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Structural Comparison of Shear Walls vs Bracing in Concrete Frames Applying Value Engineering

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Abstract **-** Introduction: The Honduran Construction Code (CHOC-08) prohibits the construction of common rigid frame systems for concrete frameworks for buildings in the Municipality of the Central District (MDC). Due to this, it's necessary to consider frames that work with earthquake-resistant elements such as shear walls or braces. The study's objective was to determine which of two systems is the most efficient system in terms of seismic performance for a 30-story building based on structural variables. Methods. Structural modeling and Value Engineering have been used to meet the objective. The structural variables considered in the comparison were displacements, stiff-ness, structural weight, seismic absorption, and distribution of internal forces. To determine the weight/relevance of each of these, 16 self-prepared surveys were applied to teachers, graduates, and students of the Master of Structures at UNITEC. Results: Both shear walls and braces have shown significant structural benefits in the modeled frames. however, when applying the weighted analysis with the previously mentioned variables, the shear walls and braces have obtained ratings of 87.4% and 62.3%, respectively. Conclusions: It has been determined that shear walls are more efficient elements than braces in terms of their seismic performance due to the results obtained from modeling in conjunction with the application of Value Engineering.

Keywords**:** Modal Seismic, Seismic Resistant Elements, Structural Modelling, Weighting Analysis.

1. Introduction

[1] mentions that Francisco Morazán is the department of Honduras with the highest demand for projects. This growth occurs because the careers with the highest demand require offices to generate jobs. [2] confirms that the demand for offices has increased in Latin America in 2021, and [3] confirms this interest for the Municipality of the Central District (MDC); and these projects basically consist of vertical buildings.

[4] mentions that vertical building structures are characterized by having different structural requirements. These buildings are based on space optimization, and in the MDC the demand for vertical buildings has increased since 2004.

[5] determined that concrete frames are the preferred solution by civil engineers in the Central District compared to steel frames for the construction of apartments or ordinary buildings. [6] adopts the Honduran Construction Code (CHOC-08) in Decree No. 173-2010 as a guiding tool within construction with strict compliance.

[7] prohibits the use of common rigid frame (MRC) systems for concrete frames in seismic zone 3, which includes the Central District, but CHOC-08 also mentions that semi-rigid and special rigid frames, frames building, and dual systems can be used in place of MRCs.

According to [8] for buildings greater than 20 stories, special rigid and semi-rigid frames are not an efficient option due to their construction methods and other structural considerations, therefore, he recommends using building frames or dual systems for these structures, and These systems include seismic-resistant elements within the porch. [7] mentions that they can be shear walls or bracing.

[9] mentions that a bracing is the earthquake-resistant element used to stiffen or stabilize the structure, preventing or limiting the displacements or deformations it presents. This author demonstrated that bracing could provide the advantages in a regular frame. [10] demonstrate that bracing can considerably reduce the internal forces received by beams or columns; This was determined from a steel bracing rehabilitation analysis for a concrete frame.

[11] mentions that bracing is usually constructed of steel due to its tensile strength and that there is variety in bracing cross section and bracing type. [12] indicate that different types of bracing distribute the loads on the frame in different ways. [13] recommend performing optimizations within the bracing modelling due to its variety.

[14] mentions that a shear wall is a vertical element used to stiffen a frame and improve its seismic performance. [15] demonstrate that these are earthquake-resistant elements that can reduce dis-placements and that, as in the case of braces, their location on the frame plan affects their performance.

[16] demonstrate that shear walls, in addition to reducing dis-placements in concrete frames, can reduce the magnitude of internal forces.

The objective of the study was to determine, based on structural models, which is the most efficient system in terms of seismic performance between shear walls and bracing for a 30-story building based on the structural variables considered.

To make the structural comparison between shear walls and bracing, the Value Engineering methodology was applied, which is used to optimize projects through the analysis and evaluation of specific variables [17]. [18] mentions that Value Engineering is beneficial to carry out a functional analysis of alternatives.

2. Methods

2.1. Focus and Scope

The study presented a mixed approach due to the inclusion of quantitative and qualitative variables. The quantitative part consisted of the assignment of all the variables to evaluate the seismic performance of the shear walls and bracing through modelling and structural analysis, while the qualitative part of the study was the determination of the weight/relevance of the variables through the application from surveys to teachers, graduates and students of the Master of Structures of UNITEC.

