# Seismic Performance of Existing R/C Building with Irregular Floor Plan Shape

Agus*, Muhammad Ridwan, Febriyan Ramadhana

Institut Teknologi Padang, Civil Engineering Department, Padang, West Sumatra, Indonesia

**Abstract**. Building with irregular floor plan has the eccentricity of force to the centre of building isappears to be more susceptible to deformation and damage when subjected to earthquake movements than with regular floor plan. This study aims to determine the seismic performance of buildings with the irregular floor plan in displacement and drift by service and ultimate performance limit. The object of research is Padang Pariaman public works office building. The evaluation method used non-linear static analysis (Pushover) which is one method to evaluate the seismic performance of the building. Push-over analysis performed by providing a static load in the lateral direction gradually to achieve a specific displacement target. This research is based on SNI-1726-2012, ATC-40 and FEMA 356. The results of the analysis show that the maximum lateral force of 10909.9 kN occurs in step-6 pushover analysis with a displacement of 0.165 m, maximum drift = 0.0705 m and maximum in-elastic drift = 0.025 m. This means the building is included in the IO (Immediate Occupancy) performance level. Although there is damage from small to medium level, still has a big threshold against the collapse, which means the building is safe against the earthquake.

## 1 Introduction

Earthquake disasters basically happen because of damage to buildings not because the earth shakes. Based on the experience of a major earthquake that occurred in West Sumatra-Indonesia on 30 September 2009, many caused the collapse of the building structure. The collapse of reinforced concrete buildings is generally caused by failure of the column structure [1]. On the other hand, the irregular shape of the floor plan has a profound effect on the movement of the building. Ahmed Abdelraheem Farghaly (2010), who conducted a study on the Influence of Irregular Floor Plan on the seismic response of the building, showed that the base shear induced in a perpendicular direction ranged between 40% and 80% of the base shear in the direction of the earthquake motion. In addition, the top displacements for T and L models increased up to 1.9 times the top displacement in the I-model [2].

To investigate the vulnerability of existing buildings due to the earthquake, nonlinear static pushover analysis was performed to evaluate the apparent strength of existing buildings. A study by Sameh A. El-Betar (2017) found that the existing building vulnerability occurred at the ground accelerations (*ag*) greater than 0.125 g on Egyptian seismic map, while the EC-94 buildings designed behaved elastically up to (*ag*) equal to 0.2 g and if exceeded a slight damage may occur [3]. On the other hand, studies of the effect of floor characteristics on seismic performance of Soft Storey RC Frames with Pushover Analysis by B. Shiva Kumaraswami (2015) show that structural ductility decreases when structures are irregular and higher, as are the stages of structural collapse. The seismic performance evaluation of Bethesda Hospital Yogyakarta building structure by Edi Purwanto (2016) has proved that in performance-based design, the performance level for hospital building is lmmediate occupation (OI) fulfilled in actual with pushover analysis [4-5].

The following research aims to determine the seismic performance of buildings with the irregular floor plan in displacement and drift by service and ultimate performance limit. The object of research is Padang Pariaman- Indonesia public works office building is a two-story reinforced concrete building with a distinctive architectural form. Built in areas of strong earthquake risk, the seismic performance evaluation of this building is interesting and important and for that reason, non-linear static analysis (Pushover analysis) is used as one of the methods.

## 2 Literature Review

Many countries always set and update their seismic standards. Several standards that determine the performance level of seismic buildings include SNI 1726-2012, ATC-40 1996 and FEMA 365. This performance level shows the description of the damage experienced by the building after the earthquake. For the estimation of building performance characteristics, different failure criteria are incorporated in a

* Corresponding author: agus@itp.ac.id

methodology established to predict the failure mode of the buildings [6].

