Comparative Structure Behavior System of Fixed Base and Base Isolation as Earthquake Result in Irregular Building Configuration

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**Abstract**

Indonesia is prone to earthquakes because the region is traversed by some of the world's most active seismic lines, namely the Mediterranean and the Circum-Pacific earthquake belt. Indonesia has experienced thousands of earthquakes, both documented and undocumented. This is due to Indonesia traversing the most active earthquake belt in the world, namely the Mediterranean and the Circum-Pacific earthquake belt. One of the largest earthquakes that occurred in Indonesia recently, namely the earthquake in Aceh in 2004, accompanied by the Tsunami. The result of this earthquake is not only the destruction of buildings but also the loss of thousands of lives and the damage to the infrastructure and the environment.

In this study, an experimental method is used to study the type of simulation experiments. Architecture and structures data used as a model hospital in STAADPRO software then analyzed the numerical results with existing theories.

The research results:

- The use of base isolation reduces the base shear force than the fixed base system.
- The use of base isolation minimizes the drift between floor levels than the fixed base system.
- The use of base isolation building eccentricity relatively increases it than the fixed base system.

Keywords: earthquake, irregular, fixed base, base isolation
In many earthquake-resistant building regulations, one of the basic principles for the design of earthquake-resistant buildings that regularity. With irregular shapes is not expected to occur eccentricity stiffness center / rotation and the center of mass coincides so that the torque of the building due to the lateral force is relatively no or small. Regular configuration also causes a more equitable distribution of forces to the structural elements such as beams and columns so that the stress concentration on certain structural elements can be avoided. But in reality it is difficult to maintain the configuration of the building in the regular state with functional reasons and subjective. While the design of earthquake resistant structures there are two principles that can be done: first; make the building into a rigid, second; make the building to be relatively flexible.

The principle design of earthquake resistant building structure by making the building to be relatively flexible to follow the direction of motion of the earthquake, is a relatively new (around 1980s) compared to rigid structures or better known as seismic isolation. The purpose of this is to reduce seismic isolation seismic inertial forces (demand) rather than increasing the capacity of the building structure (Trevor EK, 2001). Seismic isolation can be placed in the substructure, upper structure and roof. The position of seismic isolation in sub-structures called base isolation and in this way the more popular done.

If the base isolation mounted on irregular building configuration, positive or negative effect whatever on the behavior of the structure? And this will be studied in this paper with a case study 10 storey private hospital in Palembang which have irregular L-shaped configuration

2. Eccentricity and Torque

Eccentricity is due to the mass center of the building and the building does not coincide stiffness center. According to SNI 1726: 2002, the center of mass is the point of capture resultant dead load following appropriate live load acting on the level floor. At the center of mass of the structural design of the building is earthquake loads catching point static or dynamic seismic forces. While the
center of rotation is a point at the level of the floor when a horizontal load acting on it is not rotating floor level but only translating floors while other levels are not occure horizontal load everything rotation and translation.

Simply put, the center of mass can be said geometrical center of the building so easily calculated quite simply, while the center of stiffness is to calculate the stiffness of the columns and other vertical elements such as shear walls, stairs and so on, so the calculation is quite complicated (Kardiyono, 1997).

![Diagram](image.png)

Figure 2. Deformation relative floor (Source : T. Paulay dan MJN. Priestley, 1992)

In Figure 2, the effect of eccentricity ex and ey (d) in buildings causes (a). deformation of the x-direction ($\Delta x'$), (b). deformation y-direction ($\Delta y'$) and (c). additional rotation and deformation floor x-direction ($\Delta x''$) and y-direction ($\Delta y''$). Deformation and rotation of the above can cause damage to the building.

3. Building Performance

The goal of the performance consisted of the design earthquake magnitude and extent of damage is tolerated or performance level of the building response to the earthquake load. The level of performance is based on the FEMA 273 structures, namely:

- Immediately usable (IO = Immediate Occupancy)
- Safety occupants guaranteed (LS = Life-Safety)
- Avoid a total collapse (CP = Collapse Prevention).
The criteria for acceptance in Planning Performance-Based Earthquake Resistant Buildings are internal forces (moments, shear force, axial force) and deformation (displacement, drift ratio, plastic hinge rotation, permanent deformation) that can be tolerated at a certain level of performance as a result of the earthquake level planned.

Criteria for admission / acceptance criteria can also be applied to all types of seismic analysis of the results of the analysis are elastic (equivalent static, linear-elastic dynamic analysis) and inelastic analysis (static pushover, inelastic dynamic analysis). If the performance of the structure still meet the criteria for the desired level of performance has been achieved (Widodo, 2012).

