Seismic performance analysis of retrofitting building structure with type X bracing

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Abstract. The result of the earthquake causes a lateral force that occurs on the building structure. Loads caused by earthquake loads need to be calculated and designed based on standards, so that when an earthquake occurs, the structure of the building is still able to resist the resulting lateral forces. The calculated building structure has a height of 12 floors with structural elements consisting of columns, beams, and shear walls. This building structure is loaded with earthquake loads which refer to SNI 1726-2019 Procedures for Earthquake Resistance Planning for Building and Non-Building Structures. Based on the calculation of the existing building structure due to the earthquake load of SNI 1726-2019, it was found that the story drift and Demand–Capacity Ratio (DCR) in column and beam did not meet the planning standards. The building structure was remodeled using type X bracing retrofitting to determine the value of story drift and DCR. Building structure modeling with type X bracing consists of three model shapes varying the location of placement and the number of type X bracing per floor. The results show that the addition of type X bracing can reduce the story drift up to 32.77% for the x direction and 33.75% for the y direction. In the cross-section of the beam element, the reduction in internal forces can reduce the Demand–Capacity Ratio (DCR) value in the beam. The cross-section of column element, the internal force has decreased but for the column which is attached to the type X bracing system showed an increase in internal force which causes an increase in the DCR value.

Keywords: seismic performance, building structure, type X bracing

1. Introduction

In 2019, Meteorological, Climatological, and Geophysical Agency (BMKG) recorded 11473 earthquakes in Indonesia with varying magnitudes. Some of the major earthquakes that occurred included the Maluku Earthquake (M 7.1) on November 14 2019, the Banda Earthquake (M 7.4) June 24, and the Ambon Earthquake (M 6.5) on September 26, 2019. The load of this severe earthquake will have an impact on the behavior of reinforced concrete buildings after the earthquake. For this reason, a visual inspection and calculation of the seismic behavior analysis of the building is necessary due to the earthquake load.

Earthquake load calculation design standards will be continuously updated based on recorded earthquake data in an area. In 2019, the national standardization body issued the SNI 1726-2019 planning standards for Earthquake Resistance Planning Procedures for Building and Non-Building Structures [1]. So that the calculation of the earthquake load on the building structure must refer to
SNI 1726-2019. Before the existence of SNI 1726-2019, existing building structures were designed and calculated using the previous earthquake planning standards, namely SNI 1726-2012 or SNI 03-1726-2002. Questions will arise on existing buildings, whether these buildings will meet the standard planning criteria for SNI 1726-2019.

Reinforced concrete buildings in existing conditions are at risk of having inadequate seismic performance based on the current standards, SNI 1726-2019. This is due to periodic updating of seismic standards or procedures in each region. Some of these structures may perform well in the possibility of future earthquakes, but others may not have the ability to withstand severe damage, and may collapse as a result of insufficient seismic performance according to SNI 1726-2019 seismic planning standards. In these circumstances, there is a significant need to carry out an adequate performance assessment of RC buildings and to investigate possible retrofitting schemes prior to future seismic events [2].

Strengthening the structure can be used as an effort to prevent collapse [3]. There are a variety of retrofitting techniques that can help reduce lateral displacement, including using FRP laminates, concrete or steel jacketing and steel braces. Steel bracing as a retrofitting method, is a very suitable technique for reducing global displacement and increasing building capacity [4]. Bracing itself has several common forms, namely Z, X, and V. Bracing type X has the smallest story drift compared to other types and reduces the basic shear forces on the building structure [5][6],[7],[8]. In addition to shape, bracing placement modeling also affects the performance of the structure of a building [9]. The use of X-type steel bracing reinforcement systems in low-rise buildings has a positive response in almost all aspects of the building, while in medium and high-rise buildings, the side effect of retrofitting on columns with bracing reinforcement needs to be considered, because of the additional axial force on the columns bracing is placed, so that other reinforcement such as jacketing may be required [10].

In this study, an analysis of the performance of the existing building will be carried out before and after the reinforcement of X steel braces with various configurations of placement of braces and type X braces (per 1 floor and per 2 floors). The building performance will be reviewed in terms of the story drift and Demand/Capacity Ratio (DCR) on the beams and columns. Dynamic response spectrum analysis will be carried out using 3D modeling software (ETABS) with dynamic response spectrum analysis.