**SNI 1726-2012**

The ultimit limit performance of the buildings structure are determined by the maximum deflection and the maximum drift due to the Earthquake Plan in the condition of the structure of the building on the verge of collapse, namely to limit the possibility of collapse of building structures that can cause human casualties and to prevent collisions. The maximum drift according to SNI 1726 - 2012 section 8 is as follows [7]:

- Must not exceed R 0.03 times height of the building level or 30 mm, depending on which is the smallest value.
- Must not exceed 0.02 times the relevant of height of the building level

**ATC – 40 1996**

Building performance levels based on ATC-40, 1996 are divided into the following five stages [8]:

- *Immediate Occupancy* (IO)
  Conditions that explain vertical and lateral load-bearing systems are almost identical to those prior to the earthquake, and the risk of loss of life due to structural collapse is negligible.
- *Damage Control*
  Where after the earthquake, the damage occurred within the range between IO and LS
- *Life Safety* (LS)
  Where after the earthquake, significant damage to the structure occurs. The main components of the structure are not dislocated and collapsed, so the risk of loss of life to structural damage is very low.
- *Limited Safety*
  Conditions that explain that after the earthquake, the damage occurred in the range between LS and CP
- *Structural Stability* / *Collapse Prevention* (CP)
  The condition of the structure after the earthquake was so severe that the building could have either partially or totally destroyed the structure and the possibility of casualties caused by large structural damage

**FEMA 365**

In the displacement coefficient method (FEMA 356), the calculations were performed by modifying the linear elastic response of the SDOF system structure equivalent to the modification factors *C0, C1, C2* and *C3* so as to calculate the switching target by specifying the effective vibration time (*Te*) to calculate the inelastic condition of the structure building [9].

$$\delta_t = C_0.C_1.C_2.C_3.S_a.\left(\frac{T_e}{2.\pi}\right)^2.g \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots 1$$

Where :

$\delta_t$ transition targets

*Te* effective natural vibration time.

$C_0$ modification factors to convert *spectral displacement* structure of SDOF equivalent becomes *roof displacement* structure of MDOF system.

$C_1$ modification factor to relate the maximum inelastic switching with the switching of linear elastic response. $C_1$= 1,0 for $Te \geq Ts$ and

$$C_1 = \left[\frac{1+(R-1).\frac{T_s}{T_e}}{R}\right] \text{ for } T_e < T_s \qquad \ldots\ldots\ldots\ldots 2$$

Where :

$C_2$ modification factors to show *pinched hysteresis shape,* degradation of stiffness and decreased strength in the maximum switching response, accordingly FEMA 356 table 3-3.

$C_3$ modification factor to show the transitional rise due to the p-delta effect. For buildings with positive post-melting stiffness behavior then $C_3$= 1,0. As for the building with post-melting negative stiffness behavior,

$$C_3 = 1{,}0 + \frac{|\alpha|(R-1)^{\frac{3}{2}}}{T_e} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3$$

*R* :is *strength ratio*, can be calculated by the equation:

$$R = \frac{S_a}{V_y/W}.C_m \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 4$$

Where :

*Sa* is the acceleration of the response spectrum at the effective fundamental natural vibration time and the damping ratio in the direction under consideration.

*Vy* is the base shear at the yield point

*W* is the effective weight of seismic.

*Cm* effective mass factor, table 3-1 FEMA 356.

*a* is the stiffness ratio of the post-yield to the effective elastic stiffness, in which the nonlinear transitional relationship is idealized as a bilinier curve.

*Ts* the characteristic vibration time of the spectrum response.

*g* acceleration of gravity 9,81 m/det².

## 3. Performance Evaluation of Reinforced Concrete Seismic Performance

**Description of the building**

The object of research is Padang Pariaman- Indonesia public works office building is a two-story reinforced concrete building. The following are the specifications and drawings of the Building structure plan. Total building height 11.36 m, building length 46,000 m, building width 46,000 m, compressive strength of concrete is 25 MPa , and tensile strength of steel reinforcement is 390 MPa.