Acceptance criteria for each performance level can be viewed globally drift Vision 2000.

### Tabel 1. Drift global design criteria for each level of performance of the ATC 58

<table>
<thead>
<tr>
<th>System Description</th>
<th>Operational</th>
<th>Life Safety</th>
<th>Near Collapse</th>
<th>Collapse</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall Building Damage</td>
<td>Light</td>
<td>Moderate</td>
<td>Severe</td>
<td>Complete</td>
</tr>
<tr>
<td>Permissible Transient Drift</td>
<td>&lt; 0.50 %</td>
<td>&lt; 1.50 %</td>
<td>&lt; 2.50 %</td>
<td>&gt; 2.50 %</td>
</tr>
<tr>
<td>Permissible Permanent Drift</td>
<td>Negligible</td>
<td>&lt; 0.50 %</td>
<td>&lt; 2.50 %</td>
<td>&gt; 2.50 %</td>
</tr>
</tbody>
</table>

### 4. Base Isolation

As it is known that the earthquake is hard to control. The intensity of the earthquake in earthquake-resistant design is a demand that must be accommodated by the building structure by increasing the capacity of the building structure. Thus increasing the capacity of the building structure properties (stiffness, strength and ductility) is not easy and not cheap, by making the structure becomes ductile so that when a strong earthquake the building was still able to survive the collapse, despite experiencing inelastic deformation.

The concept of base isolation using a different approach with the above. By reducing demand rather than increasing the capacity properties of building structures so that when a strong earthquake intensity can be reduced and the building still can behave elastic (Trevor EK, 2001).

There are 3 fundamental to the practice of seismic isolation system (Ronald LM in Farzad N, 2001), namely:

- Installation of flexible isolators will extend the natural period of the total system is extended to sufficiently reduce the response force (Fig. 4b).
• Damper or energy dissipation tool will work on the relative deflection between the building and the land can be controlled according practical level design.
• Still gives rigidity under (service) level loads such as wind and small earthquakes.

Figure 4. a). Seismic isolation tool frequently used. Which on: high dumping rubber, middle: lead rubber, and under: friction pendulum, b). Idealization response style spectrum 
(Source : Ronald LM dalam Farzad N, 2001)

There are some similarities to the seismic isolation design with lateral equivalent analysis according to FEMA 450-1 (2003), namely:

\[ T_D = 2\pi \frac{W}{\sqrt{K_{d,m} \cdot g}} \]  
\[ (1) \]

\[ D_D = \frac{g \cdot S_D \cdot T_D}{4\pi \cdot B_D} \]  
\[ (2) \]

\[ V_s = \frac{K_{d,m} \cdot D_D}{R_1} \]  
\[ (3) \]

Keterangan :

\[ W \] = Total seismic dead load weight of the structure above the isolation interface.
\( K_{\text{DMIN}} \) = Minimum effective stiffness of the isolation system at the design displacement in the horizontal direction under consideration.

\( K_{\text{DMAX}} \) = Maximum effective stiffness of the isolation system at the design displacement in the horizontal direction under consideration.

\( g \) = Acceleration of gravity.

\( D_D \) = Design displacement at the center of rigidity of the isolation system in the direction under consideration.

\( S_{\text{DI}} \) = Parameter percepatan spektral disain untuk periode 1 detik

\( T_D \) = Effective period, in seconds (sec), of seismically isolated structure at the design displacement in the direction under consideration.

\( B_D \) = Numerical coefficient related to the effective damping of the isolation system at the design displacement, (table 13.3-1 FEMA 450-1, 2003)

\( V_s \) = Total lateral seismic design force or shear on elements above the isolation system.

\( R_i \) = Numerical coefficient related to the type of lateral-force-resisting system above the isolation system. (tabel 4.3-1 FEMA 450-1, 2003).

Total lateral seismic design force or shear on elements above the isolation system \((V_s)\) is distributed to the upper structure by the following formula:

\[
F_x = \frac{w_x \cdot h_x^k}{\sum_{i=1}^{n} w_i \cdot h_i^k} V_s \quad \text{-----------------(4)}
\]

Where :

\( w_x, w_i \) = Portion of \( W \) that is located at or assigned to level \( x \) or \( i \).

\( h_x, h_i \) = Height above the base level \( x \) or \( i \).

\( k \) is a coefficient that depends on the period of the fundamental vibrating structure. The \( k \) value is:

\( k=1 \) if \( T<0.50 \) sec.

\( k=2 \) if \( T>2.50 \) sec.

\( k \) is linearly interpolated value when \( 0.50 < T <2.50 \) sec.

