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# A Study of BIM Modelling in Seismic Analysis according to SNI 1726:2019

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***Abstract***-The process of building structures analysis is generally done separately with the process of estimating the volume of concrete which is done manually. This can result in a discrepancy in the needs of concrete calculated manually with the model of the building analyzed. References related to BIM implementation in building planning referring to SNI 1726:2019 are still very limited. This study discusses the implementation of BIM in structural modelling of simple concrete buildings with 3, 9, and 12-story variations in Revit as 2D and 3D models. The same BIM model is used in Robot Structural Analysis to analyze the structure against earthquake loads using the equivalent static method and spectrum response method according to SNI 1726:2019 to determine story shears and story displacements. Modelling with same specifications and loading is also performed in ETABS to determine the story shear and story drifts as control, independent structural analysis models. The results of story shear and story drifts of structural components from BIM models, independent structure analysis models, and manual calculations are compared to determine the accuracy of BIM implementation results in simple concrete structure analysis in terms of the mentioned aspects.

***Keywords-*** *BIM, Response Spectrum, Static Equivalent, Story Drift, Story Shear*

## I. INTRODUCTION

The planning of a building is very complicated and requires the cooperation of various parties with professional backgrounds to achieve complex targets [1]. However, there is often a mismatch of planning between disciplines. These discrepancies can affect budgets, structural calculations, or slow down construction schedules during the running of a project [2]. This can happen due to weak coordination and collaboration between disciplines in work [3].The construction industry relies heavily on information and still dependent on physical documents as a traditional method of communication [2]. According to Crotty [1], Building Information Modelling (BIM) in the Architectural, Engineering, and Construction (AEC) industry is able to optimize work, increase design creativity, reduce work, improve quality, shorten construction periods, reduce overall costs, increase collaboration between disciplines, and achieve multidimensional visualization and building lifecycle management. BIM is a collaborative way to store, share, exchange, and manage multidisciplinary information across the lifecycle of a building project that encompasses the planning, design, construction, operational, maintenance, and development phases [4].

Currently, the Indonesian government focuses on increasing investment in infrastructure to boost economic expansion and improve connectivity across the archipelago. Infrastructure development in Indonesia is one of the factors increasing the impact of the construction sector on the Indonesian economy which can be seen from the large percentage of the construction sector to Gross Domestic Product (GDP) of 10.39% in the third quarter of 2021 [5]. But unfortunately, the implementation of BIM in Indonesia in the construction sector is still very low compared to other countries in Southeast Asia [6] which means Indonesia still holds the potential for development in the construction sector. The Indonesian Minister of Public Works and Housing has released a guideline in building construction (Permen PUPR 22/PRT/M/2018) that requires BIM implementation on complex building with area greater than 2000 m2 but currently it only applies on state buildings.

The process of building structural analysis is generally done separately with the process of estimating the volume of concrete which is done manually. This can result in a discrepancy in the needs of concrete calculated manually with the model of the building analyzed. Inaccuracy of estimating material volumes will result in inaccuracies in the estimated cost required. Errors in the calculation of concrete volume manually are also very likely to occur in complex building structures.

References related to BIM implementation in building planning that take SNI 1726:2019 [7] into consideration are still very limited. This study discusses the implementation of BIM in modeling simple concrete structures with variations in the number of stories. The results of structural analysis using BIM models will be compared to independent structural analysis models.

### A. Building Information Modelling

According to United States National BIM Standard [8], BIM is a digital representation of the physical and functional characteristics of a facility that serves as a shared source of knowledge to inform the facility and form the basis for reliable decisions during its life cycle. BIM also defined as a collaborative way for multidisciplinary information storing, sharing, exchanging, and managing throughout the entire building project lifecycle including planning, design, construction, operation, maintenance, and demolition phase [9].

Earlier research [10] has investigated the benefits, risks, and challenges in BIM implementation in the Architecture, Engineering & Construction (AEC) industry. BIM is a technological innovation that makes it very easy for AEC industry players. However, this technology is still not fully adopted widely because of the various challenges faced by each party such as the initial capital that is not small to update software and hardware, user training, adaptation of new ways of working that have previously been running for many years. The most common factors inhibiting the development of BIM implementation at various levels are the inadequate experience of BIM projects and lack of competent personnel [11]. Despite these challenges, BIM has the potential to satisfy clients through model visualization, clear expectations, effective team collaboration, more practical data sharing, control over information, minimization of errors that impact minimization of repetitive requests for information, reduced reworking and safety risks, accurate scheduling, and facility management tools [12, 13, 14].

