Performance Analysis of Earthquake-Resistant Multi-Story Buildings with Dynamic Loading (Case Study: Rd Kandou Hospital Building in Manado)

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Abstract

Earthquakes are natural disasters with a high likelihood of occurrence. The presence of many multi-story buildings in earthquake-prone areas can result in significant damage. Therefore, an analysis of building structures was conducted. In this final project, the analyzed object is the multi-story building of RD Kandou Hospital in Manado. The objective of this study is to determine the values of drift, horizontal displacement, and structural performance levels based on ATC-40. The analysis was conducted using dynamic loading with the response spectrum and time history methods. Structural modeling was performed using ETABS software, in accordance with SNI 1726:2019 and SNI 1727:2020. The analysis results yielded maximum displacement values of 32.710 mm in the X direction and 31.387 mm in the Y direction using the response spectrum method, while the maximum deflection values using the time history method for the Niigata earthquake were 34.140 mm in the X direction and 28.545 mm in the Y direction, for the Iwate earthquake were 30.620 mm in the X direction and 30.675 mm in the Y direction, and for the Tokachi earthquake were 32.454 mm in the X direction and 29.308 mm in the Y direction. The structural performance level results indicate that the building structure is at the Immediate Occupancy performance level, meaning the building only sustained minor damage.

Keywords: Earthquake, dynamic loading, ETABS, RD Kandou Manado, ATC-40, SNI 1726:2019, SNI 1727:2020

1. INTRODUCTION

Earthquakes are among the most frequent and destructive natural disasters, especially in Indonesia, which lies on the Ring of Fire where three major tectonic plates—Indo-Australian, Eurasian, and Pacific—converge. This makes the country highly prone to seismic hazards, including along the megathrust zones that stretch from Sumatra to Sulawesi.

Manado, the capital of North Sulawesi Province, is located in a seismically active zone and has many multi-story buildings, including the 11-story RD Kandou Hospital, which plays a critical role in emergency response. Given the high earthquake risk, it is essential to assess the hospital's structural performance under seismic loads.

This study applies dynamic earthquake load analysis using the response spectrum and time history methods, aiming to evaluate inter-story drift, horizontal displacement, and structural performance level in accordance with current seismic design standards.

1.1. Earthquake

An earthquake is a shaking of the ground caused by the collision and shifting of Earth's tectonic plates, fault (fracture) activity, or volcanic activity from a volcano. This type of disaster is destructive in nature, occurs suddenly, and lasts for a short duration. In general, earthquakes are triggered by the release of energy resulting from pressure caused by the movement of tectonic plates. Over time, this pressure builds up until it reaches a point where the plates can no longer resist the stress, leading to a sudden shift and the release of energy in the form of seismic waves.

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1.2. Earthquake-Resistant Building Systems

Earthquake-resistant structures aim to minimize damage and maintain functionality after seismic events. These buildings often use dual systems, such as moment-resisting frames combined with shear walls, to improve lateral stiffness and reduce deformation under earthquake loads.

1.3. Seismic Design Regulations

The main design standard in Indonesia is SNI 1726:2019, which provides guidelines for seismic zoning, site classification, response spectra, and structural system requirements. SNI 1727:2020 outlines load combinations, including seismic, for structural analysis and design.

1.4. Seismic Analysis Methods

There are two primary types of seismic analysis:

- Static Analysis, including Equivalent Static Force Method and Pushover Analysis, which assumes lateral loads increase gradually to simulate seismic forces.
- Dynamic Analysis, including the Response Spectrum Method and Time History Analysis, which evaluate structure responses based on spectral acceleration curves or actual earthquake records..

1.5. Performance-Based Design

Earthquake-resistant structures aim to minimize damage and maintain functionality after seismic events. These buildings often use dual systems, such as moment-resisting frames combined with shear walls, to improve lateral stiffness and reduce deformation under earthquake loads.

1.6. Structural Modeling with ETABS

ETABS software enables comprehensive modeling and simulation of building structures under static and dynamic loads. It is widely used in engineering practice for its ability to perform multi-story seismic analysis and evaluate displacement, drift, and overall structural response.

2. METHOD

This chapter outlines the methods used to evaluate the seismic performance of the RD Kandou Hospital building in Manado under dynamic earthquake loading. The analysis was conducted using both the response spectrum and time history methods, in accordance with current Indonesian seismic design standards. A systematic approach was employed, beginning with data collection and structural modeling, followed by the application of seismic loads and performance evaluation based on the ATC-40 guidelines. Each step was carefully designed to ensure accurate representation of the building's behavior under earthquake conditions.

