Optimizing the Integration of Building Information Modelling using Response Spectrum and Linear Time History Analysis. Case Study: Irregular Hangar Structure

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Abstract. The increasing use of technology in the construction industry has introduced the concept of Building Information Modeling (BIM), which is widely utilized to streamline construction activities. BIM enables the exchange of data across various disciplines quickly, as well as facilitates analysis, design, and on-site construction processes. The implementation of BIM will be carried out in the analysis and design processes of structures with irregularities to assess the effectiveness and performance of BIM in modeling and analyzing structures. Considering the burgeoning development of the construction industry in Indonesia, there is a necessity for a laboratory hangar dedicated to conducting structural model tests and construction material examinations. The aim of this study is to compare the response and the volume output between the response spectrum and linear time history analysis of an irregular structure. The case study conducted in this research focuses on the 5-stories Laboratory Hangar in Indonesia. The software used in this study includes Autodesk Revit 2023 for BIM modeling and ETABS V21 for structural analysis. Data and model exchange are performed between both software platforms to evaluate the BIM integration between them.

1 Introduction

As the pace of time advances, shifts in human lifestyles have led to the evolution of architectural styles in buildings [1]. Modern architectural styles are formulated to meet both the aesthetic and functional aspects of structures [2]. Modern buildings feature distinctive forms with geometric variations, giving rise to irregularities in their structures that necessitate further analysis in accordance with existing regulations [3]. The progression of modern architectural trends is also supported by an increasingly simplified planning process, facilitated by supporting software tools and advanced construction methodologies.

The behavior of any structure depends on the structural configuration which are geometry, shape, and size of the building [4]. Regular structures offer advantages such as mitigating unpredictable stress concentrations that could lead to local collapse and alterations in dynamic behavior [5]. Irregular structures are characterized based on the criteria of irregularity stipulated by prevailing regulations. Typically, structural irregularities introduce torsional effects which results in damage to the structure that must be considered during the planning phase. Many researchers have been carried out on the comparison of the structural responses between the regular and irregularity structure [6], the performance point on irregularity structure of university building [7], the torsion reducing method of irregularity structure [8], the influence of stiffness contribution on irregularity structure [9]. This study entails the identification of structural irregularities in a building in accordance with Indonesian National Standard which is SNI 1726:2019.

The identification of structure irregularities is carried out to determine the seismic analysis procedures to be performed on a building. Based on the type and the behavior of the structure, seismic analysis can be further classified as linear static analysis, nonlinear static analysis, linear dynamic analysis, and nonlinear dynamic analysis [10]. This research compares the structural response based on two linear dynamic analysis methods, which are response spectrum and time history analysis. Response spectrum is a fundamental tool in seismic analysis because it shows the maximum dynamic response subjected to specified ground motion, time period and damping ratio [11].

Given the ongoing sustainable development occurring from major cities to remote regions in Indonesia, the implementation of Building Information Modeling (BIM) has gained considerable traction [12]. BIM constitutes a technology within the Architecture, Engineering, and Construction (AEC) field, encompassing interrelated information [13]. The interconnectivity of information across various project disciplines streamlines tasks from the planning stage through construction execution. The application of BIM

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to buildings with irregularities undoubtedly simplifies the construction process across various facets. Considering that BIM encapsulates information ranging from volume analysis [14] to reinforcement detailing in a structure [15] until the post construction phase of building. For instance, BIM already used for assessing the seismic performance educational building [16], cost-optimization of seismic retrofit strategies [17]. The integration between structural analysis software and BIM modeling software can streamline the building design process [18]. This streamlined design process significantly impacts construction procedures, with the anticipation that BIM implementation can address longstanding issues.

To support the ongoing construction projects in Indonesia, the establishment of laboratory hangar structures is imperative for conducting testing procedures. The primary function of these laboratory hangars is to facilitate material testing as a means of quality control for various materials, such as concrete, steels, etc. The design of these laboratory hangars must adhere to the prevailing standards in Indonesia, specifically the SNI.

2 Matrial and method

The object of this study pertains to a five-story laboratory hangar situated within the premises of the University of Indonesia, characterized by a building height of 16.4 meter and an approximate total floor area of 4800 square meters by the method is shown in Fig. 1. The story elevation of the structure is given in Table 1.

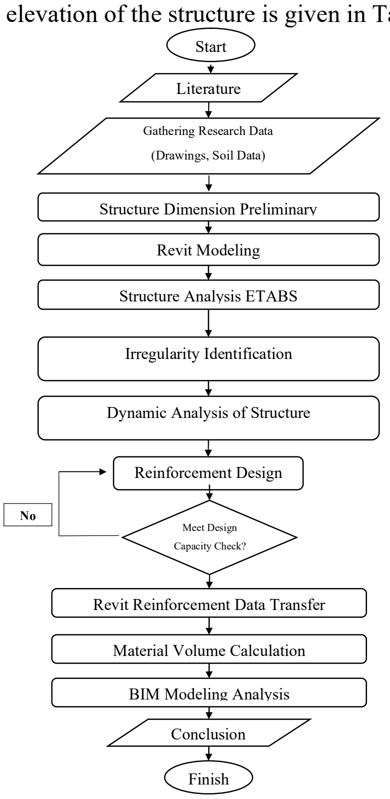

Fig. 1. Research Method Diagram

Table 1. Structure Story Elevation

Story	Floor level finish	Slab structure level
Base (Ground)	+ 0.55 m	+ 0.5 m
Mezzanine	+ 4.25 m	+ 4.2 m
3A	+ 7.95 m	+ 7.9 m
3B	+ 11.65 m	+ 11.6 m
5	+ 16.4 m	+ 16.35 m