2.2. Value Engineering Process

[19] mentions that Value Engineering follows a series of phases to meet its objective. The author suggests that the following process be used in their respective order: (1) Information Phase, (2) Speculation Phase, (3) Analysis Phase, (4) Development phase, (5) Execution Phase, and (6) Implementation Phase.

In the information phase, the problem is identified and information on possible solutions is collected; in the speculation phase, the proposals are listed and filtered to select the most appropriate ones. In the analysis phase, the functions of the selected proposals are studied in greater depth, [19].

According to [19], in the development phase the tools for execution are defined. In the execution phase, benefits and preliminary results are compared while opportunities for improvement are identified. These changes are processed in the implementation phase and a new analysis of the results obtained is carried out.

2.3. Modelling and Structural Analysis

For the configuration and assignment of variables, structural modeling and analysis were implemented using the Etabs computer program, which specializes in building structures. [5] mentions that the tallest buildings in the Central District are 30 floors on average, therefore, due to that and the fact that in that number of stories the effects of the shear walls and bracing will be of greater magnitude, porticos were modelled of 30 floors, each 3m high.

A Central District location was considered for the portico and an office occupancy. For the structural plan, a portion of the architectural plan of the "Torre Suyapa 504" office building was used courtesy of "Inmobiliaria ISULA". In this way, the portico resulted with the following parameters: (1) Porch Material: Rein-forced Concrete, (2) Location: Central District Municipality, (3) Occupation: Offices, (4) Number of Floors: 30 floors of 3 m each, and (5) Area of 410.5 m² per floor.

A pre-sizing of the frame was carried out following the equations of the [20] and considering concrete of f'c=3000psi for the beams and the slab and f'c=4000psi for the columns, it was reached the following results: (1) 60×30cm beams, (2) Columns 85×85cm, and (3) 12.5cm thick slab.

For the comparison of shear walls vs braces, 3 different frames were modelled, one with a common rigid frame system (MRC), one with a braced frame system (SMA) and another with shear walls (MMC). The MRC was used solely as a basis to analyse the effects and benefits that bracing, and shear walls provide to that system. In Figure 1 you can see the models made for this study. For the structural analysis, the design loads indicated by CHOC-08 were considered: (1) Dead weight, (2) Live load, (3) Wind Load, and (4) Static and Dynamic Seismic Load.

These were determined according to the indications of [7] and the envelope was determined considering the load combinations of [20]. In the case of seismic loads, modal analysis was used to use the critical periods within the static earthquake and to analyse the critical scenarios produced by the dynamic seismic load. These loads were placed in modelling software and a comparison was made based on the results.

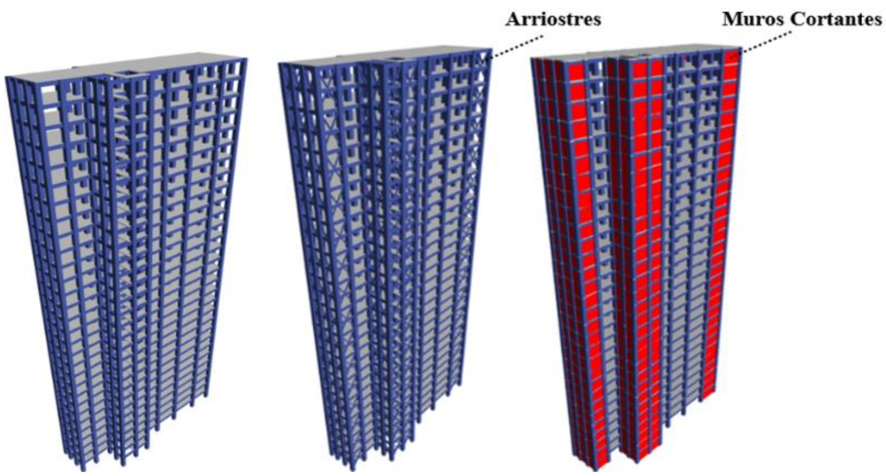
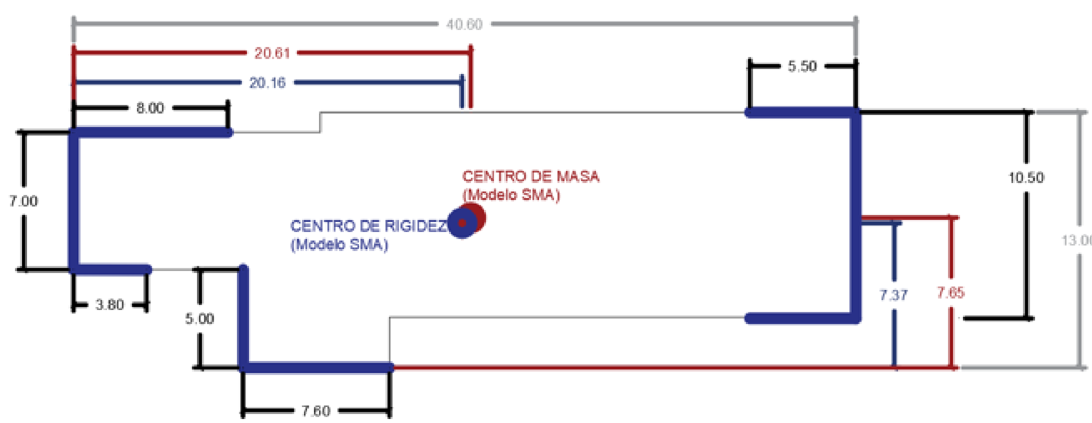