2. Methodology

Research starts with problem identification so that the research carried out can achieve its objectives. Literature studies are compiled in order to obtain literature for solving problems raised for research. Modelling of the geometry structure and dimension of beams and column using ETABS software. The loading data on the building structure will then be entered with gravity loading based on SNI 03-1727-2013 [11] and earthquake loads based on SNI 03-1726-2019. Structural retrofitting using type X bracing is used as a reinforcing material in buildings. The variations of braces used were X braces per 1 floor and X braces per 2 floors with three modeling locations of each type of brace. Dynamic response spectrum analysis will be carried out on the existing building and the building after the addition of bracing retrofitting to review the seismic performance of each building condition in terms of the story drift and cross-sectional capacity. A Comparison of the results of the analysis of each condition will be carried out to draw conclusions based on the results of the research analysis.
3. Results and discussion

The results of the analysis were obtained based on the stages of research described below.

3.1 Building Geometry Modeling

The building reviewed in this study is a 12-story reinforced concrete building structure with shear walls. The function of the building under review is used as a hospital and is located in the city of Ambon with soft soil types. Modeling is done with the help of the ETABS application in 3D as follows.
3.2 Loading

Gravity loading on buildings is based on SNI 03-1727-2013 concerning Loading Procedures for Houses and Buildings. Dead load is permanent loading which includes loads from the structural components of the building (reinforced concrete = 2400 kg/m$^3$) as well as additional dead loads such as ceramics (24 kg/m$^2$), plastering (2100 kg/m$^2$), ceilings (7 kg/m$^2$), plafond (11 kg/m$^2$), mechanical electrical installation (30 kg/m$^2$) and others [11] [12].

Live Load

Live loading is a load that can be moved or a load that is not integrated with the building structure and does not have permanent properties. Live Load for the hospital function consists of operation room and laboratorium (2.87 kN/m$^2$), Patient room (1.92 kN/m$^2$), all floor corridor except first floor (3.83 kN/m$^2$), corridor first floor (4.79 kN/m$^2$), flat roof (0.92 kN/m$^2$) [11] [12].

3.3 Earthquake Load

Earthquake load data is obtained based on the SNI 03-1726-2019 reference on Earthquake Resistance Planning Procedures for Building and Non-Building Structures as follows [1].

![Response spectrum](image)

**Figure 4.** Response spectrum

The seismic force retaining system used in the building under review is a special bearer double frame system and special reinforced concrete shear walls with a response modification coefficient (R) of 7, an over strength factor ($\Omega_0$) of 2.5, and a deflection magnification factor (Cd) of 5.5. The combination of loading used in the study is taken from SNI 03-1726-2019 article 4.2 [1].

3.4 Existing Building Analysis

The dynamic response spectrum analysis carried out in the existing building using the ETABS application produces the story drift graph in Figure 5. Based on Figure 5, it can be seen that the story drift that occurs in the existing building exceed the allowance story drift based on SNI 03-1726-2019 in the X direction starting from the 4th floor to the 12th floor while in the Y direction it starts from the 5th floor to the 12th floor.
Checking the cross-sectional capacity of the building beam and column is carried out by obtaining the DCR or Demand/Capacity ratio value by comparing the force that occurs according to the ETABS output against the capacity of the column or beam according to SNI 03-2847-2019. The column under review is located on the 5th floor, the beam section in question is located on the 11th floor with the analysis results in accordance with Table 1.