The identification of the laboratory's structure is carried out in accordance with the regulations for vertical and horizontal irregularities as stipulated in the Indonesian National Standard (SNI) 1726:2019. This endeavor is undertaken to determine the types of structural irregularities and the requisite analyses necessary for the building in accordance with the established standards. The laboratory building with irregularities is modeled based on the existing architectural drawings using Revit software, which is subsequently integrated with structural analysis software ETABS, to ascertain the structural behavior under seismic forces, encompassing both time history and response spectrum analyses. Following the reinforcement design process in compliance with the stipulated provisions of the special moment resisting code based on SNI 1726:2019.

The reinforced model is then transferred back to Revit to compute material volumes and reinforcement quantities within the structure, thereby facilitating a comprehensive comparison of the two analyses. The integration between Revit and ETABS software streamlines the author's modeling of the building for subsequent analysis [19] is shown in Fig. 1.

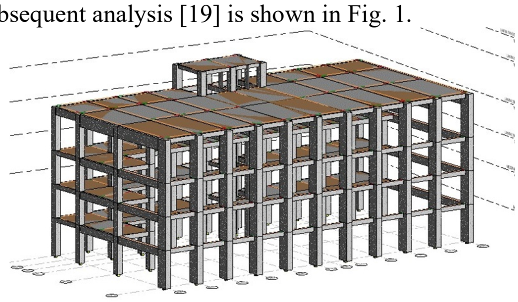

Fig. 2. Revit First Draw Model

Using the same model, a structural analysis is performed to evaluate the effects of both gravity loads and seismic loads, with the assistance of the ETABS software. Using the BIM Integration, the Revit model can be directly Exported to ETABS Software as shown in Fig. 3.

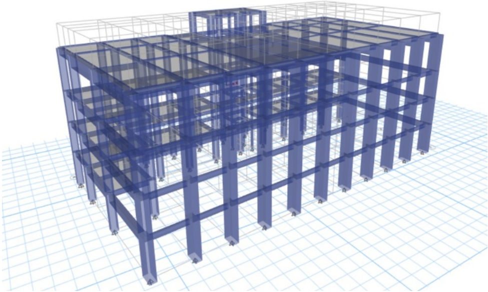

Fig. 3. ETABS Exported Model

In this study, seismic forces will be applied using response spectrum at Depok (Site Class SE) and linear time history methods. The selection of ground motion data is based on the Seismic Hazard De-Aggregation Map of Indonesia for Depok, West Java in 2022. The chosen ground motion data for the time history analysis are Chi-Chi Earthquake 1999, Kobe Earthquake 1995, and the Kocaeli Earthquake 1999. The ground motion data will be spectrally matched with the response spectrum curve of Depok using the ETABS Software. The seismic force resisting system used in this study is Special Moment Resisting Frame (SMRF).

The procedure for static analysis of base shear forces is carried out in accordance with the Indonesian National Standard (SNI) 1726:2019, utilizing the given parameters of the building's peak elevation at 16.5 meters. The fundamental vibration periods of the building are determined as 0.659 seconds in the X direction and 0.718 seconds in the Y direction. Considering a total building mass of 26938.59 kN, the calculated static shear forces at the foundation level are found to be 3562.04 kN in the X direction and 3562.04 kN in the Y direction. The equivalent static method is limited to finding static lateral forces for base shear scaling process as shown in Table 2.

Table 2. Base Shear Scaling

Load Case	Base Shear X (kN)	Base Shear Y (kN)	Resultant (kN)	Scale Factor
RSx	2783.32	262.17	2795.64	1.14
RSy	246.05	2788.02	2798.86	1.14
THx ChiChi	2666.75	238.96	2677.43	1.19
THy ChiChi	186.17	2704.31	2710.71	1.17
THx Kobe	2243.37	211.47	2253.31	1.41
THy Kobe	244.84	2337.73	2350.51	1.35
THx Kocaeli	2642.81	254.47	2655.03	1.19
THy Kocaeli	244.98	2800.83	2811.53	1.13

The research methodology commenced with the application of linear time history method. Subsequently, an evaluation was carried out using the response spectrum method. In instances where certain structural components based on the previous design (LTH) were identified as overstressed (OS), axial moment (PMM), beam-column capacity (BCC), or joint shear (JS), iterative dimension adjustments were performed until each component achieved a safe condition according to ETABS. Consequently, two design outcomes were obtained, one based on linear time history and the other on the response spectrum. The ETABS design results were refined to include detailed reinforcement using ETABS v21. The finalized ETABS design was then exported to Revit 23 for material volume calculations (concrete and reinforcement). The disparity in volumes between the two methodologies is anticipated to signify the optimized form resulting from the differential approaches.

3 Result and discussions

The modeled structure is subsequently imported into the ETABS software for structural analysis, resulting the following mass participation distribution (Table 3).

Table 3. Building Mass Participation

Mode	Period	UX	UY	RZ
1	0.718	0.008	**0.8061**	0.0017
2	0.621	**0.7234**	0.0105	0.0891
3	0.557	0.0963	0.0004	**0.7258**

In the third mode of the structure a torsional mass participation of 72% is observed, indicating the structure's susceptibility to torsional effects. Consequently, further identification is warranted to identify both vertical and horizontal irregularities of the building in accordance with the SNI 1726:2019 [20], resulting in the following outcomes.