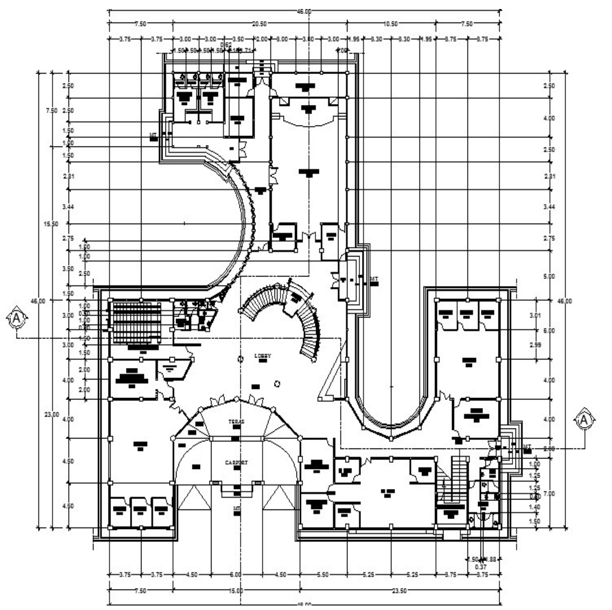

**Fig. 1**. Building plan

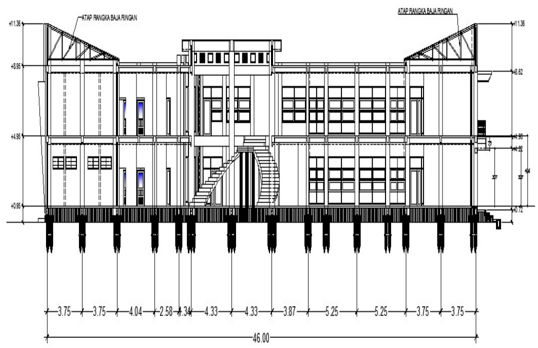

**Fig. 2**. Cross section A-A

**Structural Modeling**

The structure modeling is made in 3-dimensional drawing using SAP 2000 V 14 program with reference to drawing plan.

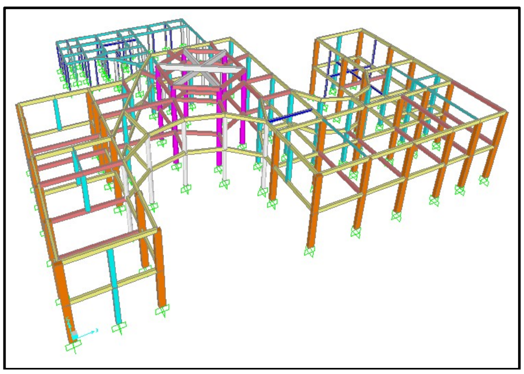

**Fig. 3.** 3D Structured Modeling

The load analysis on Padang Pariaman- Indonesia public works office building covers dead load (DL), additional dead load (SDL), live load (LL), earthquake lateral load (EL). There are some lateral loading provided for pushover analysis. Each load is defined as a different load case and will be preceded by a gravity loading that is adjusted to the mass of the building (during an earthquake). As previously defined, building masses include 30% live load, 100% dead load, and 100% additional dead load. The value of spectrum response in accordance with the latest Indonesian regulation is SNI 1726-2012.

## 4 Analysis Results

The result of pushover analysis shows that at the loading of stage 6 there are 8 points of the beam structure that has been at the maximum limit of shear force that can be retained so that the beam almost collapse. There has been a displacement of 16.46 cm with a shear force of 10909.9 kN. This means there is damage from mild to moderate, where some of the beams have collapsed.