2.1. Research Flow

This study follows a structured process: identifying the problem, collecting structural data, modeling the building using ETABS, applying seismic loads, performing dynamic analysis (response spectrum and time history), and evaluating structural performance based on ATC-40 criteria.

2.2. Object of Study

The research object is the 11-story RD Kandou Hospital building located in Manado, North Sulawesi. The hospital is a critical facility situated in a seismic-prone area, making it essential to assess its response under earthquake loading.

2.3. Data Collection

The study uses architectural and structural design drawings, material specifications, and load data. Seismic parameters follow SNI 1726:2019, while load combinations refer to SNI 1727:2020. Ground motion records for time history analysis were sourced from global earthquake databases.

2.4. Building Modelling

The hospital building was modeled using ETABS software, with input data including material properties (concrete and steel), cross-sections of beams, columns, and shear walls, as well as floor and live loads. The structural system consists of moment-resisting frames.

2.5. Seismic Load Application

Two dynamic methods were used:

- Response Spectrum Method: Seismic design spectra derived from site classification and parameters according to SNI 1726:2019.
- Time History Method: Ground acceleration records from three earthquake types—Shallow Crustal (Niigata), Benioff (IbarakiOff), and Megathrust (Tohoku)—were scaled and applied to simulate real-time earthquake response.

2.6. Structural Performace Evaluation

Structural responses such as story drift, horizontal displacement, and inter-story deformation were measured. Performance levels were assessed using the ATC-40 standard, classifying the building into Immediate Occupancy (IO), Life Safety (LS), or Collapse Prevention (CP) based on drift criteria.

3. RESEARCH AND DISCUSSION

3.1. Structural Model

The RD Kandou Hospital building is an 11-story reinforced concrete structure designed with a dual system of moment-resisting frames and shear walls. The model includes floor loads, live loads, and seismic loads based on SNI 1726:2019 (Earthquake Resistance Design) and SNI 1727:2020 (Load Combinations). ETABS was used to simulate the building's behavior under dynamic loading.

3.2. Response Spectrum Analysis Results

The analysis using the response spectrum method provided the following results:

- Maximum Horizontal Displacement:
  X-direction: 74.225 mm
  Y-direction: 74.057 mm
- Maximum Inter-story Drift:
  X-direction: 32.710 mm
  Y-direction: 31.387 mm

These values are within acceptable limits and suggest that the building exhibits good flexibility and ductility under spectral earthquake loads.

3.3. Time History Analysis Results

Time history analysis was conducted using three ground motion records:

- Niigata (Shallow Crustal Earthquake)
- Iwate (Benioff Earthquake)
- Tokachi (Megathrust Earthquake)

The results of the maximum displacements and inter-story drift for each earthquake are as follows:

a) Niigata Earthquake

- Horizontal Displacement:
  X: 75.671 mm, Y: 73.279 mm
- Inter-story Drift:
  X: 34.140 mm, Y: 28.545 mm

b) Iwate Earthquake

- Horizontal Displacement:
  X: 69.583 mm, Y: 70.884 mm
- Inter-story Drift:
  X: 30.620 mm, Y: 30.675 mm

c) Tokachi Earthquake

- Horizontal Displacement:
  X: 71.569 mm, Y: 71.689 mm
- Inter-story Drift:
  X: 32.454 mm, Y: 29.308 mm

Among these, the Niigata earthquake produced the highest displacement and the Tokachi earthquake produced the highest drift, especially in the Y-direction, suggesting a strong lateral force impact associated with megathrust events.

