6	0.477	0.344	0.198
5	0.558	0.353	0.389
4	0.608	0.359	0.319
3	0.612	0.274	0.322
2	0.539	0.281	0.256
1	0.294	0.147	0.215

Table 11 summarizes the drifts per floor in the Y-Y direction for the three structural models that have been analyzed. The maximum recorded drift is 0.624% on level three for the Dual, 0.371% on level four for Type A Diagrid, and 0.389% on level five for Type B Diagrid.

Table 11. Inter-story drifts in the Y-Y direction

Inter-story drifts in the Y-Y direction			
Number of Floors	Dual Structure	Type A Diagrid	Type B Diagrid
	Inelastic drift Δ (%)	Inelastic drift Δ (%)	Inelastic drift Δ (%)
8	0.275	0.308	0.085
7	0.372	0.341	0.330
6	0.473	0.363	0.198
5	0.557	0.353	0.389
4	0.613	0.371	0.308
3	0.624	0.278	0.322
2	0.558	0.285	0.256
1	0.307	0.147	0.214

The results obtained are presented in Figures 8 and 9 for the three analyzed models, in the major analysis directions X-X and Y-Y. According to the results, the Dual structural system presents drift values near the maximum limit of 0.007 for Technical Standard E.030 [13]. On the other hand, it is found that the Diagrid Type A and Type B models present better lateral deformation control, indicating that this type of structure performs its function more effectively under seismic action due to greater stiffness and restriction of displacements up to levels where structural safety could be compromised.