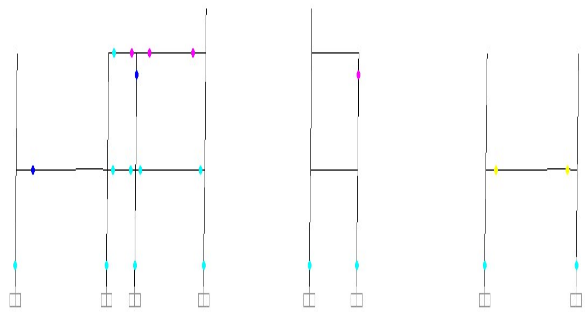

**Fig. 4.** Portal As 17 Distribution of Plastic Joint Stage 6

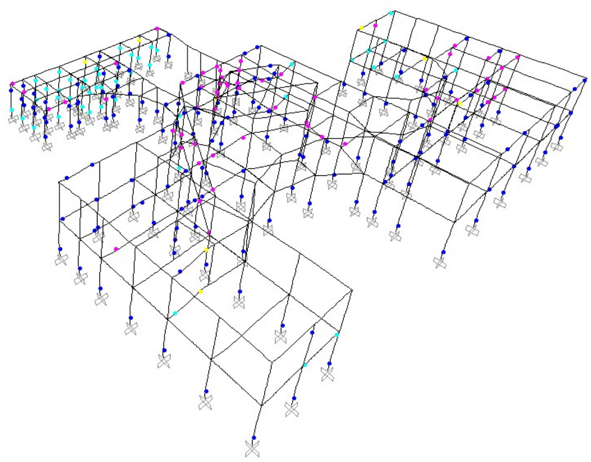

**Fig. 5.** Plastic Jointing Mechanism (loading of stage 6)

The result of a pushover analysis in the form of a capacity curve shows a comparison of shear forces to the displacement. Here are the output output curves of *ATC-40*, and *FEMA 356*.

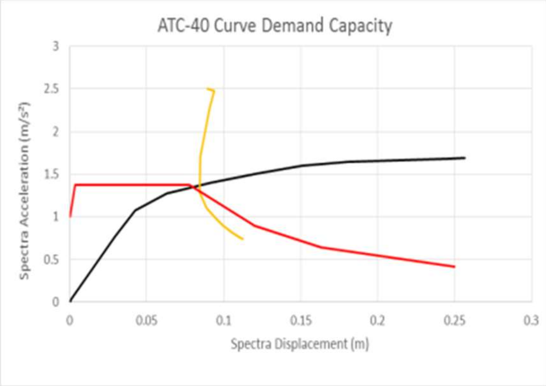


**Fig. 6.** *Atc-40 Curve Demand Capacity*

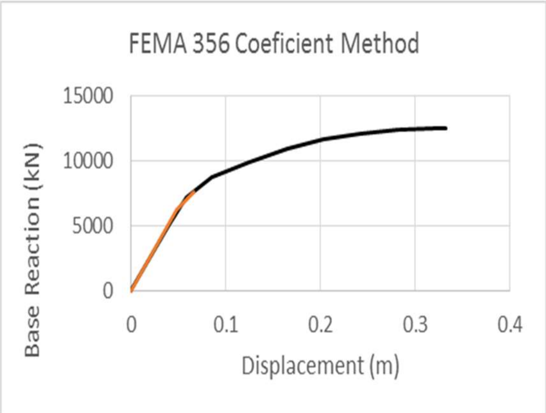


**Fig. 7.***FEMA 356 Coefficient Method.*

Output for the capacity curve of the ATC-40 Capacity Spectrum (figure 6) shows the Spectra Acceleration comparison of Spectra Displacement. The point of performance point is in the cross-cutting curve of capacity (black) with the damping variable line (yellow). While the red line is a damping line with a ratio of 0.2. From figure 6 obtained performance point value of 9642.845 kN with displacement of 0.114 m.

Building performance based on displacement target the ATC-40 Coefficient Method is:

- *Maximum Drift* = Dt / Htot
  = 0.067 / 9,5 m
  = 0.00705 m = 7,05 cm
- *Maximum in-elastic drift* = Dt – D1 / Htot
  = 0,067 – 0,043 / 9,,5 m
  = 0,0025 m = 2,5 cm

So based on the above table, it can be concluded that the structure has an Immediate Occupancy (IO) performance level because the value of Maximum Drift = 0.0705 m <Maximum total drift = 0.01 m and Maximum in-elastic drift = 0,025 m <Maximum in-elastic drift = 0.005 m.