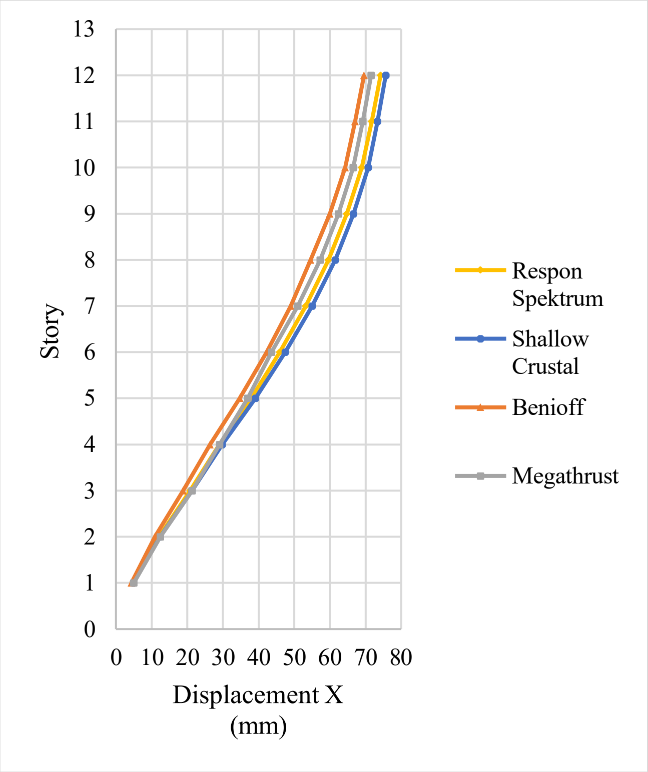

Figure 1.Graph of Recapitulated Displacement in the X-Direction

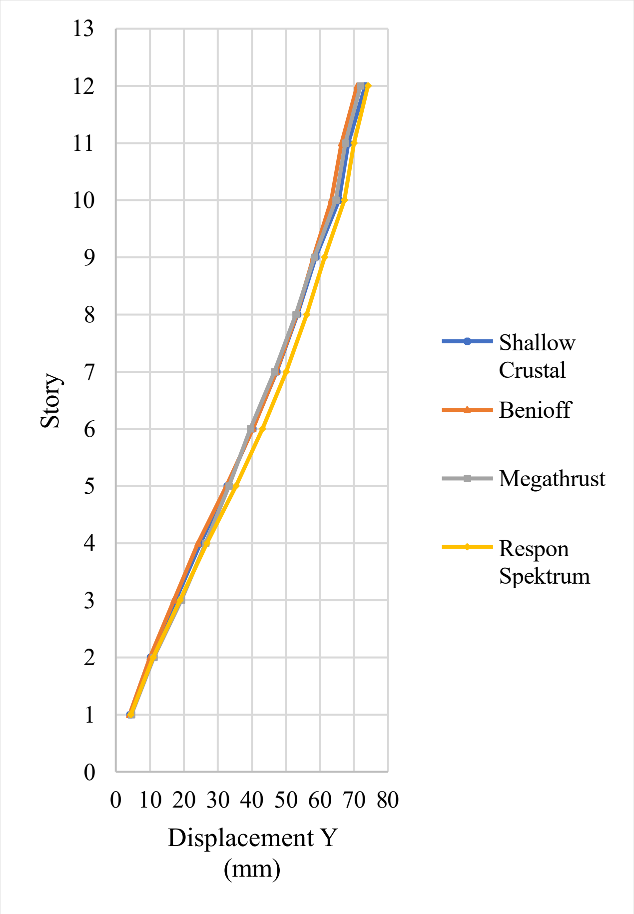

Figure 2.Graph of Recapitulated Displacement in the Y-Direction

3.4. Structural Performance Model

Based on the ATC-40 performance criteria:
All drift values for both response spectrum and time history methods remained below 2%, the allowable drift limit for Immediate Occupancy.
Thus, the RD Kandou Hospital building achieves an Immediate Occupancy (IO) performance level under all scenarios.
This performance classification indicates the building will experience minimal structural damage and can remain operational immediately following an earthquake—a critical requirement for hospital infrastructure.

4. CONCLUSION

The seismic performance analysis of the 12-story RD Kandou Hospital in Manado, using both response spectrum and time history methods, shows that the structure meets the Immediate Occupancy (IO) performance level as defined by ATC-40. Response spectrum analysis produced maximum displacements of 60.813 mm (X) and 63.304 mm (Y), with inter-story drifts of 33.875 mm and 35.277 mm, respectively. Time history analysis using Niigata, Iwate, and Tokachi earthquake records revealed that the Tokachi earthquake resulted in the highest response, with maximum drift reaching 38.566 mm. Nevertheless, all results remained within the 2% drift limit, indicating that the building would experience only minor damage and remain functional after a major earthquake. This confirms that the RD Kandou Hospital is structurally resilient and suitable for continued operation in the event of seismic activity, which is crucial for healthcare facilities.