Professor Charles Eastman who is a pioneer in the field of building modeling, began introducing the concept of BIM in 1970 and by mid-2000 the AEC industry had implemented BIM in construction projects [15]. The first few countries to implement BIM were the United States followed by the United Kingdom, Australia, Hong Kong, Denmark, Norway, Finland, and Singapore [16].

Charles Eastman created the Building Description System (BDS) program in 1975 as a tool for designing buildings and examining clashes between building elements. BDS is able to save time and cost in the building image creation process but unfortunately not many have the opportunity to use BDS due to the limitations of technology to create more than one BDS system. Eastman developed graphical language for interactive design (GLIDE) in 1977 based on BDS with the advantage of estimating costs and analyzing structures. BDS and GLIDE are limited in use only for the planning stages.

In 1989 a new program was created called Building Product Model (BPM) which has included the planning stage to the implementation stage with a project library that contains all the information needed during the course of the project and can be used by various construction project implementers. Although BPM can accommodate the required information, the information is still not well integrated between disciplines. The [17] Generic Model Building (GBM) program was developed in 1955 that was able to integrate information during the project lifecycle and enhance interdisciplinary cooperation. [18]

BIM is the result of the integration of information and communication technology (ICT) in the construction industry to face problems in collaboration, management of large amounts of information, efficiency of construction time and costs, and improving the quality of work. The presence of BIM has been a driver of the development of innovation and productivity of the construction industry. [10] [19]

### B. Seismic Analysis

#### 1) Static Equivalent

Static equivalent method is used in this study to analyze seismic loads that occurred in buildings. The equivalent static force is a representation of a simplified earthquake load and works statically as a horizontal force on a building. This method refers to SNI 1726:2019 [7].

Approximate fundamental period ($T_a$) is determined from:

$$T_a = C_t h_n^x \quad (1)$$

where $C_t$ and x are fundamental period coefficients based on structure type as defined in SNI 1726:2019, and $h_n$ structural height.

Then, structure base shear force is determined using:

$$V = C_s W \quad (2)$$

with Cs determined with the following equations:

$$C_{s\,min} \leq C_s \leq C_{s\,max} \quad (3)$$

$$C_s = \frac{S_{DS}}{\frac{R}{I_e}} \quad (4)$$

$$C_{s\,min} = 0.044\, S_{DS}\, I_e \geq 0.01 \quad (5)$$

$$if\ T \leq T_L, C_{s\,max} = \frac{S_{D1}}{T\left(\frac{R}{I_e}\right)} \quad (6)$$

$$if\ T > T_L, C_{s\,max} = \frac{S_{D1}\, T_L}{T^2\left(\frac{R}{I_e}\right)} \quad (7)$$

Where V is shear force at the base, $C_s$ seismic response coefficient, W effective seismic weight of the building, $S_{DS}$ spectral response acceleration parameter at short periods, $S_{D1}$ spectral response acceleration parameter at a period of 1 s, $I_e$ importance factor, and T the fundamental period of building.

Then portion of the seismic base shear induced on each level is determined as follows:

$$F_x = C_{vx} V \quad (8)$$

$$C_{vx} = \frac{w_x\, h_x^k}{\sum_{i=1}^{n} w_i . h_i^k} \quad (9)$$

where $F_x$ lateral seismic load at level x, $C_{vx}$ vertical distribution factor, $w_i$ and $w_x$ portion of W that is located or assigned at level i and x, $h_i$ and $h_x$ the height above the base to level i and x, and k distribution exponent with the value of 1 for structures with $T \leq 0.5$ s, 2 for structures with $T \geq 2.5$ s, and linear interpolation between 1 and 2 for structures with $0.5 < T < 2.5$.