3.1 Horizontal irregularity

3.1.1 Torsional irregularity

Fig. 4 represents the identification of torsional irregularity involves comparing the maximum drift experienced by a specific story with its corresponding average drift. If this ratio exceeds 1.2, the structure is identified as torsional irregularity (limit 1a). In cases where this ratio surpasses 1.4, the structure is categorized as excessive torsional irregularity (limit 1b) [20].

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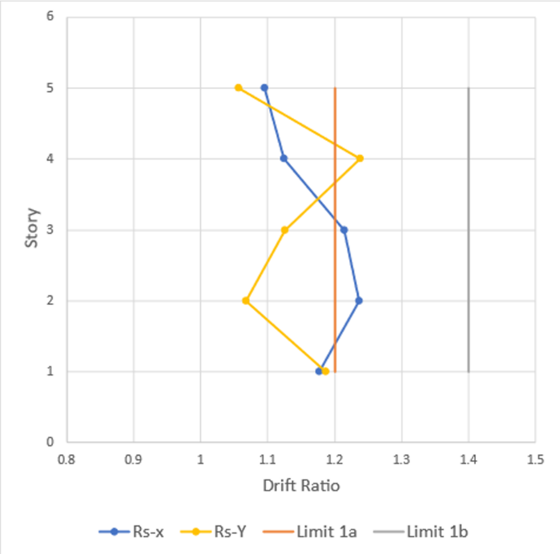

Fig. 4. Torsional Irregularity Check

Torsional irregularity 1a is observed in both the X and Y directions on floors 3A, 3B, and 5.

3.1.2 Re-entrant corner irregularity

The evaluation of re-entrant corner irregularity is conducted by comparing the projected area of the interior angle to the diaphragm dimension. If the projected area-to-diaphragm dimension ratio exceeds 0.15 (15%) [20], then the re-entrant corner irregularity is observed. In this case, there is no interior angle.

3.1.3 Diaphragm discontinuity irregularity

The identification of diaphragm discontinuity irregularity involves comparing the area of openings to the total diaphragm area. When the area of openings exceeds 50% of the diaphragm area, diaphragm discontinuity is observed as shown in Fig. 5 [20].

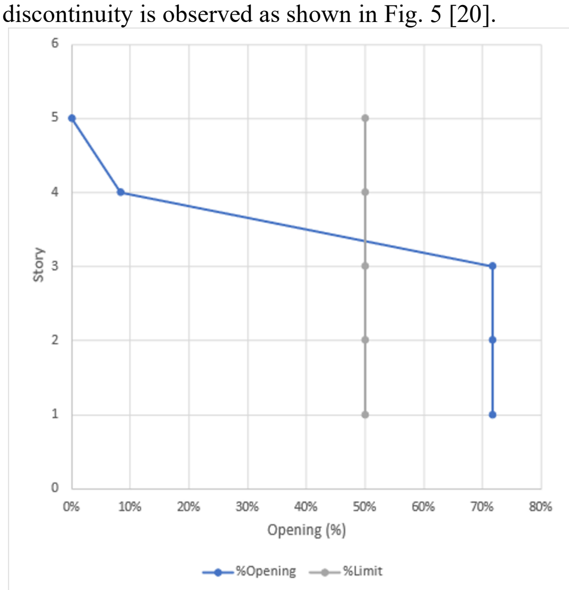

Fig. 5. Diaphragm Discontinuity Check

Diaphragm discontinuity irregularity occurs at the mezzanine level, as well as on floors 3A and 3B.

3.2 Vertical irregularity

3.2.1 Stiffness irregularity

Soft-story stiffness irregularity is identified when a structure has one level with significantly lower stiffness compared to the levels above it. This soft-story stiffness irregularity is considered typical when a specific level's stiffness is less than 70% of the level directly above it or less than 80% of the average stiffness of the three levels above it. It is classified as severe when a particular level's lateral stiffness is less than 60% of the level directly above it or less than 70% of the average stiffness of the three levels above it [20].