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Efficiency of Steel Structures with Eccentrically Braced Frame (EBF) Horizontal Link Systems

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Abstract

This article analyses the efficiency of the steel structure of the Sumber Kasih Hospital building in Cirebon City, which uses an Eccentrically Braced Frame (EBF) system with vertical and horizontal links. The study's primary objective is to compare the performance and efficiency of using steel material in the Horizontal Link type of EBF, with the aim of producing a structure that is both economical and earthquake-resistant. Three structural models were analysed: the existing model without bracing and a model incorporating horizontal EBF links. All modelling and analysis were conducted using ETABS software in accordance with SNI standards relating to earthquake resistance and steel structure design. The response spectrum method was used for earthquake loading, and the evaluations included base shear control, inter-story drift, P-Delta effects and structural performance levels. The research results showed that using the horizontal EBF link system increased steel mass efficiency by approximately 3.20%, reducing the existing structure's steel mass by around 23 tons.

Keywords: Eccentrically Braced Frame, Efficiency, Steel, Building,

1. INTRODUCTION

The need for efficient, strong, and earthquake-resistant building structures continues to increase in line with the development of public facilities, particularly healthcare facilities that require high operational continuity. Steel structures have become the primary choice in many modern construction projects due to their ability to support vertical loads from their own weight and occupants, as well as resist lateral loads such as earthquakes. However, one of the main challenges in steel structure construction is the high material requirements, which directly impact construction costs and have negative environmental effects due to the exploitation of natural resources and carbon emissions during the production process.

Optimizing material usage in steel structures is crucial to reduce steel consumption without compromising structural strength or stability. One common approach is the use of efficiently designed bracing systems to enhance lateral stability and minimize deformation caused by horizontal loads, such as wind and earthquakes. Proper bracing design not only reduces production costs and material waste but also contributes to minimizing environmental impact.

This article aims to examine the efficient effect of using eccentrically braced frame (EBF) system with horizontal links The research utilizes dynamic response spectrum methods in earthquake load calculations and evaluates changes in beam and column dimensions (re-dimensioning) to achieve maximum efficiency in the use of steel materials in earthquake-resistant structures.

1.1. Eccentrically Braced Frame

Eccentrically braced frames (EBFs) are a structural system that confines inelastic behaviour to the link beam between two eccentric restraints. The outer beams, columns and diagonal restraints remain elastic under seismic loads. [1]. Meanwhile, Egor P. Popov defined EBF (Eccentrically Braced Frame) as a structural steel framing system designed to resist lateral loads (seismic and wind), where the braces are connected to the beam at points offset from the beam-column joints. This configuration creates a short beam segment known as the 'link'. The link is deliberately engineered to yield and dissipate energy during extreme events, while the rest of the frame remains predominantly elastic [2].

The distinctive feature of an EBF is the deliberate offset of its braces. They do not meet directly at the beam-column joints but instead connect at points along the beam, creating a short segment known as a "link." This link is engineered to deform plastically during seismic events, absorbing and dissipating energy to protect the rest of the structure, which remains elastic and undamaged. By concentrating inelastic behavior in this easily replaceable link, EBFs enable buildings to withstand strong lateral loads with reduced risk of collapse and simplified repairs after a major event. This approach combines the strength and stiffness of traditional braced frames with the controlled energy dissipation of moment frames, offering an optimal balance between performance and safety in earthquake-prone areas. Bracing Configurations in EBFs can vary, including D-braces, Split K-braces, V-braces, Chevron (inverted V) braces.

1.1.1. Component of EBF

An eccentrically braced frame (EBF) consists of several key components, each performing a specific function to enhance both the strength and ductility of the structural system, particularly during seismic events. Here is a short explanation of each part in an Eccentrically Braced Frame :

- Beams: These horizontal elements run between columns and support floor loads. While standard in most frames, in an EBF, a segment of the beam acts as the critical "link." Outside the link region, beams are designed to remain elastic under even severe loading, ensuring the frame's integrity after a major event.
- Columns: Vertical members transfer building loads down to the foundation. In EBF systems, columns provide vertical support and serve as anchoring points for braces and beams. They are sized to remain elastic, avoiding yielding or failure during large lateral (seismic or wind) loads.
- Braces: Diagonal (or sometimes chevron or other configurations) braces connect beams and columns but, uniquely in EBFs, at least one end of each brace connects to the beam at a point offset from the column rather than at a joint. This eccentricity creates the specialized link region, enabling the desired inelastic behavior. Braces offer stiffness to the frame, reducing sway and increasing its ability to resist lateral loads.
- Links: The heart of the EBF system, the link is a deliberately short segment of beam between the brace connection and the nearest column (or between two braces in some configurations). During strong earthquakes, the link is designed to yield and deform plastically, absorbing and dissipating a significant portion of the seismic energy. The rest of the frame stays elastic. Links can be oriented horizontally (along the beam) or vertically, affecting the repairability and energy dissipation characteristics of the frame. The length and cross-section of the link are critical design variables: shorter links tend to yield in shear (providing high energy dissipation), while longer links may yield in flexure.
- Gusset Plates and Connectors: These steel plates and fasteners are used at brace and beam intersections to ensure reliable load transfer between braces, beams, and columns without premature failure or slippage. Their detailing is crucial for maintaining the intended behavior of the system during extreme loading
- Link Stiffeners (when required): To ensure that the link deforms as intended (in shear or flexure) without premature buckling, stiffeners are welded inside the web of the link. The need, size, and placement of these stiffeners are carefully detailed according to design codes.
- Foundation and Base Plates: These transfer loads from the columns down into the ground and are designed to remain elastic as well..