Fig. 1: MRC Model (left), SMA Model (center) and MMC Model (right).

2.4. Distribution of Shear Walls and Braces

The same distribution was used for shear walls and bracing. The distribution carried out aimed to minimize the eccentricity between the centers of mass and rigidity. [21] recommends an eccentricity of no more than 10% of the shaft length so that the accidental torsion factor is sufficient for consideration of torsion in the building. The distributions made are found in Figure 2; both eccentricities were acceptable.



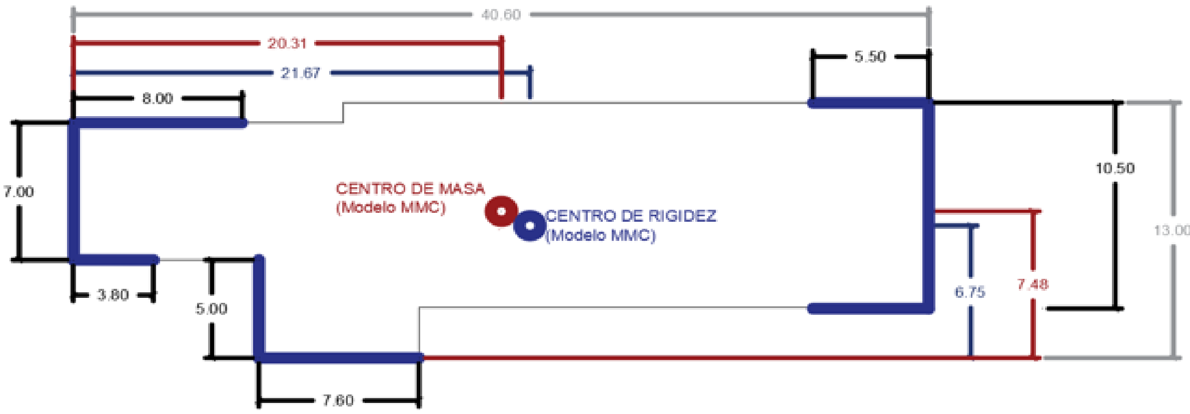


Fig. 2: Distribution of Shear Walls and Braces in Structural Plan (units in meters).

2.5. Optimization of Shear Walls

In the same way as the centers of mass and rigidity, the optimization of the shear walls and bracing was carried out through an iterative process. This process was carried out in such a way that both systems were evaluated in the best conditions for the frame under study, this function of the efficiency of the rigidity.

In the case of shear walls, this efficiency was determined from the thickness, and different options were tested to determine an optimal thickness of 30cm because it provided the highest efficiency per unit of thickness, generating a value of 1.982 tonf/mm², followed by 1.61 tonf/mm² and 1.219 tonf/mm² for thicknesses of 40cm and 20cm respectively.

