Tarumanagara University Campus 1 Sky-bridge Structure Evaluation

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Abstract. In this study an evaluation of the structure of the sky-bridge at Tarumanagara University campus 1 on earthquake regulations SNI 1726: 2019. The sky-bridge connects the two buildings, parking building (8 floors) and the main building (21 floors). Type of support on the sky-bridge in the parking building is multidirectional pot bearing and in the main building is fixed pot bearing. The modeling of pot bearings in the ETABS program is modeled as a link property element. Based on the evaluation results, checking on the dimensions of installed pot bearing components have qualified the requirements set by AASHTO LRFD Bridge Design 2012. Based on earthquake redundancy factors, pot bearing on the 7th floor cannot be adjusted lateral deformation required is greater than maximum deformation limit provided by pot bearing, while based on earthquakes with strong factors, pot bearing on the sky-bridge are incorrect due to the lateral deformation that occurs. From the results of the study concluded that use pot bearings as support of sky-bridge 7th floor is not appropriate when checked against earthquake regulations SNI 1726: 2019.

1. Introduction

Human population is increasing every year but the amount of available land is increasingly limited especially in big cities so many buildings are built in close proximity, consequently the tendency of tall buildings in close proximity are designed and connected horizontally by sky-bridge. In planning the sky-bridge structure that must be considered is the lateral drift that occurs in the two buildings that are connected. The Lateral drift in buildings occurs due to lateral loads by earthquake loads or wind loads. In Indonesia, the building structure planning looks more at structural resistance to earthquake loads due to the high frequency of earthquakes occurring in Indonesia and the force that occurs is much greater. In Indonesia the building structure planning looks more at structural resistance to earthquake loads due to the high frequency of earthquakes occurring in Indonesia and the force that occurs is much greater. Therefore the design of the support on the sky-bridge must be able to accommodate lateral deformation due to lateral drift of each building that can move in the same direction or opposite direction either approaching or moving away, especially for the type of placement that behaves like a roller.
One type of bearing that is most widely used as a sky-bridge support is pot bearing. There are 3 types of pot bearing, namely multidirectional pot bearing, fixed pot bearing, and unidirectional pot bearing. The technique of multidirectional pot bearings on the sky-bridge is almost similar to base isolation. The main concept of base isolation system is to shift the natural frequency of the structure out of the frequency range which has a dominant influence due to the acceleration of the ground caused by earthquake [1]. Multidirectional pot bearing have sliding surface component so in analysis take into account the friction force that occurs [2]. There is some literature about use of bearing on sky-bridge structures, one of which is research on evaluating sky-bridge structures in apartment buildings in South Korea by determining the use of the right type of connector configuration [3]. Then the study of high-rise buildings with four towers connected by sky-bridge using friction pendulum bearings and viscous dampers at the top of the building by using a shaking table modeled with a scale of 1:25 [4]. There are studies to determine the effective location of sky-bridge in buildings to reduce lateral displacement of the two buildings [5].

The minimum design earthquake force set by the regulation is greater, this causes the lateral drift in the building will be even greater, so in this study an evaluation of the stability sky-bridge structure that connects the main building and the parking building at Tarumanagara University Campus 1 to the earthquake regulations SNI 1726 : 2019 [6]. For pot bearing evaluation, a check on the geometrical requirements of the pot bearing components based on AASHTO LRFD Bridge Design 2012 [7] can be seen in Figure 1 and checking the bearing capacity of the pot bearing based on the Indian Railways Institute of Civil Engineering [8].

1.1. Check the dimensions of pot bearing components

![Figure 1. Geometry size of pot bearing components (AASHTO, 2012)](image)

1.1.1. Elastomer pad (hr). Minimum height required:

$$hr \geq 3.33 \times Dp \times \theta_u$$  \hspace{1cm} (1)

where, hr = height of the elastomer pad, Dp = diameter internal pot, \( \theta_u \) = rotation.

1.1.2. Pot cavity depth (hp1 and hp2). Minimum height required:

$$hp1 \geq (0.5 \times Dp \times \theta_u) + hr + hw$$  \hspace{1cm} (2)

where, hw = height from the top of the elastomer pad to the bottom of the piston.

$$hp2 \geq R_o \times \theta_u + 2\delta_u + 0.125$$  \hspace{1cm} (3)

where, \( \delta_u \) = vertical deformation, \( R_o \) = radial distance from center pot to the pot wall.

1.1.3. Sealing rings. Minimum diameter required:

Sealing rings are used with the same outer diameter as Dp and the distance from the outer diameter to the inner diameter of the sealing rings must not be less than 0.0175 Dp or 4 mm.