#### 2) Response Spectrum

Response spectrum method is the representation of maximum response of idealized single degree of freedom system with a certain period and damping during earthquake ground motions [20]. The maximum response of structure for various damping is plotted against undamped natural period and can be expressed in terms of maximum absolute acceleration, maximum relative velocity, or maximum relative displacement. It is a linear-dynamic analysis, which defines the response (acceleration, velocity, or displacement) spectrum by enveloping and smoothing the spectra corresponding to different earthquake time histories [21]. Although the response spectrum method requires more calculations than the seismic coefficient method, it has the advantage that it can account for irregularities as well as higher mode contributions and gives more accurate results [22]. Therefore, this is the most widely used method in seismic analysis.

## II. METHODOLOGY

Simple building that has one 4-meter-bay on each orthogonal direction is modeled in Revit and ETABS. Revit BIM model will be exported to Robot later for its structure to be analyzed. Dead load, super-imposed dead load, and live load are applied to the model as gravitational load. Static equivalent and response spectrum methods of seismic analysis are done with the seismic parameters according to SNI 1726:2019. In this case, the structure is used as hospital which is located in Jakarta, Indonesia, with special reinforced concrete moment frame as its seismic force-resisting system. Each story have 4 meter height. The modeled building has story variations of 3, 9, and 12 stories, with each structure heights are 12-meter, 36-meter, and 48-meter, respectively. Story shear, story drift, and concrete volume of these models from each structural analysis program and manual calculations will be observed and compared to ETABS analysis results.

From the BIM model in Revit, the volume of concrete needed from structural components can be determined and manual calculation is also done for result comparation.

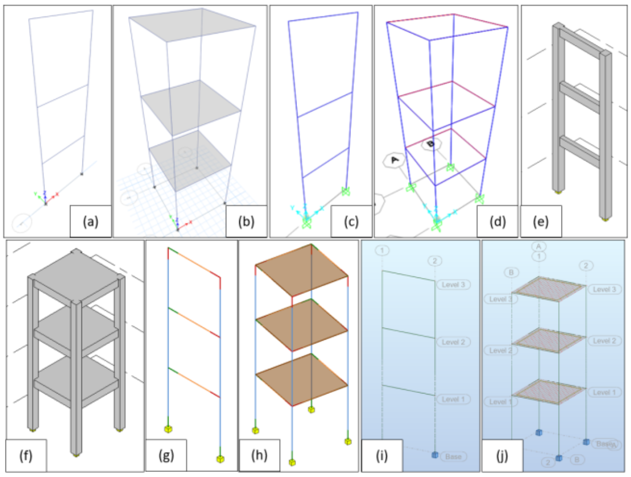


Figure 1. a) 2D 3-Story Building Model in ETABS, b) 3D 3-Story Building Model in ETABS, c) 2D 3-Story Building Model in SAP2000, d) 3D 3-Story Building Model in SAP2000, e) 2D 3-Story Building Physical Model in Revit, f) 3D 3-Story Building Physical Model in Revit, g) 2D 3-Story Building Analytical Model in Revit, h) 3D 3-Story Building Analytical Model in Revit, i) 2D 3-Story Building Model in Robot, and j) 3D 3-Story Building Model in Robot

The results of the story shear, story displacement, and concrete volume of structural components of the BIM model, independent structure analysis model, and manual calculations – are compared to determine the accuracy of BIM implementation results in structural analysis and estimation of simple structure concrete volumes.

As the concrete property used in modelling, weight density 23.599 kN/m$^3$, mass density 2406.45 kg/m$^3$, compressive strength ($f_c$') 30 MPa, Young's Modulus (E) 25742.96 MPa, and shear modulus (G) 10726.23 MPa.

Concrete beam and column sizes used are 300x600 mm and 500x500 mm, respectively. Slab thickness used is 120 mm.