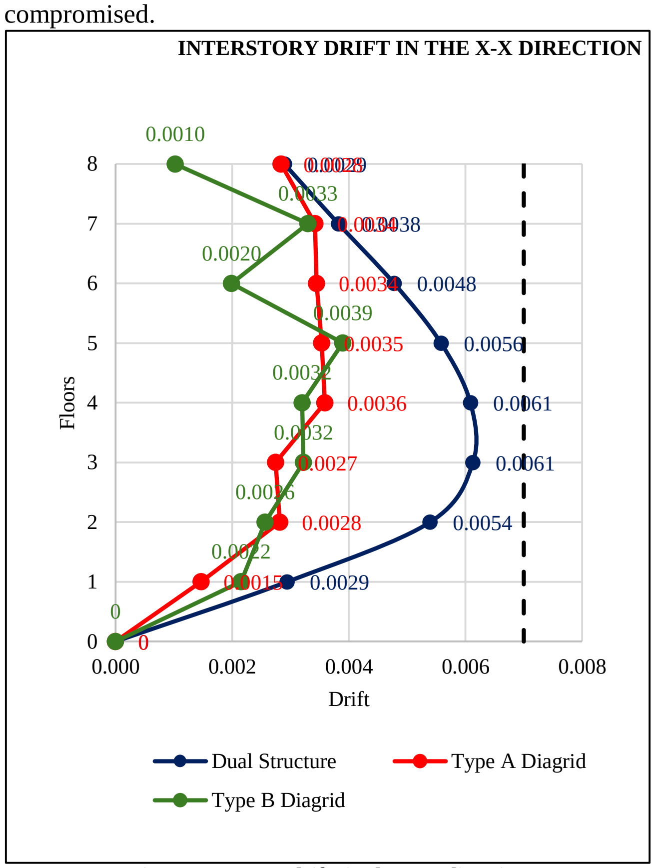

Fig. 8 Inter-story drifts in the X-X direction

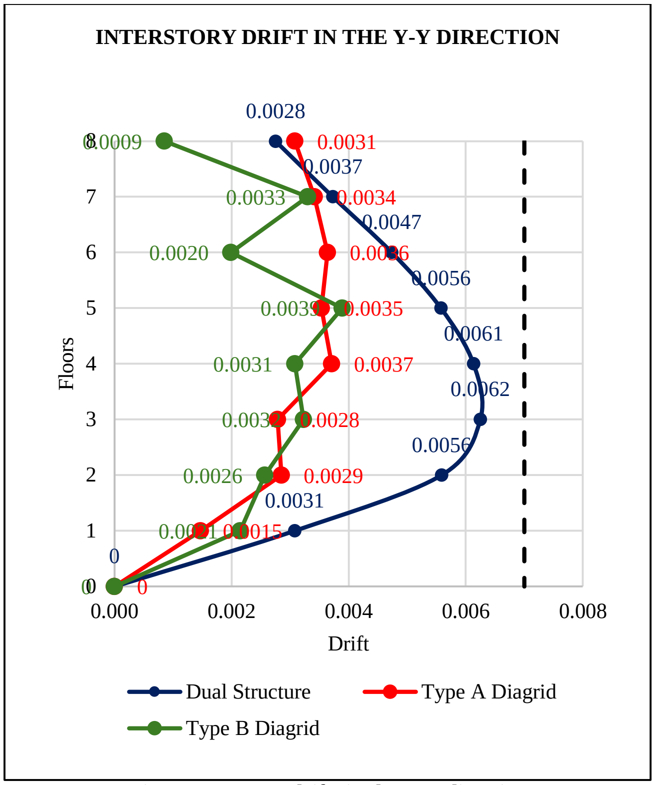

Fig. 9 Inter-story drifts in the Y-Y direction

The results appearing above indicate that the values obtained from both directions are alike due to the symmetric structure of the system; this increases the efficiency of the Diagrid models, which show deviations of no more than 0.39%, representing a 38% reduction compared to the deviation obtained from the Dual system. This efficiency is due to the incorporation of diagonal elements that make up the proposed structural system.

Its uniform distribution of stiffness and geometric symmetry mean that diagrid structures have a reduced drift between stories, since these characteristics help in distributing lateral deformation equally among the stories, and excessive drift concentration on the critical floors is avoided. For this reason, diagrid models remain well below the drift limits specified in seismic codes, thereby guaranteeing greater functionality and a reduction in non-structural damage during earthquakes compared to the conventional systems of earlier studies.

3.4. Shear Force

The maximum shear forces developed in the first level of the structure are presented in Figure 10 and 11. The outcome shows that the Dual structural system (structural walls and frames) induces internal forces of up to 1305.26 tonnes in the X-X direction and 1301.21 tonnes in the Y-Y direction, while the proposed Diagrid structural systems increase no more than 5% over these values.

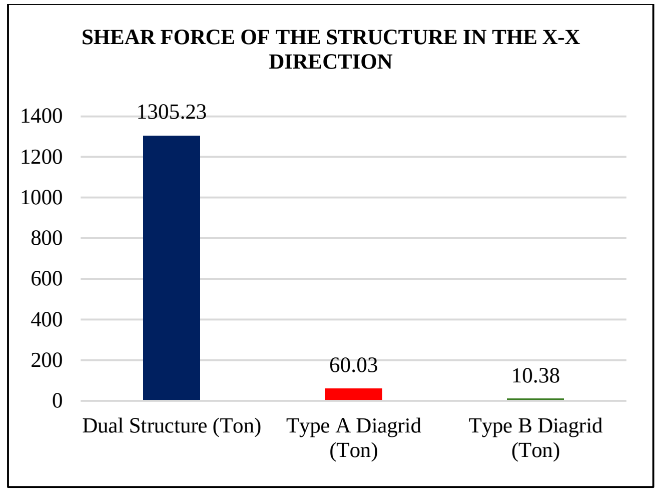

Fig. 10 Shear force, X-X direction

It is worth noting, based on the obtained results, that the shear forces in Diagrid structures are significantly reduced, resulting in better seismic performance [17]. Such a feature avoids shear failure and reduces steel reinforcement requirements [18], hence making them efficient structures.

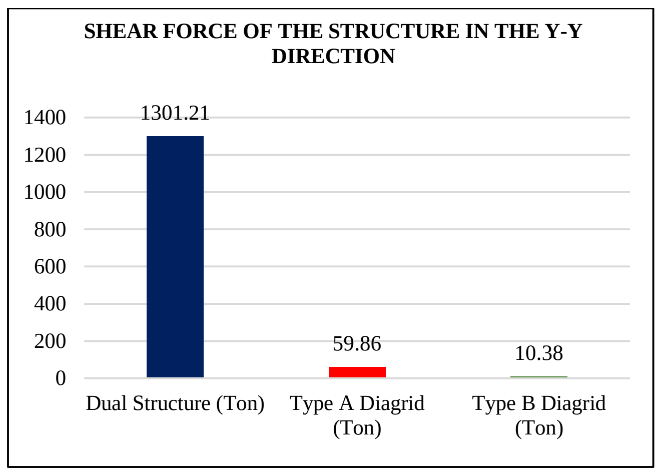

Fig. 11 Shear force, Y-Y direction

The structural symmetry considered in the models analysed allowed similar shear force results to be obtained in both directions; the lowest shear demand corresponds to the Type B Diagrid structure, giving a value of 10.38 tonnes in both directions, while in the case of the Type A Diagrid structure, the shear forces do not exceed 60 tonnes, showing efficient structural behaviour against lateral loads.