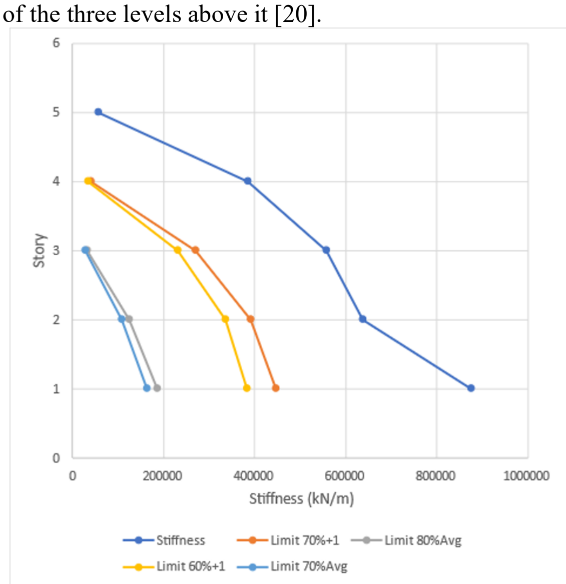

Fig. 6. Stiffness Irregularity X Direction

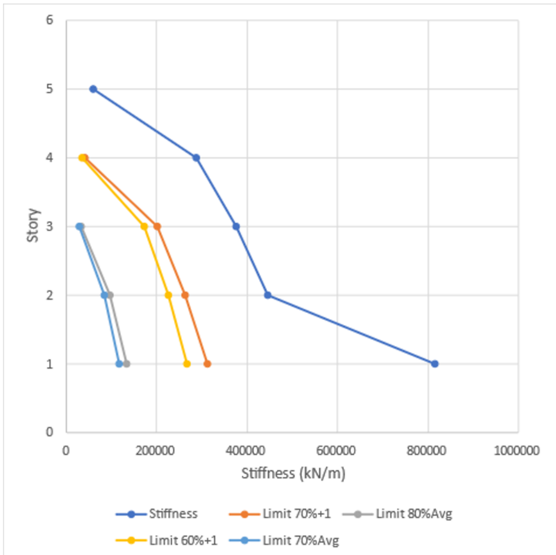

Fig. 7. Stiffness Irregularity Y Direction

Based on the identification conducted, no soft-story irregularity was found, both in the X and Y directions, within the structure of the laboratory hangar as shown in Fig. 6 and Fig. 7. Consequently, there is no need for corrective measures to address the existing irregularity.

3.2.2 Mass irregularity

The identification of mass irregularity is performed by comparing the mass of a particular floor to the adjacent floors. If there exists a floor with a mass exceeding 150% of the mass of the other floors, mass irregularity is encountered [20].

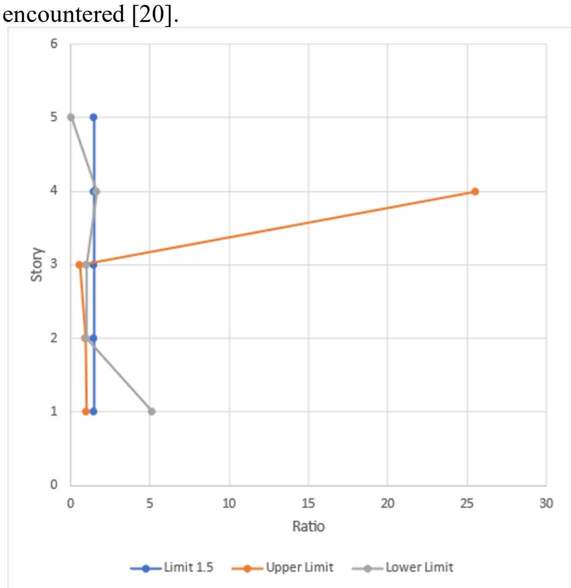

Fig. 8. Mass Irregularity

Fig. 8 showed the mass irregularity occurs on the mezzanine floor excluding the 5th floor (Story 4) due to one floor below the roof.

3.2.3 Lateral strength irregularity

The irregularity of soft story due to discontinuity in lateral strength is declared when there exists a story with strength less than 80% of the strength of the story above it; it is considered excessive if the strength of a single story is less than 65% of the strength above it. For reinforced concrete structures, the strength of a story is not solely influenced by the dimensions of structural elements but also by the reinforcement used. As the design of these elements relies on the loads borne by them, and it is assumed that the reinforcement used is proportional to the forces carried, a comparison of the forces occurring at each structural level can be performed [20].

The Laboratory Hangar does not exhibit any lateral strength irregularities at any story; thus no consequences or corrective measures are necessary for this structure as shon in Fig. 9 and Fig. 10.

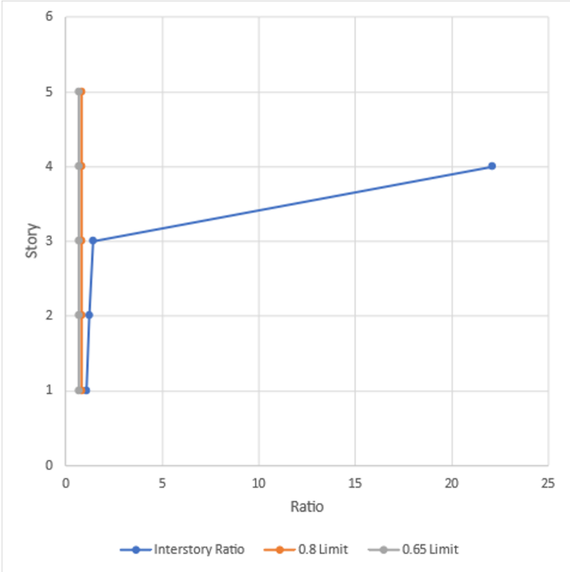

Fig. 9. Lateral Strength Irregularity X Direction

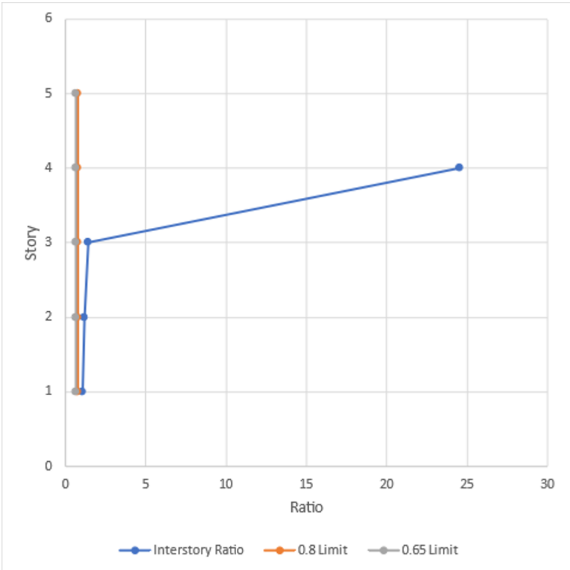

Fig. 10. Lateral Strength Irregularity Y Direction

3.3 Irregularity penalties

Based on the structural irregularity identification that has been conducted, several remedies are required to address the irregularities in accordance with the provisions outlined in SNI 1726:2019 [20] as shown in Table 4.