TABLE I. LOADS APPLIED TO MODELS

| Model | Loaded Component | Load Source | Load |
|---|---|---|---|
| 2D | Beam | Slab DL + SIDL | 12.04 kN/m |
| | | LL | 3.83 kN/m |
| 3D | Slab | SIDL | 0.86 kN/m$^2$ |
| | | LL | 3.83 kN/m$^2$ |
| | Beam | SIDL | 8.34 kN/m |

TABLE II. SEISMIC PARAMETERS USED IN MODELS ACCORDING TO SNI 1726:2019

| Model | Loaded Component |
|---|---|
| Site Class | D |
| $I_e$ | 1.5 |
| R | 8 |
| $S_S$ | 0.781 g |
| $S_1$ | 0.382 g |
| $F_a$ | 1.188 |
| $F_v$ | 1.918 |
| $S_{MS}$ | 0.927 g |
| $S_{DS}$ | 0.618 g |
| $S_{D1}$ | 0.489 g |
| $T_0$ | 0.158 s |
| $T_S$ | 0.791 s |
| $T_L$ | 20 s |

Modal analysis is done for response spectrum analysis to determine mode shapes until 100% mass participation is reached or until mode period reached 0.05 second. Mode combination used complete quadratic combination (CQC) method. Response spectrum is scaled with the value of $1/(R/I_e)$ that equals to 0.1875.

## III. RESULTS AND DISCUSSIONS

### A. Story Shear and Story Displacement

2D and 3D analysis results for each observed aspects are very similar. For that reason, 2D results are not shown in graphs.

As shown in Table III, Story shear from static equivalent method for 12-story model has the greatest error of 30.631% on 11$^{th}$ story, and the smallest error of 3.596% occurs on base level. The error percentage increases for each story higher. Story shear from response spectrum method for 12-story model has the greatest error of 5.969% also on 11th story, and the smallest error of 3.515% occurs on the 5th floor (Table IV). The error percentage increases for each stories higher but slightly decreases on the 2nd story through 5th story. Story displacement from static equivalent method for 12-story model has the greatest error of 3.369% on 11th story and the smallest error of 1.550% occurs on the 1st floor (Table V). The error percentage increases for each story higher. Story displacement from response spectrum method for 12-story model has the greatest error of 2.034% on 11th story and the smallest error of 1.433% on the 1st story (Table VI). The error percentage increases for each story higher. In all aspects observed, the greatest error occurs on the top story. 2D and 3D model display very similar story shears in static equivalent and response spectrum method. 3D model story displacements are slightly smaller than 2D models because shell element is present in 3D models contributing greater structural lateral stiffness.

TABLE III. 12-STORY MODEL STATIC EQUIVALENT METHOD STORY SHEAR (KN)

| Story | ETABS (kN) | | ROBOT (kN) | | Robot vs ETABS 3D Error (%) |
|---|---|---|---|---|---|
| | 2D*2 | 3D | 2D*2 | 3D | |
| 11 | 24.6598 | 24.6496 | 32.2 | 32.2 | 30.631% |
| 10 | 70.7626 | 70.7542 | 78.6 | 78.6 | 11.089% |
| 9 | 110.6878 | 110.6812 | 118.78 | 118.78 | 7.317% |
| 8 | 144.743 | 144.7378 | 153.06 | 153.06 | 5.750% |
| 7 | 173.2514 | 173.2473 | 181.76 | 181.75 | 4.908% |
| 6 | 196.5558 | 196.5528 | 205.2 | 205.21 | 4.405% |
| 5 | 215.0226 | 215.0203 | 223.8 | 223.79 | 4.079% |
| 4 | 229.0466 | 229.0449 | 237.9 | 237.91 | 3.870% |
| 3 | 239.0604 | 239.0591 | 247.98 | 247.99 | 3.736% |
| 2 | 245.547 | 245.546 | 254.52 | 254.51 | 3.651% |
| 1 | 249.0644 | 249.0635 | 258.06 | 258.05 | 3.608% |
| Base | 250.3 | 250.2991 | 259.3 | 259.3 | 3.596% |

TABLE IV. 12-STORY MODEL RESPONSE SPECTRUM METHOD STORY SHEAR (KN)