The reductions in the shear forces of the Diagrid systems can be explained by their capabilities to resist and distribute lateral loads efficiently through diagonal elements; whereas in the Dual system, the shear concentrates in structural walls, the Diagrid transfers substantial parts of these forces via axial action in its diagonals, thereby relieving the shear demand in the corresponding vertical components. The efficiency of the load-sharing mechanism enhances the general ductility and resilience of the structure, confirming that the seismic performance of Diagrid systems is better than that of traditional configurations.

3.5. Axial Force

The axial forces generated in the vertical structural elements of the analyzed models in both directions are illustrated in Figures 12 and 13. Owing to the structural configuration and regulatory requirements of the Dual system, its structural elements develop a total of 3,553.03 tonnes on the first level in the X-X direction and 3,597.24 tonnes in the Y-Y direction. These values are considerably higher than those recorded for the Diagrid models.

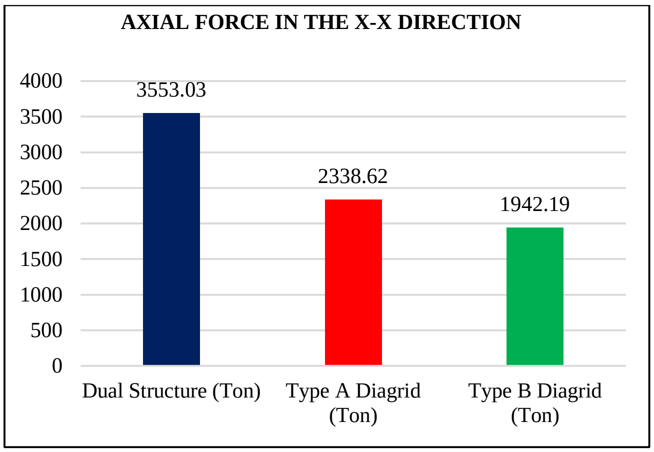

Fig. 12 Axial force, direction X-X

On the other hand, models with the Diagrid system develop lower axial forces compared to the Dual model. This difference is due to the fact that the Diagrid structural configuration does not require additional vertical structural elements to resist lateral loads. Compared to the results of the Dual System, in the X-X direction, the Diagrid Type B model shows a 45.33% reduction in axial forces, while the Diagrid Type A model shows a 34.18% reduction.

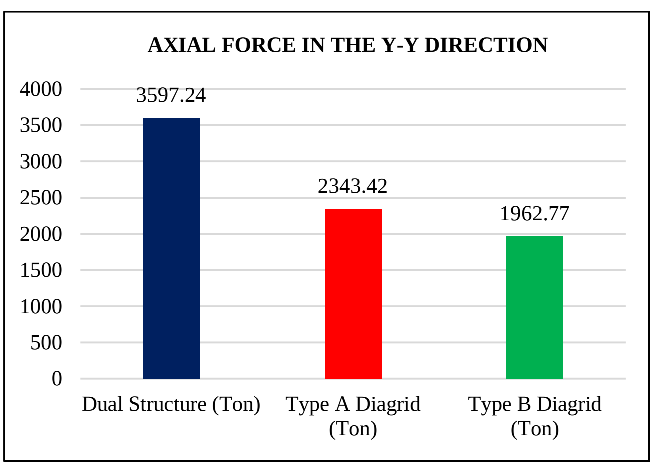

Fig. 13 Axial force, direction Y-Y

Likewise, a reduction in axial forces in the Y-Y direction is observed, with 45.44% in the Type B Diagrid model and 34.86% in the Type A Diagrid model; This reduction is a consequence of the presence of diagonal structural elements that contribute to a more effective redistribution of axial loads [19], therefore making the structure more stable and efficient.

Reduced axial forces in the Diagrid structures are basically because of the optimized load path provided by the diagonal elements, reducing vertical load concentration; in this system, partial conversion of the lateral load to axial compressive and tensile forces within the diagonals balances out the load. This leads to less axial demand on the columns and core elements, increasing stability and making the Diagrid system more material-efficient and structurally stronger than traditional Dual systems.

3.6. Bending Moments

The bending moments of the three proposed structural models in both directions are represented in Figure 14 and 15; for the Dual system, the analysis was performed for the columns and structural walls, while for the Diagrid systems, it was conducted for the diagonals and columns corresponding to the first level of each model. Consequently, it can be seen from the obtained results that the maximum bending moment developed in the Dual structural system has a magnitude of 2989.85 tonnes, while the Diagrid Type A and Type B models have 66.35 and 37.34 tonnes, respectively. This significant reduction in bending moments within the Diagrid systems is directly connected with lower levels of structural deformation, reflecting better performance under lateral loads.