2.6. Bracing Optimization

Bracing optimization considered different types of bracing and cross sections. In the case of the cross section, a hollow square section was considered because [13] recommend this type of section for bracing due to geometric symmetry. First the type of bracing had to be defined. For this study, the bracings in Figure 3 were considered:

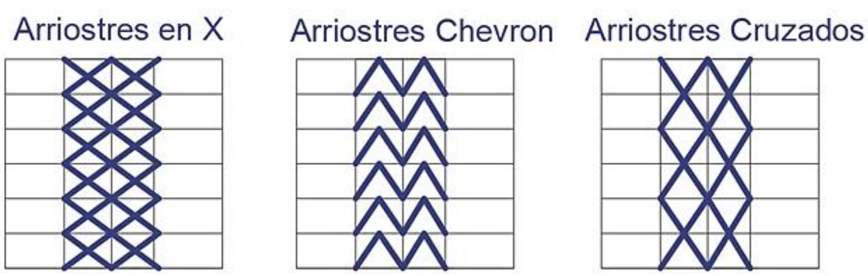


Fig. 3: Types of Bracing Considered in Optimization.

To determine the optimal type of bracing, a structural analysis was carried out to select the option with the greatest rigidity per ton of weight. Cross braces stood out with an efficiency of 249.692 (kgf/mm)/ton, followed by Chevron braces and X braces with efficiencies of 238.265 (kgf/mm)/ton and 183.728 (kgf/mm)/ton respectively.

Once the type of bracing was determined, the optimization of the cross section continued. For this, structural tubes available in hardware stores in Honduras were considered. A structural analysis was performed for each section including a strength review by the American Institute of Steel Construction (AISC) LRFD method. The optimal cross section was determined from the stiffness efficiency per unit area.

While the shear walls were configured with concrete f'c=4000psi, the braces were configured with A500 grade B steel; and the optimal cross section was the HSS8×8×0.25 profile with an efficiency of 19.184 (tonf/mm)/in².

2.7. Comparison Variables

Once the shear walls and bracing were optimized, the respective analysis of each of these was carried out based on the the following structural variables: (1) Seismic Absorption, (2) Stiffness Efficiency, (3) Relative Lateral Displacement, (4) (4) Maximum Displacement, (5) Structural Weight, (6) Average Internal Forces, (7) Average Stiffness, and (8) Maximum Maximum Internal Forces. The assignment of all these structural variables comes from the results of the structural analysis analysis of the optimized models. This represented the analysis phase of Value Engineering.

2.8. Weighted Analysis

As part of the development phase, the tools to be used in the execution phase had to be selected. In the case of this research, the weighting analysis was considered to evaluate the shear walls vs bracing in the variables.

[22] mention that weighting analysis, also known as "weighting of alternatives", is a tool that is used to evaluate proposals or alternatives based on different variables or criteria. This tool has different ways of being applied but the differences are usually only in the representation of the data and that the results of the application would be similar.

[23] mentions a series of steps for this tool: (1) List Options, (2) Determine Influence Criteria, (3) Rate the Criteria, (4) Rate Each Criteria for Each Proposal, (5) Calculate Weighted Scores, (6) Calculate Final Scores, and (7) Determine Final Decisions. For this research, this tool was used for the execution and analysis of the implementation of Value Engineering.

2.9. Information Phase

This phase represents the determined compilation, from this phase it was possible to identify the current problem, which is the uncertainty regarding the structural system to be used in concrete frames for vertical building in the Central District. In this phase, the different proposals or options available as a solution to the problem were superficially investigated.

2.10. Speculation Phase

In this phase, the different available proposals were listed, these were the following: (1) Special Rigid Frames, (2) Semi-rigid frames, (3) Frames with Seismic Dissipators, (4) Frames with Seismic Isolators, (5) Porches with Shear Walls, and (6) Braced Porches.

Because [8] mentions that in buildings with more than 20 floors, special rigid and semi-rigid frames are no longer the most efficient systems; and because seismic insulators and dissipators are not commonly used in the Central District, only shear walls and braces were considered in the comparison of seismic performance in concrete frames.

2.11. Analysis Phase

In this part, the functions, benefits and characteristics of the shear walls and bracing were placed. The data mentioned below comes from the results of structural analysis.

2.12. Development Phase

In this phase, the tools that will be used within the execution and implementation phase are defined. In the case of this research, the use of surveys and weighted analysis was considered.