1.1.4. Pot base. The minimum base thickness of the pot bearing that is directly related to concrete must exceed or equal to the largest of:

$$tb \geq 0.06 \times Dp \ or \ tb \geq 20 \ mm$$  \hspace{1cm} (4)

where, tb = thick base of the pot bearing.
1.1.5. **Pot wall.** The minimum pot wall thickness for multidirectional pot bearing must exceed or equal to the largest of:

\[ t_{w} \geq \frac{D_p \sigma_c}{1.25 F_y} \text{ or } t_{w} \geq 20 \text{ mm} \]  

where, \( t_{w} \) = thick pot walls, \( F_y \) = yield strength of steel, \( \sigma_c \) = compression stress due to vertical load.

1.1.6. **Piston.** Pot bearings that transfer loads through the piston must exceed or equal to the largest of:

\[ h_{w} \geq \frac{1.5 H_u}{D_p F_y} \text{ or } h_{w} \geq 3.5 \text{ mm} \]  

where, \( H_u \) = lateral load due to combination load.

1.2. **Checking the capacity of the pot bearing**

1.2.1. **Stress.** Checking the maximum stress on the elastomer pad and PTFE due to vertical loads and moments due to eccentricities:

\[ \sigma = \frac{P}{A} + \frac{M}{Z} \leq \sigma_a \]  

Where, \( P \) = vertical load due to combination load, \( A \) = cross-sectional area of elastomer pad, \( M \) = moments due to eccentricities, \( Z \) = plastic modulus, \( \sigma_a \) = allowable stress of 40 MPa for elastomer pad and 45 MPa for PTFE.

1.2.2. **Deformation.** Deformation in lateral and vertical direction, where vertical deformation must not exceed:

\[ \delta v = \frac{d}{Z} \tan \theta \leq 0.15 \text{ hr} \]  

Where, \( d \) = diameter elastomer pad, \( \theta \) = rotation due to combination load, \( hr \) = height of the elastomer pad. For lateral deformation that occurs should not exceed 50 mm for the longitudinal direction (U2) and 20 mm for the transversal direction (U3) based on Tensa brochure [9].

1.2.3. **Rotation.** Rotation that occurs in the pot bearing must not be greater than 0.01 radians.

2. **Methodology**

The building used as evaluation is a sky-bridge structure that connects the main building (building height + 88.95 mm) and parking building (building height + 37.78 m) on the 2nd floor at +5 m elevation and the 7th floor at +25 m elevation.

![Figure 3. 3D view of the main building, parking building and sky-bridge](image)
In this study, earthquake force analysis is based on equivalent static methods and spectrum responses that refer to SNI 1726: 2019 whereas for gravity loads on buildings and sky-bridge refer to SNI 1727: 2013 [10] according to the function of each room. In the etabs program, pot bearing are modeled as link property elements. Vertical stiffness of the link property based on FEMA 356 [11] with the following equation:

\[ K_v = \frac{E_c A}{H} \]  
\[ E_c = \left( \frac{1}{6G \alpha^2} + \frac{4}{3K} \right)^{-1} \]  
\[ s = \frac{d}{4H} \]  

where, \( K_v \) = vertical stiffness of the pot bearing, \( E_c \) = compression modulus, \( A \) = cross-sectional area of pot bearing, \( H \) = height of the pot bearing, \( G \) = shear modulus of 80000 MPa, \( s \) = shape factor, \( K \) = bulk modulus of 2000 MPa. Multidirectional pot bearing are used in parking buildings while fixed pot bearings are used in the main building.

**Table 1.** Link property of multidirectional pot bearing in parking building

| Property                  | Input                                      |
|---------------------------|--------------------------------------------|
| Type of link              | Rubber Isolator                            |
| Mass of links             | 39 kg                                      |
| Rotational Intertia       | 0.000317 ton.m^2                           |
| Stiffness U1              | 952854.8 kN/m                              |
| Stiffness U2, U3, R1, R2, dan R3 | 0 kN/m dan 0 kN.m.rad                      |

**Table 2.** Link property of fixed pot bearing in main building

| Property                  | Input                                      |
|---------------------------|--------------------------------------------|
| Type of link              | Rubber Isolator                            |
| Mass of links             | 39 kg                                      |
| Rotational Intertia       | 0.000317 ton.m^2                           |
| Stiffness U1              | 1 x 10^9 kN/m                              |
| Stiffness U2, U3, R1, R2, dan R3 | Fixed                                      |

Link property modeling in the etabs program can be seen in Figure (4) for the 2nd floor sky-bridge and Figure (5) for the 7th floor sky-bridge.