Table 4. Irregularities Summary

Irregularity		Status	Penalty
Horizontal			
1a	Torsional Irregularity	v	Torsion Factor Amplification, P-Delta Analysis
3	Diaphragm Discontinuity	v	Static Equivalent is prohibited
Vertical			
2	Mass Irregularity	v	Static Equivalent is prohibited

3.4 Structural response comparison

Given the identified irregularities as presented in the Table 4, the structural configuration will be designed exclusively through the utilization of response spectrum and linear time history methodologies. A comparative analysis conducted on the Structural Response under seismic forces as presented in Fig 11 – Fig 18, employing both response spectrum and linear time history methodologies.

3.4.1 Story displacement

Story displacement represents the deflection of a single story relative to the base or ground level of the structure. The comparison between the response spectrum and the linear time history can be observed in Fig. 11 and Fig. 12.

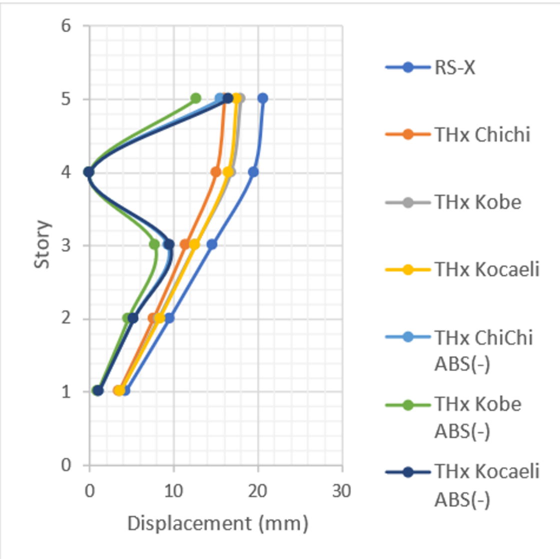

Fig. 11. Response Spectrum vs Linear Time History Displacement Comparison X-direction

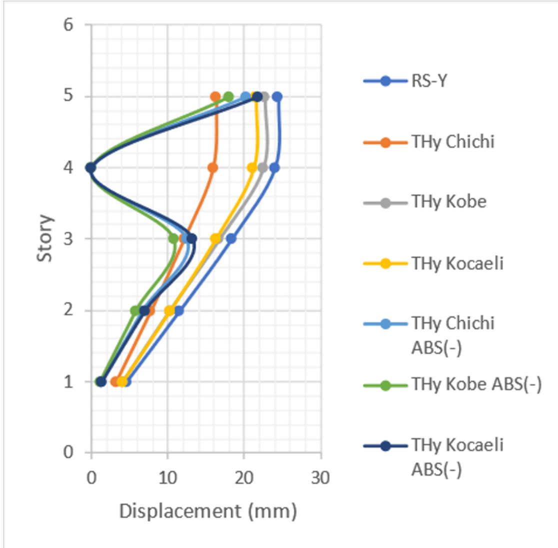

Fig. 12. Response Spectrum vs Linear Time History Displacement Comparison Y-direction

The structure response of the response spectrum analysis has higher values in displacement whether in X direction and the Y direction.

3.4.2 Story drift

Story drift represents the lateral displacement of a story relative to the story below. The response comparison between the response spectrum and the linear time history can be observed in Fig. 13 and Fig. 14.