5. Research Methods and Building Datas

5.1 Research Methods

In this study uses quantitative methods to study the type of simulation experiments. Data architecture and data structures used as a model hospital in STAADPRO software and analyzed by the method of equivalent static seismic analysis then the numerical results are tabulated and analyzed by existing theories.
5.2 Architecture Datas Hospital

Hospital building consists of 10 floors, which consists of semi basement floor and 9 floors above. As each floor functioned as:

- semi basement floor: motorcycle parking space, mechanical & electrical and other service spaces.
- 1st floor: emergency room and administration manager.
- 2nd floor: surgery room.
- 3rd to 8th floor: inpatient unit.
- 9th floor: meeting room, elevator machine room, water tank.

5.3 Structure Datas Hospital

Sub structure used bore pile with $\phi$ 60 cm to a depth varying between 9 to 11 m. While the structure of the type of structure used in this hospital is a rigid frame system concrete beams and columns. While the lateral load resisting system used concrete moment resisting frame system intermediate level. The main structure of the column used dimensionless 60/60 and 40/60. 30/60 beam used while joist vary 30/60, 20/50 and 20/40. Floor plate which is used by 12 cm thick.

Figure 4. 3D structure of the hospital

6. Results and Discussion

6.1 Base shear force

Spectral acceleration values of design parameters for the period from 1 second to Palembang, $S_{D1} = 0.235 \, g$. For building weight $(DL + 0.3LL)$, $W = 10077.64$ tons and $T_{U-S} = 1.58$ sec. and $T_{B-T} = 1.48$ sec. (Livian, 2015). As for the $T_D$ value is typically between 0.5T to 1.5T, natural period (T) fixed base = 1.58 sec. so the value of $T_D = 1.5T = 1.5 \times 1.58 = 2.37$ sec. $\approx 2, 5$ dt. For preliminary is used $T_D = 2.5$ sec. Then look for the effective lateral stiffness of the building with the following formula:

$$k = \frac{4\pi^2 W}{g T^2} = \frac{4 \times 3.14^2 \times 10077.64}{9.81 \times 2.5^2} = 6482.3 \, \text{t/m}.$$ 

At the hospital building there are 41 columns. So each column having an effective lateral stiffness values:
\[
\frac{k}{41} = \frac{6482.3}{41} = 180.3 \text{ t/m} = 1803 \text{ Kn/m}.
\]

Of the value of the effective lateral stiffness per kolom sought specification seismic isolation approaching these values, such as the table below:

<table>
<thead>
<tr>
<th>Total rubber thk.</th>
<th>Axial stiffness</th>
<th>Lateral effective stiffness</th>
<th>Damping ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>197.2 mm</td>
<td>4128x10³ Kn/m</td>
<td>2.68x10³ Kn/m</td>
<td>30.2</td>
</tr>
</tbody>
</table>

Having obtained the k values of the table above each column recalculated effective lateral stiffness value total:

\[
k = 2.68x10^3 \times 41 \text{ columns} = 109.880 \text{ Kn/m} = 10988 \text{ t/m}, \text{ while the value of } T_D \text{ becomes:}
\]

\[
T_D = 2\pi \sqrt{\frac{W}{k_{\text{avg}},g}} = 2\times3.14 \sqrt{\frac{10077.64}{10988\times9.81}} = 1.92 \text{ sec.}
\]

For design displacement value \(D_D\):

\[
D_D = \frac{g.S_{D1}.T_D}{4\pi.B_D} = \frac{9.81\times0.235\times1.92}{4\times3.14\times1.7} = 0.066 \text{ m}
\]

So, total lateral seismic design force or shear on elements above the isolation system \(V_s\):

\[
V_s = \frac{K_{\text{Dmax}},D_D}{R_t} = \frac{10988\times0.066}{2} = 362.6 \text{ tons.}
\]

While lateral force with fixed base \(V_{(US)} = 453.49 \text{ tons}\) and \(V_{(BT)} = 483.73 \text{ tons}\) (Livian Teddy, 2015). Compared seismic base shear force values without isolators (fixed base), the value of the seismic base shear force with isolators (base isolation) decreases 20 to 25%. This is advantageous because the seismic forces detained structure is reduced significantly.
Figure 5. Comparison of vertical shear force distribution system fixed base and base isolation
(source: Analysis)

Likewise, the distribution of shear forces - the base isolation system to the structure above is also reduced (Fig. 5). For a base isolation system, the value of axial and lateral stiffness specifications included as the data support the software STAADPRO and value Vs and Td above as a value control outputs Vs and Td STAADPRO. For other inputs are relatively similar between the fixed base and base isolation system.