![Figure 4](image_url)  
**Figure 4.** Link property elements with labels K5, K6, K7, and K8 on the 2nd floor sky-bridge

![Figure 5](image_url)  
**Figure 5.** Link property elements with labels K1, K2, K3, and K4 on the 7th floor sky-bridge
3. Result and discussion

3.1. Check the dimensions of pot bearing components

The minimum dimension checking of pot bearing components based on AASHTO LRFD Bridge Design 2012 [7] is presented in table 3.

| Component          | Minimum dimension (mm) | Dimension attached (mm) | Check |
|--------------------|------------------------|-------------------------|-------|
| Elastomer pad      | 4.25                   | 30                      | Ok    |
| Pot cavity depth   |                        |                         |       |
| hp1                | 32.07                  | 55                      | Ok    |
| hp2                | 1.10                   | 5                       | Ok    |
| Sealing rings      | 250                    | 250                     | Ok    |
| Pot base           | 15                     | 20                      | Ok    |
| Pot wall           | 1.6192                 | 20                      | Ok    |
| Piston             | 7.5                    | 25                      | Ok    |

Based on table 3, it can be concluded that the components of the pot bearing have met the minimum requirements set by AASHTO LRFD Bridge Design 2012 [7].

3.2. Checking the capacity of the pot bearing

3.2.1. Stress. The stress calculation that occurs on the elastomer pad and PTFE is the same because of the same cross-sectional area. The results of the calculations can be seen in table 4 due to earthquake factor redundancy and table 5 due to earthquake with overstrength factors.

| Link   | P (kN) | Mx (kN.m) | My (kN.m) | Elastomeric pad | PTFE layer |
|--------|--------|-----------|-----------|-----------------|------------|
|        |        |           |           | σ (MPa) | σa (MPa) | Check | σ (MPa) | σa (MPa) | Check |
| K1     | 94.75  | 12.42     | 3.88      | 12.56  | 40       | Ok    | 12.56  | 45       | Ok    |
| K2     | 94.72  | 11.81     | 3.81      | 12.11  | 40       | Ok    | 12.11  | 45       | Ok    |
| K3     | 94.27  | 0         | 0         | 1.93   | 40       | Ok    | 1.93   | 45       | Ok    |
| K4     | 94.34  | 0         | 0         | 1.93   | 40       | Ok    | 1.93   | 45       | Ok    |
| K5     | 101.80 | 2.53      | 1.81      | 4.90   | 40       | Ok    | 4.90   | 45       | Ok    |
| K6     | 101.91 | 2.45      | 1.95      | 4.95   | 40       | Ok    | 4.95   | 45       | Ok    |
| K7     | 136.97 | 0         | 0         | 2.80   | 40       | Ok    | 2.80   | 45       | Ok    |
| K8     | 137.10 | 0         | 0         | 2.80   | 40       | Ok    | 2.80   | 45       | Ok    |

| Link   | P (kN) | Mx (kN.m) | My (kN.m) | Elastomeric pad | PTFE layer |
|--------|--------|-----------|-----------|-----------------|------------|
|        |        |           |           | σ (MPa) | σa (MPa) | Check | σ (MPa) | σa (MPa) | Check |
| K1     | 94.75  | 24.48     | 7.26      | 22.62  | 40       | Ok    | 22.62  | 45       | Ok    |
| K2     | 94.72  | 23.37     | 7.15      | 21.82  | 40       | Ok    | 21.82  | 45       | Ok    |
| K3     | 94.27  | 0         | 0         | 1.93   | 40       | Ok    | 1.93   | 45       | Ok    |
| K4     | 94.34  | 0         | 0         | 1.93   | 40       | Ok    | 1.93   | 45       | Ok    |
| K5     | 101.80 | 4.52      | 3.40      | 7.23   | 40       | Ok    | 7.23   | 45       | Ok    |
| K6     | 101.91 | 4.37      | 3.55      | 7.23   | 40       | Ok    | 7.23   | 45       | Ok    |
| K7     | 136.97 | 0         | 0         | 2.80   | 40       | Ok    | 2.80   | 45       | Ok    |
| K8     | 137.10 | 0         | 0         | 2.80   | 40       | Ok    | 2.80   | 45       | Ok    |