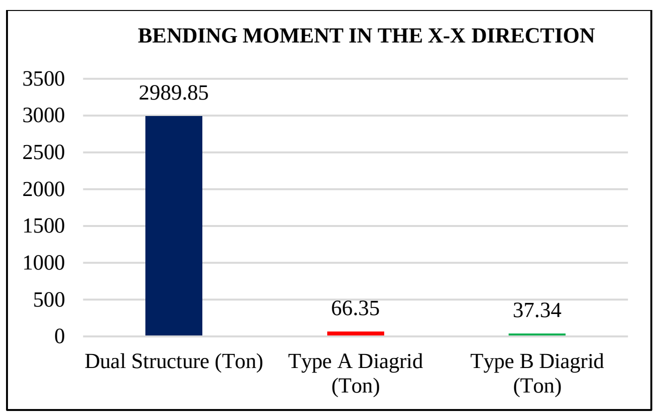

Fig. 14 Bending moment, direction X-X

Bending moments in the Diagrid structures give results very much the same for both directions, with a difference of not more than 5% from the Dual structural model; this consistency in the structural response obtained through the symmetry and regularity of the configuration of the Diagrid system is regarded as favorable for the uniform distribution of the forces and the avoidance of significant moment concentrations due to geometric or stiffness irregularities.

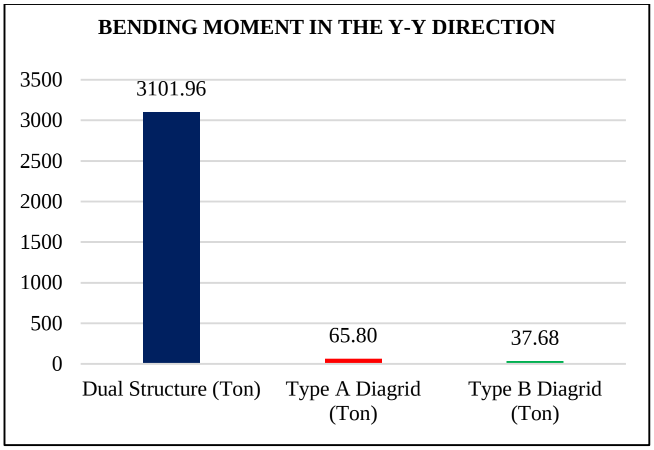

Fig. 15 Bending moment, direction Y-Y

The notable decrease in bending moments observed in Diagrid systems indicates a marked enhancement in structural performance when these systems are exposed to lateral forces. The diagonal elements, acting axially, absorb and redistribute the bending effects, thereby minimizing the bending stresses on columns and beams. This results in smaller bending moments, lower levels of deformation, greater stiffness, and increased ductility of the entire structure. Therefore, Diagrid models exhibit a greater capacity to resist lateral loads compared to conventional Dual systems and similar structures described in previous research.

4. Conclusion

The seismic performance of the Diagrid Structural System is much better than the Dual Structural System in important buildings, since, when performing both static and dynamic linear seismic analysis, more favorable values were obtained for the Diagrid System according to the six indicators evaluated in accordance with Peruvian regulations. The vibration periods of the Type A Diagrid Structural System were reduced by up to 50% compared to the Dual Structural System, from 0.464 seconds to 0.227 seconds, specifically in Mode 3. In terms of displacement, the Type B Diagrid Structural System also achieved a 46.85% reduction compared to the Dual Structural System, going from 15.88 cm to 8.44 cm. With regard to inter-story drifts, the Type A Diagrid Structural System also obtained better results, reducing drifts by up to 40.54% compared to the Dual Structural System. On the other hand, the Type B Diagrid Structural System performed better against shear forces compared to the Dual Structural System, as it only obtained a shear force of 10.38 tonnes, which is less than 1% of what was obtained with the Dual System. With regard to axial forces, the Type B Diagrid System performed better, obtaining 1962.77 tonnes, which represents 54.56% compared to the result of the Dual System. Finally, the Type B Diagrid Structural System obtained a lower bending moment of 37.68 tonnes, which represents only 1.21% compared to the Dual Structural System. It was concluded that the Type A Diagrid Structural System modulated every two floors is the best option for application in the city of Huancayo, as it had a cleaner structural configuration with fewer vertical elements, such as columns. In addition, this structural system did not suffer from irregularities as the Type B Diagrid did, since the seismic analysis for the latter found soft floor irregularities, requiring the incorporation of a greater number of columns to avoid this irregularity in height.

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