| Story | ETABS (kN) | | ROBOT (kN) | | Robot vs ETABS 3D Error (%) |
|---|---|---|---|---|---|
| | 2D*2 | 3D | 2D*2 | 3D | |
| 11 | 30.565 | 30.433 | 32.34 | 32.25 | 5.969% |
| 10 | 79.329 | 79.227 | 82.62 | 82.57 | 4.220% |
| 9 | 114.547 | 114.509 | 118.9 | 118.92 | 3.852% |
| 8 | 138.929 | 138.918 | 143.96 | 144.01 | 3.666% |
| 7 | 155.595 | 155.545 | 161.08 | 161.09 | 3.565% |
| 6 | 168.157 | 168.029 | 174.02 | 173.94 | 3.518% |
| 5 | 180.152 | 179.965 | 186.44 | 186.29 | 3.515% |
| 4 | 194.088 | 193.906 | 200.92 | 200.75 | 3.530% |
| 3 | 210.467 | 210.348 | 217.94 | 217.83 | 3.557% |
| 2 | 227.691 | 227.644 | 235.84 | 235.79 | 3.579% |
| 1 | 242.365 | 242.358 | 251.08 | 251.07 | 3.595% |
| Base | 250.300 | 250.299 | 259.3 | 259.3 | 3.596% |

TABLE V. 12-STORY MODEL STATIC EQUIVALENT METHOD STORY DISPLACEMENT (MM)

| Story | ETABS (mm) | | ROBOT (mm) | | Robot vs ETABS 3D Error (%) |
|---|---|---|---|---|---|
| | 2D | 3D | 2D | 3D | |
| 12 | 194.012 | 189.901 | 200.23 | 196.299 | 3.369% |
| 11 | 185.407 | 181.387 | 190.894 | 187.059 | 3.127% |
| 10 | 174.257 | 170.394 | 178.982 | 175.305 | 2.882% |
| 9 | 160.496 | 156.867 | 164.499 | 161.05 | 2.667% |
| 8 | 144.494 | 141.169 | 147.826 | 144.67 | 2.480% |
| 7 | 126.703 | 123.746 | 129.42 | 126.615 | 2.318% |
| 6 | 107.593 | 105.053 | 109.747 | 107.34 | 2.177% |
| 5 | 87.623 | 85.541 | 89.269 | 87.297 | 2.053% |
| 4 | 67.248 | 65.653 | 68.438 | 66.927 | 1.941% |
| 3 | 46.933 | 45.843 | 47.721 | 46.687 | 1.841% |
| 2 | 27.299 | 26.702 | 27.734 | 27.168 | 1.745% |
| 1 | 9.79 | 9.612 | 9.93 | 9.761 | 1.550% |

TABLE VI. 12-STORY MODEL RESPONSE SPECTRUM METHOD STORY DISPLACEMENT (MM)

| Story | ETABS (mm) | | ROBOT (mm) | | Robot vs ETABS 3D Error (%) |
|---|---|---|---|---|---|
| | 2D | 3D | 2D | 3D | |
| 12 | 157.373 | 153.949 | 160.348 | 157.08 | 2.034% |
| 11 | 150.555 | 147.202 | 153.29 | 150.095 | 1.965% |
| 10 | 141.855 | 138.622 | 144.33 | 141.254 | 1.899% |
| 9 | 131.296 | 128.239 | 133.502 | 130.595 | 1.837% |
| 8 | 119.208 | 116.38 | 121.142 | 118.455 | 1.783% |
| 7 | 105.895 | 103.345 | 107.56 | 105.138 | 1.735% |
| 6 | 91.552 | 89.325 | 92.951 | 90.836 | 1.692% |
| 5 | 76.269 | 74.407 | 77.406 | 75.638 | 1.654% |
| 4 | 60.089 | 58.633 | 60.967 | 59.584 | 1.622% |
| 3 | 43.12 | 42.102 | 43.741 | 42.774 | 1.596% |
| 2 | 25.758 | 25.192 | 26.125 | 25.586 | 1.564% |
| 1 | 9.451 | 9.279 | 9.575 | 9.412 | 1.433% |