Table 1. Analysis of column capacity reviewed at the existing condition of the building

| No | Column Type | Floor | Grid | Pu (kN) | Mu (kN.m) | φPn (kN) | φMn (kN.m) | Ratio D/C |
|----|-------------|-------|------|---------|-----------|----------|------------|----------|
| 1  | K2          | 5th  | 1 – A3 | -25.24  | 410.00    | -2052.7  | 540        | 0.76     |
| 2  |             |       | 2 – A3 | -1251.43| 370.38    | -2052.7  | 225        | 1.65     |
| 3  |             |       | 3 – A3 | -1048.31| 263.87    | -2052.7  | 270        | 0.98     |
| 4  |             |       | 6 – A3 | -1408.57| 229.87    | -2052.7  | 160        | 1.44     |
| 5  |             |       | 7 – A3 | -876.58 | 262.66    | -2052.7  | 320        | 0.82     |
| 6  |             |       | 8 – A3 | -861.22 | 261.36    | -2052.7  | 315        | 0.83     |
| 7  |             |       | 9 – A3 | -892.99 | 265.94    | -2052.7  | 310        | 0.86     |
| 8  |             |       | 10 – A3| -1376.31| 241.54    | -2052.7  | 180        | 1.34     |
| 9  |             |       | 13 – A3| -1308.41| 401.86    | -2052.7  | 190        | 2.12     |
| 10 |             |       | 14 – A3| -1111.01| 332.92    | -2052.7  | 255        | 1.31     |
| 11 |             |       | 1 – D  | 350.09  | 555.66    | 10623.0  | 1500       | 0.37     |
| 12 |             |       | 1 – C  | 528.65  | 468.84    | 10623.0  | 1600       | 0.29     |
| 13 |             |       | 1 – B  | 539.39  | -465.64   | 10623.0  | -1550      | 0.30     |
| 14 |             |       | 1 – A  | 186.79  | 647.57    | 10623.0  | 1450       | 0.45     |

Table 2. Analysis of the capacity of beams reviewed at the existing condition of the building

| No | Beam Type | Floor | As   | DCRmoment | DCRshear | DCRtorsion |
|----|-----------|-------|------|------------|----------|------------|
| 1  |           |       | 2-3/C | 0.65       | 0.56     | 1.17       |
| 2  |           |       | 3-4/C | 0.65       | 0.54     | 1.16       |
| 3  |           |       | 4-5/C | 0.64       | 0.55     | 1.16       |
| 4  |           |       | 5-6/C | 0.64       | 0.55     | 1.15       |
| 5  | B1        | 11    | 6-7/C | 0.63       | 0.54     | 1.12       |
| 6  |           |       | 7-8/C | 0.63       | 0.54     | 1.13       |
| 7  |           |       | 8-9/C | 0.63       | 0.54     | 1.15       |
| 8  |           |       | 9-10/C| 0.63       | 0.54     | 1.18       |
| 9  |           |       | 10-11/C| 0.63      | 0.54     | 1.22       |
Based on Table 1 and Table 2, it can be seen that in some of the columns and beams under review, a DCR value of 1 or more is obtained, which indicates that the force exceeds the cross-sectional capacity.

3.5 Building Modeling with Braces Reinforcement

Building modeling with the addition of braces as reinforcement or retrofitting is done with three models with variations in the location of the placement and also two types of braces, namely X braces per 1 floor and X braces per 2 floors. Figures 6, 7, and 8 are illustrations of placement of modeling 1, 2, and 3.

|   |     |     |     |
|---|-----|-----|-----|
| 10| 11-12/C | 0.63 | 0.55 | 1.25 |
| 11| 12-13/C | 0.63 | 0.54 | 1.27 |
| 12| 13-14/C | 0.64 | 0.53 | 1.30 |
| 13| 2/A3-A  | 0.32 | 0.70 | 0.12 |
| 14| 2/A-B   | 0.58 | 0.45 | 0.58 |
| 15| 2/B-C   | 0.57 | 0.44 | 0.56 |