1.2. ETABS

ETABS (Extended Three-dimensional Analysis of Building Systems) is structural engineering software developed by Computers and Structures, Inc. (CSI). It is widely used in civil engineering for modelling, analysing and designing multi-storey building structures, particularly those that are earthquake-resistant. ETABS features three-dimensional modelling capabilities that enable users to create comprehensive 3D structural frame models comprising components such as beams, columns, slabs, shear walls, and various lateral load-bearing systems, including bracing and shear walls. The program simplifies the process of simulating structural behaviour under various loading conditions, including dead loads, live loads, wind loads, and seismic loads [3].

1.3. Building Efficiency

Efficiency is seen as closely connected to optimizing a structure’s ductility, strength, and energy dissipation while minimizing unnecessary use of materials or overdesign [4]. Building Efficiency refers to the ability to maximise results while minimising the use of resources such as time, labour, materials and costs. This concept is particularly important in the construction industry, where limited budgets and time constraints are common challenges. Applying the principles of efficiency enables construction projects to be completed more quickly and cost-effectively without compromising quality. One way to achieve this is by using modern technology, such as automation and robotics, to increase productivity and reduce human error. Efficiency could also be achieved by using performance-based design, advocating for engineers to achieve the required structural performance (ductility, drift control, energy absorption) with the minimum necessary intervention—an inherently material-efficient philosophy.

2. METHOD

This research is a numerical study based on computer simulation using ETABS. It uses a descriptive method with a quantitative approach. A quantitative approach is used in research by measuring research variable indicators to obtain an overview of the existing variables.This approach enables data from existing building and modified bulding using Eccentrically Braced Frame (EBF) using Horizontal Link to be analized and compared, thereby identifying the difference of steel usage efficiency between the two model.

2.1. Study Case Location

This research was conducted at the Sumber Kasih Hospital Building, located on Jalan Ciremai Raya, Kecamatan Harjamukti, Cirebon City, West Java 40513. This project was selected as a case study because it represents a multi-story building project using steel as its main construction material.

2.2. Research Data

This research utilizes secondary data obtained from the construction project of the Sumber Kasih Hospital in the form of structural design drawings and technical project data. Additionally, a literature review comprising academic sources such as textbooks, journals and relevant online references was conducted to support the collection of secondary data and strengthen the theoretical foundation and research context.

2.3. Research Stages

The research begins with modelling the existing building in ETABS using the design drawings as a guideline. Once modelling is complete and the structural integrity has been verified, the steel mass will be extracted from ETABS for further analysis. The next step involves calculating an eccentrically braced frame using horizontal links according to the building's requirements. After checking its structural integrity, the same steps are taken as for the existing building model, and the masses of both models are compared..

3. Results and Discussion

This study presents a comparison of conventional steel structure and steel structure reinforced with eccentrically braced frame (EBF) using horizontal link. the steel section used is in accordance with the preliminary design that has been determined by the contractor that were responsible for the planning building.. Based on Moestopo et al. [5], the procedures to design a structure are determining the dimensions or geometries, connection design, designing the elements outside the links with capacity design concept and checking the failure methods. Based on design given by the contractors, the steel section used is tabulated in Table 1.

Table 1: The Steel Section Dimension Used In Model I

Floor	Column	Beam
Floor 6	-	IWF 450 x 300 x 11 x 18
Floor 5	IWF 400 x 400 x 45 x 70	IWF 450 x 300 x 11 x 18
Floor 4	IWF 400 x 400 x 45 x 70	IWF 450 x 300 x 11 x 18
Floor 3	IWF 400 x 400 x 45 x 70	IWF 450 x 300 x 11 x 18
Floor 2	IWF 400 x 400 x 30 x 50	IWF 450 x 300 x 11 x 18
Floor 1	IWF 400 x 400 x 30 x 50	IWF 450 x 300 x 11 x 18
Ground Floor	IWF 400 x 400 x 30 x 50	IWF 450 x 300 x 11 x 18

Meanwhile, based on preliminary design results, the steel section used for the building with EBF is tabulated in Table 2.