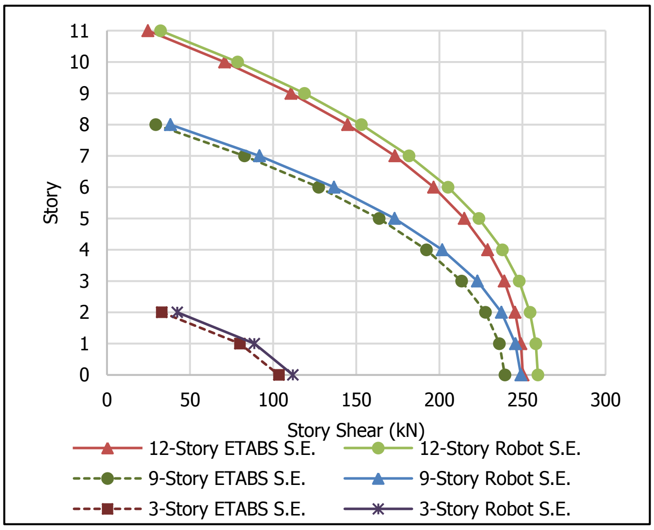


Figure 2. Story Shear of ETABS and Robot 3D Model Caused by Static Equivalent (SE) Seismic Load for Each Story Variations

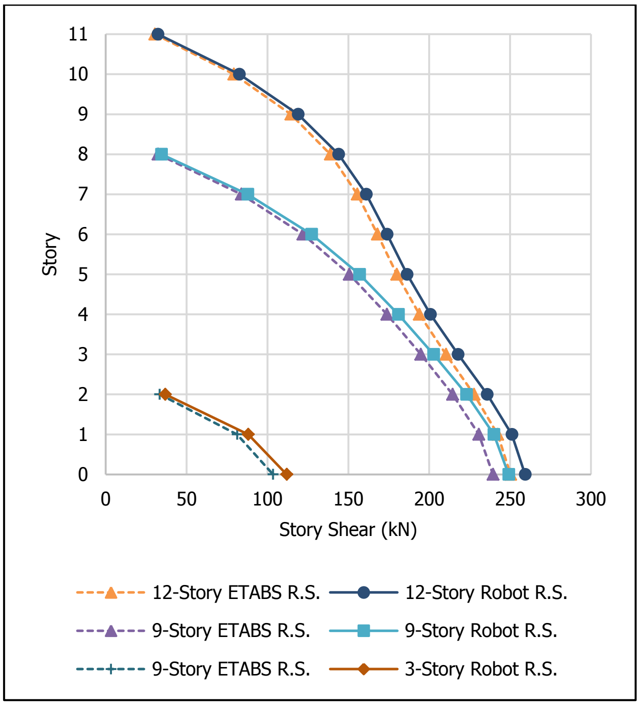


Figure 3. Story Shear of ETABS and Robot 3D Model Caused by Response Spectrum (RS) Seismic Load for Each Story Variations

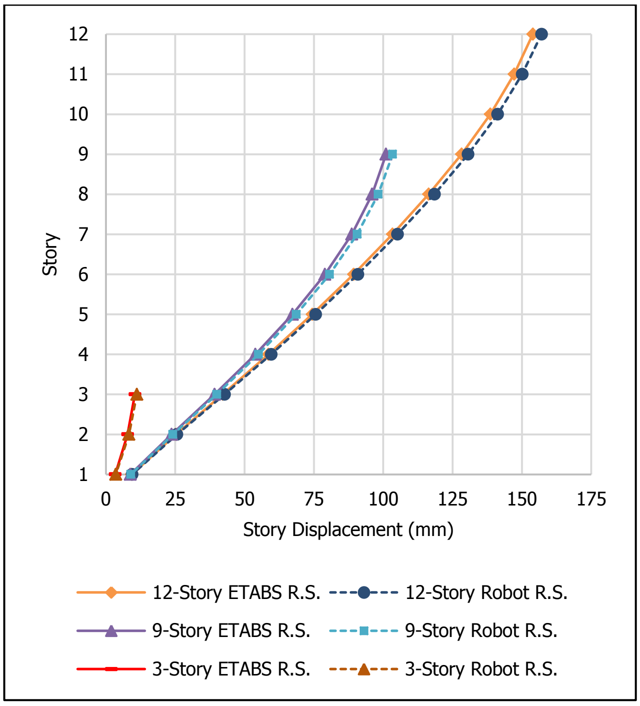


Figure 5. Story Displacement of ETABS and Robot 3D Model Caused by Response Spectrum (RS) Seismic Load for Each Story Variations