A survey was applied to a sample calculated from the population made up of teachers of undergraduate and graduate structural classes, students graduating from Civil Engineering and master's degree in Structures from UNITEC, to determine the weight/relevance of each structural variable based on scales from 0 to 5. Based on the 16 responses obtained, it was determined that seismic absorption is the variable that received the highest rating based on its relevance to earthquake-resistant performance.

2.13. Execution Phase

In this phase, the weighting analysis was carried out to determine the proposal that prevails between shear walls and bracing. The weighting matrix used is shown in Table 1 taking the data resulting from the structural analysis, the weights of the survey results and the weighting as a division of the proposal data that prevails in a category over the proposal data evaluating. If you want to maximize a variable, the relationship will be the reciprocal of that result.

3. Results

3.1. Movements

The maximum lateral displacement of the MRC was 193,631 mm, this data was compared with the displacements MMC model (84,345 mm) and the SMA model (148,049 mm). In this way, it has been shown that the shear walls reduced the displacement of the MRC by 56.44% and the bracing by 23.54%, data calculated through percentage differences.

Additionally, an analysis of the relative lateral displacements, also known as drift, has been carried out, from which it has been shown that the shear walls have reduced the drift of a frame by 52.29% and the bracing by 22.29%, always maintaining the limits established by [7].

Because shear walls improve the MRC to a greater extent than bracing, they have prevailed in both the maximum and relative lateral displacement variables. In Figure 4 there is a graph that shows the difference between these systems in terms of their displacement.

3.2. Average Stiffness

[24] indicates that stiffness can be interpreted as the load necessary to move a frame per unit of length. When analysing the differences as in the case of displacements, this research showed that both shear walls and braces present benefits for common rigid frames in terms of average stiffness, which has increased by 41.03% using braces and 322.68% using shear walls. Because shear walls provide a greater improvement in stiffness, they have prevailed in the evaluation of this variable. In Figure 4 there is a graph that shows the difference between these systems in terms of stiffness due to height in the frame.

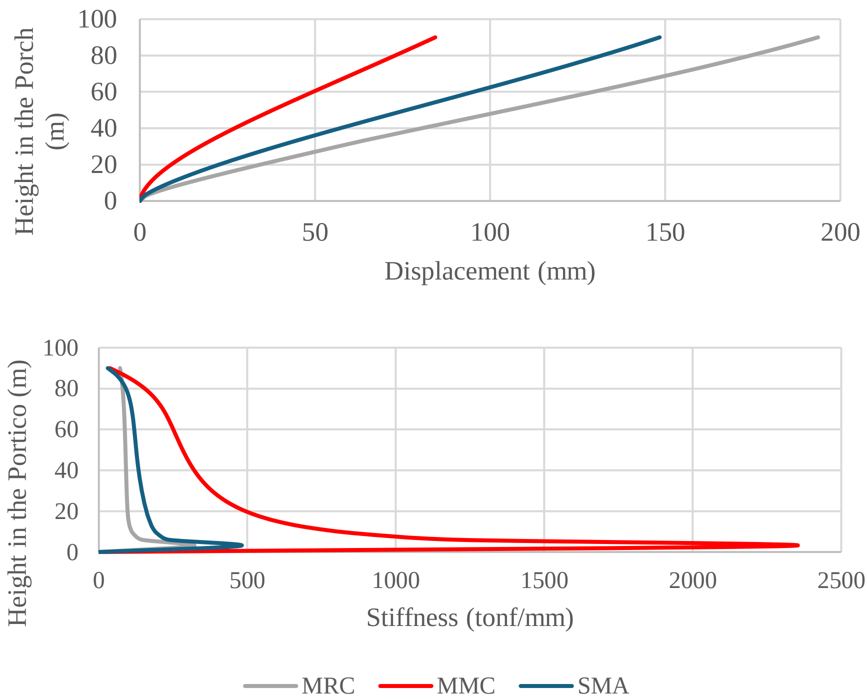


Fig. 4: Comparison of Displacements and Rigidity due to Height in the Portico.

3.3. Structural Weight

The porch with braces has a weight of 17,244.33 tons and the porch with shear walls 19,264.138 tons. Since weights usually influence costs, we want to minimize these, therefore, bracing has better performance.
However, when evaluating the efficiency of stiffness per unit of weight, a value of 20.666 (kgf/mm)/ton has been determined for the frame with shear walls and 7.847 (kgf/mm)/ton for bracing, demonstrating that the Shear walls provide greater rigidity and efficiency than braces, although these were heavier.