3.6 Comparison of Building Analysis Results

The analysis results obtained on the building with bracing reinforcement for each model will be compared with the results of the analysis of the existing building conditions to determine the effect of adding bracing as reinforcement to the seismic performance of the building under review. The comparison of the deviation between floors in the X direction can be seen in the graph in Figure 9 while in the Y direction it can be seen in the graph in Figure 10. Based on Figures 9 and 10 it can be seen that the story drift that occurs in the building with model 1 does not exceed the allowable story drift according to the standard while at model 2 and model 3 still have story drift that exceed the allowable based on SNI 1726-2019. The use of X braces per 1 floor can reduce the story drift that occurs more than X braces per 2 floors with reference to Table 3.
Based on Table 3, it can be seen that the addition of type X braces can affect the internal force that occurs in the column. The reduction in internal force that occurs in the column can improve the performance of the column itself because it can reduce the DCR (Demand / capacity ratio) value which is used as a reference for column performance where the DCR value is more or equal to one which is considered a failure. The use of braces can also have a negative impact which can be seen with the addition of internal forces that occur so as to increase the DCR value of a column, especially in columns that are reinforced with braces [9]. The side effects of adding braces as reinforcement to the surrounding columns with column numbers 4, 5, 6, 7, and 8 can be used as examples to configure the effect. In each modeling failure occurs in columns 4, 5, 6, 7, and 8 because the force exceeds the capacity of the column even though the bracing reinforcement has been installed.

**Figure 9.** Comparison graph story displacement direction x

**Figure 10.** Comparison graph story displacement direction y

| Model Configuration          | X Direction Reduction | Y Direction Reduction |
|-----------------------------|-----------------------|-----------------------|
| Model 1 with 1 story X brace| 8.18 % - 35.81 %      | 5.75 % - 33.74 %      |
| Model 1 with 2 story X brace| 8.1 % - 35.74 %       | 6.07 % - 33.13 %      |
| Model 2 with 1 story X brace| 4.33 % - 21.73 %      | 4.83 % - 17.26 %      |
| Model 2 with 2 story X brace| 4.29 % - 21.45 %      | 4.77 % - 16.85 %      |
| Model 3 with 1 story X brace| 3.88 % - 21.58 %      | 4.23 % - 8.98 %       |
| Model 3 with 2 story X brace| 3.84 % - 21.35 %      | 4.17 % - 8.77 %       |
Whereas in the cross section of the beam, based on Table 5 to Table 7, it can be seen that the beam under review in the existing conditions has failed because the DCR (Demand / Capacity Ratio) value by the torsional force exceeds 1, which indicates that the torsional force that occurs in the beam exceeds capacity. The addition of X-type bracing to the structure has an impact on beam performance which can be seen by the reduction in the DCR value caused by the moment, shear force, and torsional force on the beam under review. The biggest reduction occurs in model 1 where the DCR value is below 1, which means that the torsional force that occurs is less than capacity.

### Table 4. Recapitulation of DCR value on column under review

| No | Column Type | Floor | Grid | Existing | Model 1 | Model 2 | Model 3 |
|----|-------------|-------|------|----------|---------|---------|---------|
|    |             |       |      | DCR (Demand / Capacity Ratio) | 1 Storey X Brace | 2 Storey X Brace | 1 Storey X Brace | 2 Storey X Brace | 1 Storey X Brace | 2 Storey X Brace |
| 1  | 1 - A       | 1     |      | 0.76    | 0.74    | 0.72    | 0.79    | 0.79    | 0.95    | 0.93    |
| 2  | 2 - A       | 1     |      | 1.65    | 1.22    | 1.24    | 1.38    | 1.45    | 1.75    | 1.86    |
| 3  | 3 - A       | 1     |      | 0.98    | 0.31    | 0.31    | 0.63    | 0.59    | 0.59    | 0.61    |
| 4  | 6 - A       | 1     |      | 1.44    | 1.45    | 0.94    | 2.54    | 1.65    | 2.37    | 1.66    |
| 5  | 7 - A       | 1     |      | 0.82    | 1.46    | 1.08    | 3.37    | 1.75    | 1.08    | 2.18    |
| 6  | 8 - A       | 1     |      | 0.83    | 0.33    | 1.56    | 0.60    | 0.62    | 0.75    | 0.76    |
| 7  | 9 - A       | 1     |      | 0.86    | 1.28    | 1.68    | 0.62    | 0.65    | 0.88    | 0.92    |
| 8  | 10 - A      | 1     |      | 1.34    | 1.69    | 0.58    | 0.83    | 0.88    | 2.07    | 2.07    |
| 9  | 13 - A      | 1     |      | 2.12    | 0.60    | 0.61    | 0.91    | 0.97    | 1.29    | 1.29    |
| 10 | 14 - A      | 1     |      | 1.31    | 2.83    | 1.16    | 1.02    | 1.04    | 2.78    | 2.51    |
| 11 | 1 - D       | 2     |      | 0.37    | 0.34    | 0.34    | 0.35    | 0.35    | 0.36    | 0.36    |
| 12 | 1 - C       | 2     |      | 0.29    | 0.30    | 0.40    | 0.26    | 0.26    | 0.30    | 0.30    |
| 13 | 1 - B       | 2     |      | 0.30    | 0.30    | 0.30    | 0.35    | 0.42    | 0.39    | 0.47    |
| 14 | 1 - A       | 2     |      | 0.45    | 0.43    | 0.55    | 0.46    | 0.58    | 0.51    | 0.66    |