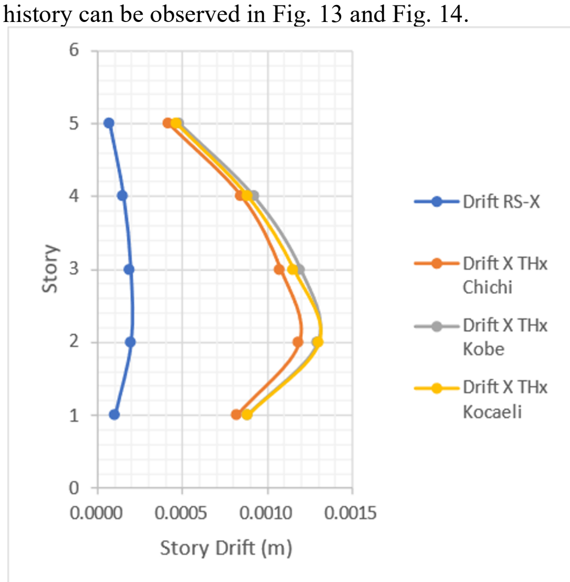

Fig. 13. Response Spectrum vs Linear Time History Drift Comparison X-direction

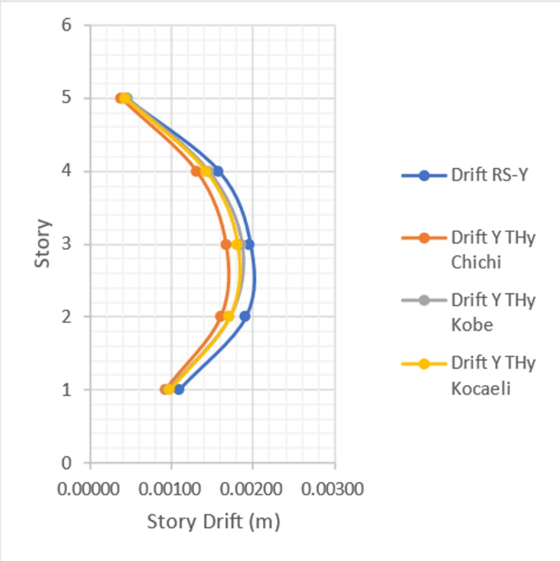

Fig. 14. Response Spectrum vs Linear Time History Drift Comparison Y-direction

The structure response of the response spectrum analysis has higher value in story drift in X direction and the time history has higher drift the Y direction.

3.4.3 Story shear

Story shear represents the lateral force acting on certain story due to the seismic force. The story shear graph on Fig. 15 and Fig. 16 show the distribution of the lateral forces for the response spectrum and linear time history analysis.

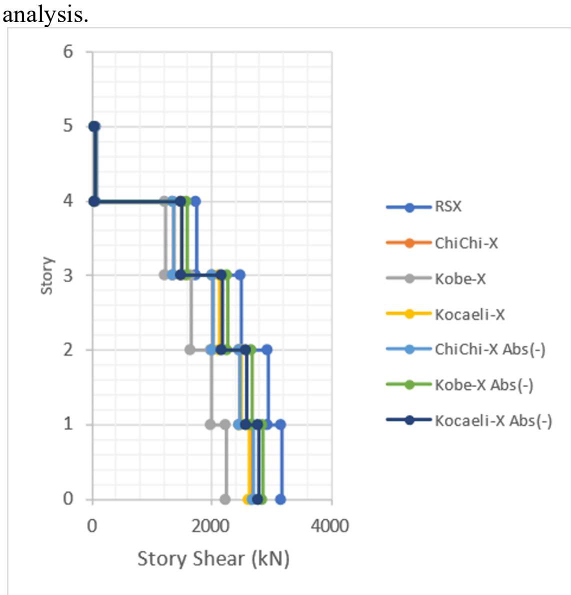

Fig. 15. Response Spectrum vs Linear Time History Story Shear Comparison X-direction

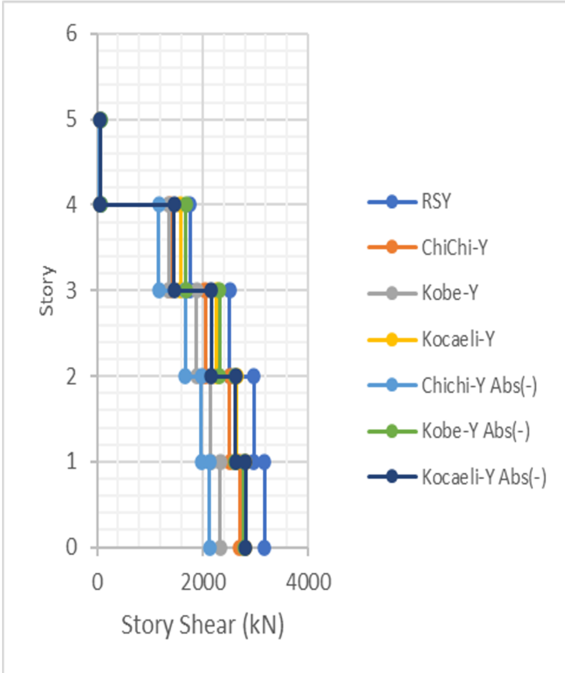

Fig. 16. Response Spectrum vs Linear Time History Story Shear Comparison Y-direction

Both Fig. 15 and Fig. 16 show the response spectrum has a higher value of story shear compared to the linear time history.

3.4.4 Overturning moment

Overturning moment represents the torsional moments should be resisted by each story. Fig. 17 and Fig. 18 shows the comparison between the response spectrum and linear time history analysis for the overturning moments in X direction and Y direction.

The values given on both Figs show the response spectrum analysis has a higher moment on each direction and each stories.

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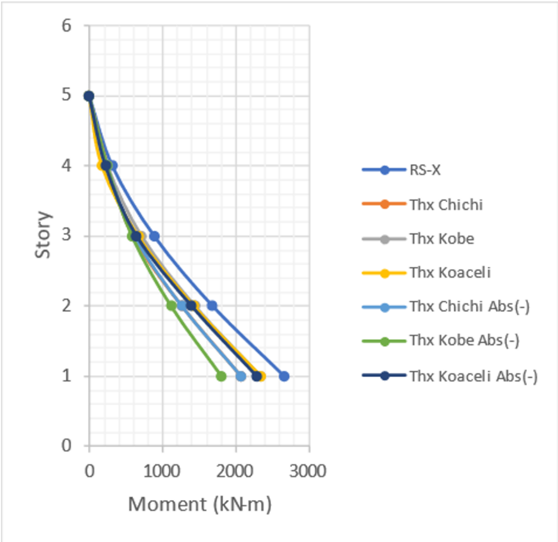

Fig. 17. Response Spectrum vs Linear Time History Overturning Moment Comparison X-direction