3.2.2. Deformation. Lateral deformation for multidirectional type bearing pots (K1, K2, K5, and K6) can be seen in table (6) for earthquakes due to redundancy factors and table (7) for earthquakes due to overstrength factors.
Table 6. Lateral deformation in the pot bearing due to earthquake redundancy factor

| Link | Longitudinal deformation | Transversal deformation | Check | Check |
|------|--------------------------|-------------------------|-------|-------|
|      | U2                      | U ijin                  |       |       |
| K1   | 131.06 mm               | 50 mm                   | Not ok|       |
| K2   | 124.64 mm               | 50 mm                   | Not ok|       |
| K5   | 24.78 mm                | 50 mm                   | Ok    |       |
| K6   | 24.03 mm                | 50 mm                   | Ok    |       |
|      | U3                      | U ijin                  |       |       |
| K1   | 40.95 mm                | 20 mm                   | Not ok|       |
| K2   | 40.12 mm                | 20 mm                   | Not ok|       |
| K5   | 17.71 mm                | 20 mm                   | Ok    |       |
| K6   | 19.12 mm                | 20 mm                   | Ok    |       |

Table 7. Lateral deformation in the pot bearing due to earthquake overstrength factor

| Link | Longitudinal Deformation | Transversal Deformation | Check | Check |
|------|--------------------------|-------------------------|-------|-------|
|      | U2                      | U ijin                  |       |       |
| K1   | 258.26 mm               | 50 mm                   | Not ok|       |
| K2   | 246.68 mm               | 50 mm                   | Not ok|       |
| K5   | 44.31 mm                | 50 mm                   | Ok    |       |
| K6   | 42.79 mm                | 50 mm                   | Ok    |       |
|      | U3                      | U ijin                  |       |       |
| K1   | 76.54 mm                | 20 mm                   | Not ok|       |
| K2   | 75.40 mm                | 20 mm                   | Not ok|       |
| K5   | 33.32 mm                | 20 mm                   | Not ok|       |
| K6   | 34.74 mm                | 20 mm                   | Not ok|       |

3.2.3. Rotation. Comparison of rotations that occur from structural analysis to permit rotation can be seen in table 8.

Table 8. Rotation pot bearing

| Link | Θ (rad) | Θ ijin (rad) | Check |
|------|---------|--------------|-------|
| K1   | 0.0025  | 0.01         | Ok    |
| K2   | 0.0025  | 0.01         | Ok    |
| K5   | 0.0051  | 0.01         | Ok    |
| K6   | 0.0051  | 0.01         | Ok    |

4. Conclusions

The use of pot bearing components in terms of dimension dimensions meets the AASHTO LRFD Bridge Design 2012 requirements based on the ultimate force and rotation that occurs but based on the evaluation of pot bearing capacity, pot bearings cannot accommodate lateral deformation that occurs from the behavior of each building. It can be said that the use of pot bearing on the sky-bridge Tarumanagara University Campus 1 is not appropriate.

Reference

[1] Christianto, Daniel. *Analysis of Damping Ratio in Passive Control Devices with Granded Sand as Fillers in the Shaft Section*. IOP Conference Series: Material Science and Engineering. 2019: 1-11.
[2] Chopra, Anil K. *Dynamic of Structures (Fourth Edition)*, California: Pearson, 2011.
[3] Lee D-G, Kim H-S, Ko Hyun. *Evaluation of coupling–control effect of a sky-bridge for adjacent tall buildings*. The Structural Design of Tall and High Building. Vol. 21 (Mar 2010): 311-328.
[4] Lu X, Lu Q, Lu W and Zhou Y. *Experimental Study on the Seismic Performance of Four-Tower High-rise with an isolated Sky-Corridor on the top*. 16thWorld Conference on Earthquake. 2017: 1-10.
[5] Abbood, Imad S. *Seismic Response Analysis Of Linked Twin Tall Buildings With Structural Coupling*. International Journal of Civil Engineering and Technology. Vol. 9. No. 11 (November 2018): 208-219.
[6] BSN. *Tata Cara Perencanaan Ketahanan Gempa untuk Struktur Bangunan Gedung dan Non Gedung*, Jakarta: Badan Standardisasi Nasional, 2019.
[7] AASHTO. *The AASHTO LRFD Bridge Design Specifications Sixth Edition*, Washington D.C.: American Association of State Highway and Transportation Officials, 2012.
[8] IRICEN. *Bridge Bearings*, New Delhi: Indian Railways Institute of Civil Engineering, 2006.

[9] TENSA. *Bearings*. Available in https://www.tensaamerica.com/sites/default/files/technology/files/brochure/tensa-bearings.pdf. Vol. 05 (accessed 21 April 2020).

[10] BSN. *Beban Minimum untuk Perancangan Bangunan Gedung dan Struktur Lain*, Jakarta: Badan Standardisasi Nasional, 2013.

[11] ASCE. *Prestandard and Commentary for the Seismic Rehabilitation of Buildings (FEMA 356)*, Washington D.C: American Society of Civil Engineers, 2000.