### Table 5. Recapitulation of DCR value caused by bending moment on the beams under review

| No | Beam Type | Floor | Grid | Existing | Model 1 | Model 2 | Model 3 |
|----|-----------|-------|------|----------|---------|---------|---------|
|    |           |       |      | DCR (Demand / Capacity Ratio) | 1 Storey X Brace | 2 Storey X Brace | 1 Storey X Brace | 2 Storey X Brace | 1 Storey X Brace | 2 Storey X Brace |
| 1  | 1 - B1    | 2     |      | 0.65    | 0.53    | 0.52    | 0.57    | 0.57    | 0.59    | 0.59    |
| 2  | 2 - B1    | 2     |      | 0.65    | 0.53    | 0.52    | 0.57    | 0.57    | 0.59    | 0.59    |
| 3  | 3 - B1    | 2     |      | 0.65    | 0.53    | 0.52    | 0.57    | 0.57    | 0.59    | 0.59    |
| 4  | 4 - B1    | 2     |      | 0.65    | 0.53    | 0.52    | 0.57    | 0.57    | 0.59    | 0.59    |
| 5  | 5 - B1    | 2     |      | 0.65    | 0.53    | 0.52    | 0.57    | 0.57    | 0.59    | 0.59    |
| 6  | 6 - B1    | 2     |      | 0.65    | 0.53    | 0.52    | 0.57    | 0.57    | 0.59    | 0.59    |
| 7  | 7 - B1    | 2     |      | 0.65    | 0.53    | 0.52    | 0.57    | 0.57    | 0.59    | 0.59    |
| 8  | 8 - B1    | 2     |      | 0.65    | 0.53    | 0.52    | 0.57    | 0.57    | 0.59    | 0.59    |
| 9  | 9 - B1    | 2     |      | 0.65    | 0.53    | 0.52    | 0.57    | 0.57    | 0.59    | 0.59    |
| 10 | 10 - B1   | 2     |      | 0.65    | 0.53    | 0.52    | 0.57    | 0.57    | 0.59    | 0.59    |

### Table 6. Recapitulation of DCR value caused by shear force on the beams under review

| No | Beam Type | Floor | Grid | Existing | Model 1 | Model 2 | Model 3 |
|----|-----------|-------|------|----------|---------|---------|---------|
|    |           |       |      | DCR (Demand / Capacity Ratio) | 1 Storey X Brace | 2 Storey X Brace | 1 Storey X Brace | 2 Storey X Brace | 1 Storey X Brace | 2 Storey X Brace |
| 1  | 1 - B1    | 2     |      | 0.65    | 0.53    | 0.52    | 0.57    | 0.57    | 0.59    | 0.59    |
| 2  | 2 - B1    | 2     |      | 0.65    | 0.53    | 0.52    | 0.57    | 0.57    | 0.59    | 0.59    |
| 3  | 3 - B1    | 2     |      | 0.65    | 0.53    | 0.52    | 0.57    | 0.57    | 0.59    | 0.59    |
| 4  | 4 - B1    | 2     |      | 0.65    | 0.53    | 0.52    | 0.57    | 0.57    | 0.59    | 0.59    |
| 5  | 5 - B1    | 2     |      | 0.65    | 0.53    | 0.52    | 0.57    | 0.57    | 0.59    | 0.59    |
| 6  | 6 - B1    | 2     |      | 0.65    | 0.53    | 0.52    | 0.57    | 0.57    | 0.59    | 0.59    |
| 7  | 7 - B1    | 2     |      | 0.65    | 0.53    | 0.52    | 0.57    | 0.57    | 0.59    | 0.59    |
| 8  | 8 - B1    | 2     |      | 0.65    | 0.53    | 0.52    | 0.57    | 0.57    | 0.59    | 0.59    |
| 9  | 9 - B1    | 2     |      | 0.65    | 0.53    | 0.52    | 0.57    | 0.57    | 0.59    | 0.59    |
Table 7. Recapitulation of DCR value caused by torsion on the beams under review