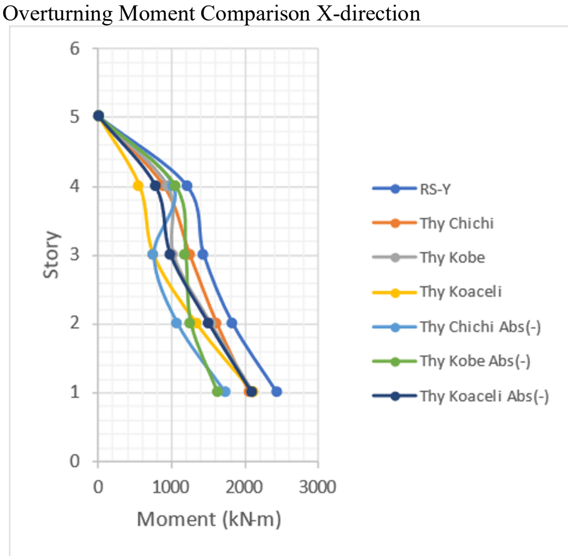

Fig. 18. Response Spectrum vs Linear Time History Overturning Moment Comparison Y-direction

Based on the comparison of structural responses to response spectrum (RS) and linear time history (LTH) seismic forces, the following analyses were obtained:

1. In terms of story displacement, RS seismic loads result in larger responses in both the X and Y directions.
2. Concerning story drift, RS seismic loads yield greater responses in the Y direction, while LTH seismic loads generate larger responses in the X direction.
3. Regarding story shear, RS seismic loads produce larger responses in both the X and Y directions.
4. In relation to overturning moment, RS seismic loads induce greater responses in both the X and Y directions.

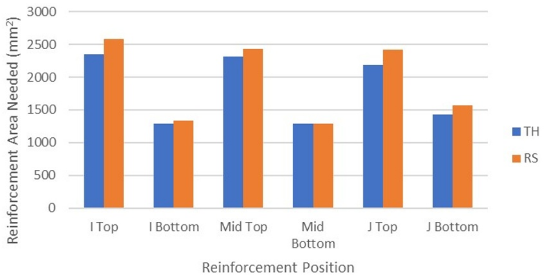

Fig. 19. Main Beam Reinforced Requirements RS vs TH

3.5 BIM integration

Based on the internal forces in the hangar, it is observed that the internal forces in beam and column structural elements are greater due to response spectrum seismic loads compared to linear time history loads. This leads to a higher demand for reinforcement area resulting from response spectrum seismic loads. The results taken from every main beam in the hangar, and the value of the reinforced area (As) is compared based on every maximum As from the Response Spectrum and Linear Time History analysis.

The structural modeling of the Laboratory Hangar was carried out using Revit, and the structural analysis was conducted using ETABS. The outcomes of this structural analysis were utilized to perform reinforcement detailing, which was also executed in ETABS V21, enabling the calculation of reinforcement volume in Revit. Given that the Hangar structure remained dimensionally unchanged in the response spectrum method, because the inner forces between these two analyses have no significance differentiation.

By employing internal force values and the "As Need" parameter, reinforcement detailing for columns, beams, and slabs is conducted in accordance with the reinforcement requirements. The diameter and quantity of reinforcement bars are automatically determined by ETABS, incorporating the following reinforcement diameter parameters: a preferred diameter of 22 mm for columns, 25 mm for beams, and 13 mm for floor slabs. Shear reinforcement with a diameter of 13 mm is employed for both columns and beams. If the selected preferred quantity of reinforcement bars does not satisfy the spacing criteria, ETABS will automatically optimize for an alternative reinforcement bar diameter that meets the stipulated conditions.

The reinforcement detailing is conFigd in adherence to the specific requirements outlined in the Special Moment Resisting Frame (SMRF) detailing provisions, as depicted in Fig. 20.

In ETABS V21, reinforcement details can be directly displayed using the ETABS software's assistance. The reinforcement detailing in ETABS is subsequently exported to Revit for the purpose of calculating volumes. Fig. 21 – Fig. 24 illustrated the reinforcement detailing in Revit after the import process.

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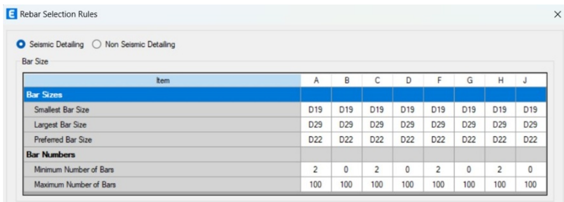
Rebar Selection Rules

Seismic Detailing / Non Seismic Detailing

Bar Size

Item	A	B	C	D	F	G	H	J
Bar Sizes								
Smallest Bar Size	D19	D19	D19	D19	D19	D19	D19	D19
Largest Bar Size	D29	D29	D29	D29	D29	D29	D29	D29
Preferred Bar Size	D22	D22	D22	D22	D22	D22	D22	D22
Bar Numbers								
Minimum Number of Bars	2	0	2	0	2	0	2	0
Maximum Number of Bars	100	100	100	100	100	100	100	100

Fig. 20. ETABS Rebar Selection

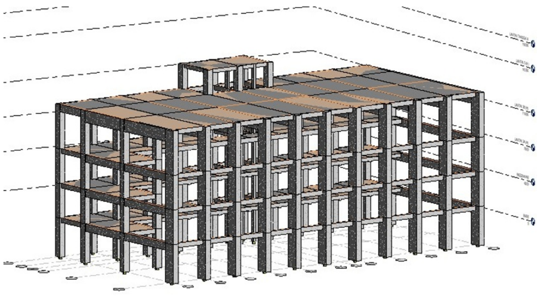

Fig. 21. Revit Model Exported from ETABS (Concrete)