Table 2: The Steel Section Dimension Used In Model II

Floor	Column	Beam	Link	Bracing
Floor 6	-	IWF 350 x 250 x 9 x 14	IWF 300 x 200 x 9 x 14	IWF 350 x 250 x 9 x 14
Floor 5	IWF 400 x 400 x 30 x 50			
Floor 4	IWF 400 x 400 x 30 x 50			
Floor 3	IWF 400 x 400 x 30 x 50			
Floor 2	IWF 400 x 400 x 30 x 50			
Floor 1	IWF 400 x 400 x 30 x 50			
Ground Floor	IWF 400 x 400 x 30 x 50			

The modelling went through standard calculation using SNI 1726:2019 and SNI 1727:2020 such as standardize load, Shear, and Displacement between floor.

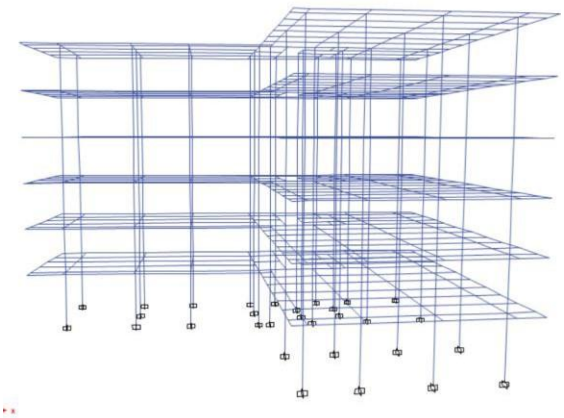

Fig. 1. Model I (Existing Structure)

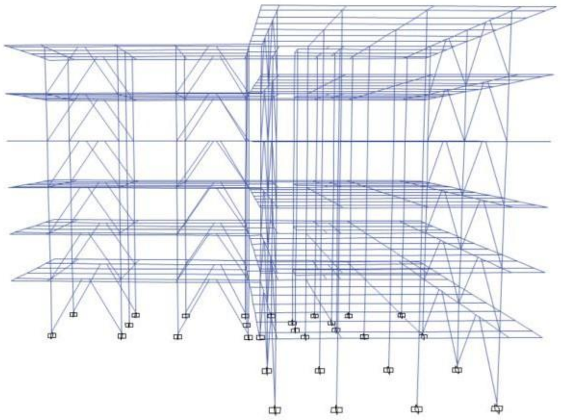

Fig. 2.Model II (Structure with EBF using Horizontal Link)

After making sure both design pass steel design check from ETABS, Seismic design from SNI 1729:2018, and Load Building according to SNI 1727:2020, the Mass are checked using ETABS with every other part of the building other than steel parts removed. ETABS will accumulate every mass that are in each story. The data are taken and analized. Said mass are displayed on Table 3.

Table 3: Total Mass for Model I and II

Floor	Mass (Ton)	
	Model I	Model II
Floor 6	83.55631	77.42193
Floor 5	107.525.53	104.32671
Floor 4	107.27154	111.08126
Floor 3	118.61794	117.47537
Floor 2	130.31321	123.953.3
Floor 1	137.02459	130.01896
Ground Floor	41.71939	39.21471
Total	726.02851	703.49224

The final result for the mass of each model were compared. Existing model (Model I) has around 726.028 Ton total mass while the Model with eccentrically braced frame (Model II) has around 703.492 total mass. The difference between both model is around 23 Ton or around 3.2% This reduction indicates significant material efficiency in the overall scale of the building structure. The reason for the difference in mass mostly came from changes occurring on the beam and column. As the bracing and link gave the building additional stiffness and strength, it allows a reduction in the profile of beam and column where the bracing were placed, with most

4. Conclusions

The main conclusion of the study is there's a significant reduction on the mass of steel used in the construction of building with eccentrically braced frame using horizontal link. Using the Eccentrically Braced Frame (EBF) Horizontal Link system affects the efficiency with which steel is used in steel buildings. There is a reduction in steel mass of around 3.20%, or around 23 tonnes, from existing building. Overall, EBF has been proven that it could be used as a measure to reduce steel usage by applying additional structure that help the column and beam, and thus, giving an opportunity to reduce the profile of the column and beam from the existing plan.

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