| No | Beam Type | Floor | Grid | Existing | Model 1 | Model 2 | Model 3 |
|----|------------|-------|------|----------|---------|---------|---------|
|    |            |       |      | 1 Storey X Brace | 2 Storey X Brace | 1 Storey X Brace | 2 Storey X Brace | 1 Storey X Brace | 2 Storey X Brace |
| 1  | B1         | 11    | C    | 1,17     | 0,85    | 1,07    | 1,12 |
| 2  |            |       | C    | 1,16     | 0,92    | 1,00    | 1,01 |
| 3  |            |       | C    | 1,16     | 0,95    | 1,03    | 1,04 |
| 4  |            |       | C    | 1,15     | 0,94    | 1,11    | 1,03 |
| 5  |            |       | C    | 1,12     | 0,93    | 1,12    | 1,04 |
| 6  |            |       | C    | 1,13     | 0,96    | 1,05    | 1,10 |
| 7  |            |       | C    | 1,13     | 0,95    | 1,05    | 1,10 |
| 8  |            |       | C    | 1,13     | 0,96    | 1,05    | 1,12 |
| 9  |            |       | C    | 1,18     | 0,95    | 1,10    | 1,22 |
| 10 |             |   10  | C    | 1,22     | 0,99    | 1,10    | 1,29 |
| 11 |             |       | C    | 1,25     | 0,99    | 1,11    | 1,35 |
| 12 |             |       | C    | 1,27     | 0,99    | 1,11    | 1,40 |
| 13 |             |       | C    | 1,30     | 0,90    | 1,11    | 1,46 |
| 14 |             |       | C    | 0,12     | 0,09    | 0,10    | 0,13 |
| 15 |             |       | C    | 0,58     | 0,52    | 0,54    | 0,56 |
|    |             |       | C    | 0,56     | 0,51    | 0,53    | 0,54 |

4. Conclusions

The following are the conclusions obtained in the study.

a. Story drift that occurs in the existing condition building exceeds the allowance limit of based on SNI 03-1726-2019. Generally, failure in the beam section under review is caused by torsional forces that exceed the capacity of the section, while in the column under review it is caused by axial and momentary forces.

b. Retrofitting the structure with modeling 1 reduces the story drift that occurs from 8.18% to 35.81% by using X braces per 1 floor and 8.1% to 35.74% using X braces per 2 floors. In the beam section, in terms of the effect of adding braces with model 1, it reduces the internal force that occurs so that there is no failure but in the column section there is still failure due to the force that exceeds the capacity of the column.

c. Retrofitting the structure with modeling 2 reduces the story drift that occurs from 4.33% to 21.73% by using X braces per 1 floor and 4.29% to 21.45% per 2 floors. In the beam section, in terms of the effect of adding braces with model 2, it reduces the internal force that occurs but has not been able to overcome the failure and also in the column section there is still failure due to the force that exceeds the column capacity.

d. Retrofitting the structure with modeling 3 has an impact on reducing the story drift that occurs from 3.88% to 21.58% using X braces per 1 floor and 3.84% to 21.35% using X braces per 2 floors. In the beam section, in terms of the effect of adding braces with model 3, it reduces the internal force that occurs but has not been able to overcome the failure and also in the column section there is still failure due to the force that exceeds the column capacity.

e. Retrofitting structure using model 1 gives the best effect compared to model 2 and model 3 with the use of X braces per 1 floor has a better effect in reducing the story drift that occurs compared to bracing X per 2 floors.

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