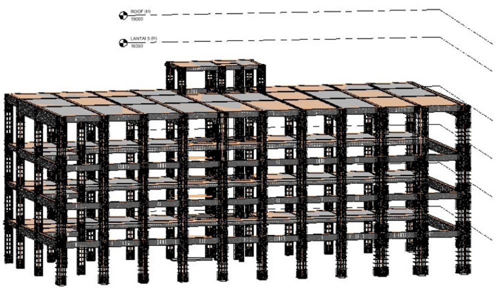

Fig. 22. Revit Model Exported from ETABS (Reinforcement)

Fig. 23. ETABS Column Stacks Detail

Fig. 24. ETABS Beam Reinforcement Detail

3.6 Tables volume computation

The volume computation process in this study is categorized into two distinct aspects: concrete volume and reinforcement volume. The volume calculations are conducted using the scheduling functionality within Revit. Two types of volumes will be generated: volumes for structures subjected to seismic loads based on Response Spectrum (RS) analysis and structures subjected to seismic loads using Linear Time History (LTH) analysis. Table 5 presented a comprehensive summary of the structural work volumes achieved through the utilization of Revit.

Table 5. Volume Comparison

Concrete Volume	**RS**	**TH**	**Diff (%)**
Columns (m^3)	337.2	337.2	0%
Beams (m^3)	337.31	337.31	0%
Slabs (m^3)	233.345	233.345	0%
Reinforcement Volume			
Columns (kg)	49138.75	48540.02	1.233%
Beams (kg)	66808.1	66098.9	1.073%
Slabs (kg)	17085.92	16572.14	3.100%
Total			
Concrete Volume (m^3)	907.855	907.855	0%
Reinforcement Volume (kg)	133032.8	131211.1	1.39%

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Based on the observed differences, it can be stated that the linear time history (LTH) analysis method would yield more cost-effective results compared to the response spectrum (RS) method. Although facilitating the data exchange process, the Building Information Modeling (BIM) integration between Revit and ETABS still exhibits several limitations, including:

1. Limitations in material property integration:
   Revit is unable to model cracked section properties, requiring this component to be manually input after the Revit structural model is imported into ETABS.
2. Challenges with inclined structural components:
   Revit and ETABS employ distinct programming languages, which can lead to errors in the merging and separation of objects. As a result of the inclined plan shape, the reinforcement in columns does not

follow the inclination of the columns, creating an appearance of protrusion from the column (Fig. 25).

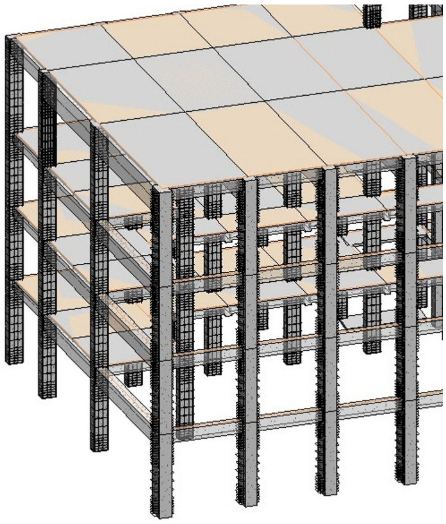

Fig. 25. Column Reinforcement Cut Trough Column Sections

4 Conclusions

1. The DTS UI Laboratory Hangar structure exhibits irregularities in the form of torsional irregularity on floors 3A-5, diaphragm discontinuity irregularity on Mezzanine - 3B, and mass irregularity on the mezzanine floor.
2. The 5-story DTS UI Laboratory Hangar structure, featuring torsional, diaphragm discontinuity, and mass irregularities, exhibits a larger response in terms of story displacement, story shear, and overturning moment under response spectrum loading, and a greater response in story drift along the X direction under time history loading.
3. The integration of ETABS-Revit in the modeling and analysis process of the DTS UI Laboratory Hangar offers advantages in transferring structural models, but accuracy in reinforcement detailing is compromised due to atypical building conditions (e.g., inclined building).
4. The internal forces in each structural element of the DTS UI Laboratory Hangar due to response spectrum seismic loads are greater than those from linear time history analysis. Although the difference in internal forces between the models is not substantial, there is no alteration in cross-sectional dimensions. However, the reinforcement quantity differs between the two models, with the response spectrum requiring approximately 1.39% more reinforcement than time history. Notably, significant variations occur in the volumes of steel plates and columns, amounting to 3.1% and 1.2%, respectively.
5. The volume of concrete casting for the DTS UI Laboratory Hangar structure remains consistent when comparing response spectrum seismic loads and linear time history analysis. This is attributed to the absence of cross-sectional dimension changes due to the two seismic loads. Nonetheless, a difference exists in the reinforcement volume of structural elements, amounting to 1821.72 kg.
6. There are limitations of the integration between ETABS V21 and Revit 2023, specifically the crack section property and for the inclined structural components. The limitations can be overcome with manual adjustment on the Revit Software to give a better result.
7. There is a recommendation for further research on the structural design of the basement in the laboratory hangar building. The research could be conducted by comparing two different methods in designing the substructure, namely using two-stage analysis and soil-structure interaction analysis. Subsequently, researchers can compare both in terms of structural response and integration with Building Information Modeling (BIM).

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