For the capacity curve of FEMA 356 Coefficient Method only displays the comparison between displacement and displacement. Performance point is in intersection between the curve line capacity (black) with bilinear curve curve (red) that is equal to 7694.966 kN with the movement of 0.067 m.

In SNI 1726 - 2012, the limit of drift (Δ), ie shall not exceed the drift permission level (Δ <0.02 x hsx) where (hsx) is the height of the level calculated from the base of the building, ie 9.5 m = 950 cm. When compared to the maximum displacement occurring (= 16.46 cm) is still within the threshold specified by SNI 1726 - 2012.

Based on the results obtained from the pushover analysis using the *ATC-40* method, *FEMA 356* obtained the performance level of the building is on *Immediate Occupancy (IO)* which means the building is safe against earthquake.

**Table 1.** Building Performance Level

| *Parameter* | *Performance Level* | | | |
|---|---|---|---|---|
| | *Immediate Occupancy* | *Damage Control* | *Life Safety* | *Struktur Stability* |
| *Maksimum Total Drift* | 0.01 | 0.01 s.d 0.02 | 0.02 | 0.33 $h\frac{Vi}{Pi}$ |
| *Maksimum Total In-elastic Drift* | 0.005 | 0.05 s.d 0.015 | *No limit* | *No limit* |

## 5 Conclusions

After analyzing and evaluating seismic performance of existing R/C Padang Pariaman- Indonesia public works office building with irregular floor plan shape, the following conclusions can be drawn:

1. The maximum lateral force of 10909.9 kN occurs at step-6 *pushover analysis* with *displacement of 0.165 m, maximum drift = 0.0705 m* and *maximum in-elastic drift = 0.025 m.*
2. The building belongs to the IO performance level category (Immediate Occupancy). Although there is damage from small to medium level, but still has a big threshold against the collapse, which means the building is safe against the earthquake.
3. The design concept of strong Column Weak Beam has been fulfilled in the planning of this building because the beam collapsed first. This is shown the formation of plastic joints starting from the beam element.

## References

1. Maidiawati and Sanada, Y., 2008. Investigation and Analysis of Buildings Damaged during the September 2007 Sumatra, Indonesia Earthquakes, Journal of Asian Architecture and Building Engineering, Vol. 7, No. 2, pp.371-378.
2. Ahmed Abdelraheem Farghaly. 2010. Influence of Structural Irregularity in Plan Floor Shape on Seismic Response of Buildings. Journal of Engineering Sciences, Assiut University, Vol. 38, No. 4, pp. 911-928.
3. Sameh A. El-Betar .2017. Seismic Performance of existing R.C. Framed Buildings. HBRC Journal. Vol. 13. Pp. 171 - 180
4. B. Shiva Kumaraswami .2015. Study on Indfluence of Floor Characteristics on the Seismic Performance of

Soft Storey RC Frames from Pushover Analysis. International Journal of Engeneering Research and Technology (IJERT), Vol. 4, Issue 05, pp. 616 – 622.

5. Edi Purwanto .2016. Structural Performance Evaluation with Pushover Analysis Case Study: The Integrated Central Surgery Building, Bethesda Hospital in Yogyakarta. Applied Mechanics and Materials , Vol 845, pp. 265-273
6. Constantinos Repapis, Elizabeth Vintzileou and Christoszeris. 2006. Evaluation of Seismic Performance of Existing RC Buildings : I. Suggested Methodology, Journal of Earthquake Engeneering, Vol. 10, Issue 2.
7. Badan Standardisasi Nasional. 2012. Tata Cara Perencanaan Ketahanan Gempa Untuk Struktur Bangunan Gedung dan Non Gedung- SNI 03-1726-2012, Bandung: Kementrian Pekerjaan Umum.
8. Applied Technical Council (ATC 40 : 1996), Seismic Evaluation and retrofit of Concrete Building. California Seismic Safety Commission, Redwood City, California.
9. Federal Emergency Management Agency (FEMA 365 : 2000), Prestandard and Commentary for The Seismic Rehabilitation of Buildings, Washington D.C.