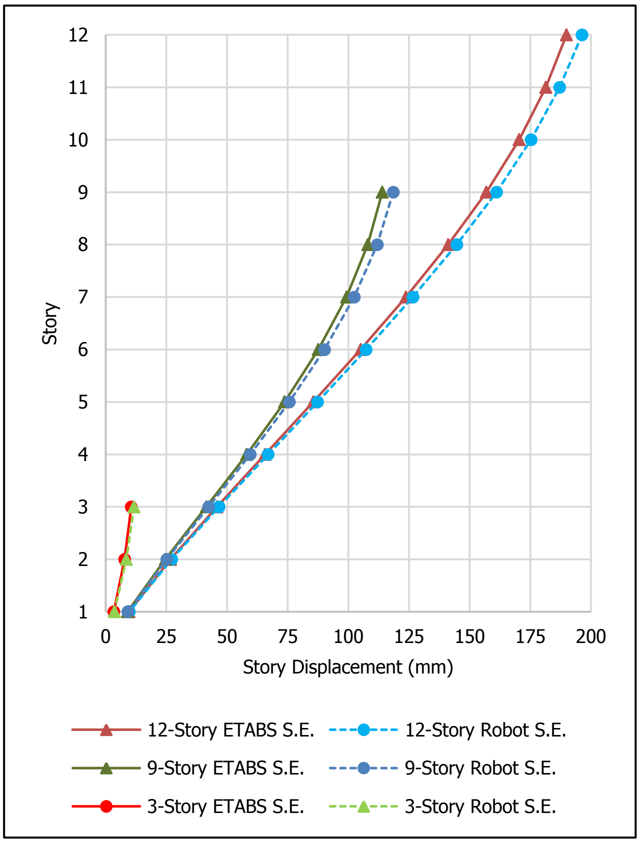


Figure 4. Story Displacement of ETABS and Robot 3D Model Caused by Static Equivalent (SE) Seismic Load for Each Story Variations

Story shears from static equivalent method of Robot models are always slightly greater than ETABS models for every story variations (Fig. 2). Story shears from response spectrum method of Robot models are always slightly greater than ETABS models for every story variations and converges as story level gets higher (Fig. 3). Story displacements from static equivalent method of Robot models are always slightly greater than ETABS models for every story variations and diverge as story level gets higher (Fig. 4). Story displacements from response spectrum method of Robot models are always slightly greater than ETABS models for every story variations (Fig. 5).

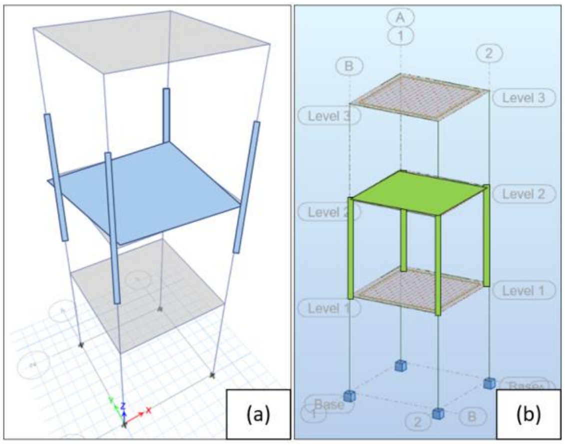


Figure 6. Story Definitions in (a) ETABS; and (b) Robot

As seen in Fig. 2 through Fig. 5, story shear and story displacement of every story-varied Robot models is always greater than ETABS models results. The gap between both programs is present consistently. The first reason on why this phenomenon occurs is because of the difference in story definition in Robot and ETABS. Robot considers slabs, beams, and full-length columns downward as its effective story weight, while ETABS considers slabs, beams, half-length columns downward, and half-length columns upward as its effective story weight (Fig. 6). This difference makes top-story effective weight in Robot to be much greater than in ETABS as much as half-column length's weight that are present below that story. That is why story shear for static equivalent method error on top story is possible to reach even 30%.