3.4. Distribution of Internal Forces

For this, an average was made of the percentage differences in the magnitudes of axial forces, shear and moment that the beams and columns of the MMC and SMA models have compared to the beams and columns of the MRC model, evaluating both the maximum values and the average values.

The magnitude of the average internal forces has been reduced by 28.47% with shear walls and 18.21% with bracing; however, when analysing the maximum internal forces of the frame, the bracing has reduced this magnitude by 17.67%, in contrast to the results obtained with shear walls, whose magnitude of maxi-mum internal forces has increased by 6.77%. In both cases the aim is to maximize the reduction, therefore, in the distribution of average internal forces the shear walls have prevailed, but in the distribution of maximum internal forces the braces have prevailed.

3.5. Seismic Absorption

This variable represents the percentage of seismic load absorbed by the shear walls and bracing. It has been determined that the shear walls have absorbed 60.58% of the seismic load and the bracing 31.17%.

This division was multiplied by the relative weight to have a representation of percentages, the final grade in this case was the sum of all the percentages. The bracing resulted in a rating of 62.3% while the shear walls resulted in a rating of 87.4%. This means that, preliminarily, the shear walls prevail over the bracing. However, the scenarios must be tested with the opportunities for change detected. In this case, making changes to the structural weight.

Table 1: Weighted Analysis of Shear Walls vs Bracing.

Variable	Data		Weight	Relative weight	Weighing	
	Bracing	**Shear Walls**			**Bracing**	**Shear Walls**
Seismic Absorption (%)	31.17%	60.58%	4.5	14.6%	7.5%	14.6%
Stiffness Efficiency ((kgf/mm)/ ton)	7,847	20,666	4.3	13.8%	5.2%	13.8%
Relative Lateral Displacement (mm)	5,751	3,531	3.9	12.8%	7.8%	12.8%
Maximum Displacement (mm)	146,026	84,345	3.9	12.6%	7.2%	12.6%
Structural Weight (ton)	17,244,330	19,624,138	3.8	12.1%	12.1%	10.7%
Average Stiffness (tonf/mm)	135,324	405,561	3.6	11.5%	3.9%	11.5%
Average Internal Forces (% Diff. MRC)	-18.21%	-28.47%	3.6	11.5%	7.4%	11.5%
Maximum Internal Forces (% Diff. MRC)	-17.67%	6.77%	3.4	11.1%	11.1%	0.0%
Total Weight and Final Qualification			**30.9**	**100%**	**62.3%**	**87.4%**

3.6. Implementation Phase

In this phase, the changes with possible improvements detected in the execution phase were applied. In this case, because the difference between the percentages of shear walls and bracing is 25.1%, changes in the bracing so that they can equal or exceed the shear walls would imply unrealistic scenarios, therefore the opportunities for improvement in bracing and a focus was placed on improvement opportunities for shear walls.

The only variable that can be improved independently is the structural weight, therefore a new model was made considering lightened concrete according to the conditions and indications of [20] in the shear walls. However, this new model resulted in a score of 84.6% because by reducing the structural weight there was a worsening in the rest of the variables that have a greater weight factor, therefore, reducing the structural weight in shear walls in this way.

4. Discussion

Both shear walls and braces provide improvements to an MRC in different areas, however, shear walls have in the greatest number of variables (6 out of 8) and in the most relevant ones, such as in the case of seismic absorption, gave them a significant advantage within the weighting analysis, resulting in a difference in favor of 25.1%, making the walls the most efficient proposal in terms of seismic performance for concrete frames in the proposed scenario.

Although Value Engineering is generally used in costs, this turned out to be an equally useful tool for structural comparison, demonstrating that it is possible to use this methodology for comparison investigations.

A future evolution of this project would involve the inclusion of construction variables such as the type of labor, aesthetics, availability or cost, to mention a few examples. This could be done to compare the bracing against the shear walls in other variables and thus be able to determine the most efficient system in global terms, already knowing that the shear walls prevail in terms of structural or earthquake-resistant performance.

5. Conclusion

It has been determined, from structural modelling and the application of Value Engineering, that shear walls have greater seismic performance than bracing for 30-story concrete frames. This is because the rating resulting from the weighted analysis was 87.4% for the shear walls and 62.3% for the bracing.

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