6.2 Eccentricity and Torque

The striking differences between regular and irregular buildings configuration are eccentricity. Eccentricity is simply the distance between the center of mass and the center of stiffness. At the distance of a regular building no or relatively small, while in the distance irregular building large enough to pose a potential torque on the building during an earthquake.

The use of base isolation is expected to minimize the distance between the center of mass and stiffness. Based on the analysis STAADPRO output, the use of base isolation is not change the coordinates of the center of mass. So the center of mass at the hospital building systems that use fixed base and the base isolation are equal. What's changed are the center of stiffness. The center of the fixed base system stiffness different from the stiffness center base isolation system.

In Figure 6, the stiffness of the base isolation center towards the 1st floor to roof floor distance near the center of mass of the system base isolation system than the fixed base. Means the use of base isolation shorten the distance between the center of mass and the center of stiffness. Different happens in -y direction, the distance between the center of stiffness of the 3rd to 9th floor base isolation system and the fixed base system with its center of mass is relatively the same. While on the 1st floor, 2nd floor and roof floor using base isolation even enlarge the distance between the center of stiffness and the center of mass, especially floor roof. Means the -y direction, the intended use of base isolation to shorten the distance between the center of mass and stiffness is not achieved.
From Figure 7, the eccentricity direction -x (ex) which use the isolators system (base isolation) decreased compared to the ex-fixed base. Both ex-fixed base and ex-base isolation worth nothing that exceeds the maximum limit 0.1B (3.85 m) for semi basement floor to 2nd floor. This is advantageous because the torque building -x direction also decreased and predictable does not pose significant problems for the hospital building. As for the eccentricity direction -y (ey) to 3rd to 9th floor both ey-fixed base and ey-base isolation are relatively equal. While on the 1st floor, 2nd floor and roof floor eccentricity direction -y (ey) which uses the isolators system (base isolation) increased compared to the ex-fixed base. Eccentricity direction -y (ey) base isolation system for the 1st floor, 2nd floor and roof floor value exceeds the maximum limit 0.1L (3.2 m), especially roof floor and this can cause problems torque on the building.
6.3 Building Performance

Hospitals are categorized Critical Facilities and Emergency Facilities that targeted performance which is when an earthquake has not damaged the structure and non-structure are slightly damaged so that it can directly operate after the earthquake. Whereas in the event of a strong earthquake damaged the structure slightly but still there is a safe and non-structural damage can still be improved so that at this level also can be used almost immediately after the earthquake. This means that in case of minor earthquake both structural and non-structural no damage at all.

Building performance level of acceptance criteria by using the global ratio of drift as table 1, to the hospital with a level of operational performance and immediate occupancy whether using a system of fixed base or base isolation is global drift ratio to be achieved <0.5%. To test the performance criteria are achieved by a private hospital if using a fixed base system by comparing the displacement of the roof with building height:

- **Direction -X axis (North-South)**
  Roof displacement = 7.873 cm and building height = 37.7 m means the ratio of its global drift = $\frac{7.873}{37.7} = 0.0028 \approx 0.28\% < 0.5\%$ Ok

- **Direction -Y axis (West-East)**
  Roof displacement = 8.821 cm and building height = 37.7 m means the ratio of its global drift = $\frac{8.821}{37.7} = 0.0021 = 0.21\% < 0.5\%$ Ok

Displacement roof on base isolation system has increased compared to the fixed base system so that the global drift ratio is also increased, both the direction of the x or y axes but all of the standard ratio are still below 0.5%

![Comparison of the drift between the level of fixed base & base isolation](Source: analysis)

Figure 8. Comparison of the drift between the level of fixed base & base isolation (Source: analysis)

See Figure 8, of the drift between the level of base isolation system drastically reduces the drift between floor levels than the fixed base system. This is very advantageous because the hospital many uses sophisticated electronic tools and expensive are susceptible to excessive swaying.
7. Conclusions and Recommendation

The use of base isolation system as a passive control of the earthquake on the building is relatively new. What's interesting about the use of base isolation is whether the use of base isolation in the building can ignore the basic principles of regularity in designing earthquake-resistant buildings?. From the description above, the use of base isolation can significantly reduce seismic base shear force and the drift between the floor level but because of the configuration of irregular shaped building contained therein eccentricity use of base isolation was able to enlarge the existing eccentricity, which means increased the potential of torque that can damage buildings on during a strong earthquake.

This should be a consideration for architects in designing earthquake resistant buildings. The use of base isolation is not necessarily able to cope with the eccentricity of the building is configured irregular and use of the principle of regularity is needed in designing buildings that use the base isolation.

Reference