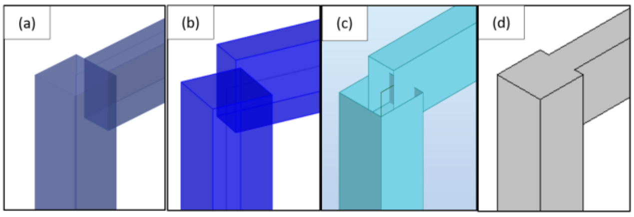


Figure 7. Beam-column ends in (a) ETABS; (b) SAP2000; (c) Robot; and (d) Revit models

Another reason Robot have greater story shear and story displacement is because of Robot considered beam and column's complete volume into structure mass calculation by default, including the intersected volume of beam-column ends which occupy the same space more than once. While ETABS only includes the intersected volume of beam-columns ends once. This different volume inclusion results in structure mass in ETABS is slightly less than Robot. For a joint where numerous beams meet, the overlapping volume will also be considered numerous times as many columns and beams meet. But for slabs, both ETABS and Robot always considered full volume as default. So, there is no difference in terms of slabs weight.

Difference in effective seismic weight affects story shear forces and story drifts. Buildings modeled in Robot always have greater effective seismic weight because of the overlapping beam-column volume counted more than once and have different story definition, which means greater story shear forces and greater story drifts.

3D analysis using membrane element as slab results similar story displacements as 2D analysis because membrane element has no bending stiffness which doesn't affect story stiffness. 3D analysis using shell element as slab results smaller story displacements than 2D analysis because of shell element has bending stiffness to contribute to story stiffness.

### *B. Concrete Volume*

Structural components that are present in this model are slabs, columns, and beams. In Revit, slab volumes are calculated fully without any reductions, column volumes are reduced by its own intersecting volume with slabs, and beam volumes are reduced by its own intersecting volume with slabs and columns. Manual calculations follow the same principle as Revit as described before. Concrete volume is compared for each structural component type and the total volume is also compared between Revit and manual calculation.

As seen in Table VII, slab concrete volume for every story variation results shows no error at all. Column concrete volume has the greatest error of 0.08% for 3-story model and decreases as the number of story increases. Beam concrete volume has 0.53% error consistently for every story variations. Total concrete volume has the greatest error of 0.19% for 3-story model. These errors are present because Revit rounds up to two decimal places during the calculation of each structural component while manual calculation includes all decimal numbers that are present. Two decimal places rounding for each structural component can cause up to 1% error. Summation of each rounded up concrete volume leads to the error that is present in this comparison between Revit and manual calculations. As we can see, the errors are very insignificant. Totaling of less than 1% error.

TABLE VII. REVIT VS MANUAL CONCRETE VOLUME ($M^3$) CALCULATION RESULT

| Component | 3-Story | | | 9-Story | | | 12-Story | | |
|---|---|---|---|---|---|---|---|---|---|
| | *Revit ($m^3$)* | *Manual ($m^3$)* | *Error (%)* | *Revit ($m^3$)* | *Manual ($m^3$)* | *Error (%)* | *Revit ($m^3$)* | *Manual ($m^3$)* | *Error (%)* |
| Slab | 5.76 | 5.76 | 0.00% | 17.28 | 17.28 | 0.00% | 23.04 | 23.04 | 0.00% |
| Column | 11.92 | 11.91 | 0.08% | 35.72 | 35.73 | 0.03% | 47.64 | 47.64 | 0.00% |
| Beam | 6.84 | 6.804 | 0.53% | 20.52 | 20.412 | 0.53% | 27.36 | 27.216 | 0.53% |
| Total | 24.52 | 24.474 | 0.19% | 73.52 | 73.422 | 0.13% | 98.04 | 97.896 | 0.15% |

## IV. CONCLUSIONS

Based on the results of the analysis, it can be concluded that:

1. Base shear for simple building models in Robot has an average error of 5.259%, top story displacement average error for static equivalent method of 6.009%, and 3.627% for response spectrum method.
2. ETABS models have smaller story shear forces and story displacements compared to Robot models because of ETABS' smaller effective seismic weight, considering overlapping beam-column ends only once by default. Robot models have greater story shear forces and story displacements because Robot includes complete structure mass as effective seismic weight while ETABS ignore bottom half columns of the first story.

3. In context of structural concrete material volume, Revit ignores intersecting volume (overlapping volume of slabs, beams, and columns). So, volumes that are occupying the same space will only be counted once. Error percentages of Revit in concrete volume calculation are less than 1%. The only reason that error percentage between manual and Revit concrete volume calculation exists is decimal rounding in Revit that is taken to two decimal numbers.

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