Building Structure Analysis With and Without Direct Foundation Modelling using Reinforced Concrete Special Moment Resisting Frame

J Propika1,3, L I Lestari2,3, Y Septiarsilia2,3, K N Julistian4
1Department of Civil Engineering, Universitas Kristen Petra, Surabaya 60236, Indonesia
2Department of Civil Engineering, Institut Teknologi Sepuluh Nopember, Surabaya 60111, Indonesia
3Department of Civil Engineering, Institut Teknologi Adhi Tama Surabaya, Surabaya 60117, Indonesia
jakapropika@itats.ac.id

Abstract. The modelling of placement upon the seismic resistant structure can be carried out separately or directly. Separated modelling refers to the modelling using fixed joint, while direct modelling is defined as the lower structure directly using spring on soil-foundation interaction. Both modelling have differences in the context of behaviour and reaction of structure that must be adjusted based on SNI 1726:2019 and pile needs. This research analysed the calculation of static bearing capacity of pile and manual calculation of k coefficient by Nakazawa method and a supporting program SAP2000 V14.2.5. The analysis results indicated that under the manual calculation, total pile needs on fixed joint modelling of spun pile in diameter 600 mm class B are 185 piles within pile cap modelling at every point of column, meanwhile using SAP2000 V14.2.5, it is obtained the pile needs of spring modelling are 176 piles within integral pile cap modelling. The structural behaviour and the reaction of both modelling demonstrated the values of drift control, period, mass participation, static dynamic shear force, and force output in the fixed joint modelling were less than spring modelling.

1. Introduction
Earthquake is a sudden movement that occurs on the surface of the earth due to the energy in the earth that creates waves in all directions. An earthquake that reaches the ground can affect the buildings above it, so it needs to be secured. To secure the building, the building must be designed as an earthquake-resistant building that is planned in accordance with existing earthquake regulations [1]. Earthquakes are natural events that cannot be known when and how big, and can cause losses that can be in the form of life or property. In Indonesia, earthquakes that occur mostly cause fatalities [2]. In relation to earthquake potential areas in Indonesia, failures are often found in building structures. The failure occurs in the upper structure, especially the column, if the collapse of the column occurs, the total collapse is unavoidable. Likewise with the substructure (foundation), the failure of the substructure occurs due to uneven land subsidence. This shows that foundation planning has a basic role in anticipating fatal damage to buildings due to earthquakes. Given this, it is necessary to calculate the need for strong piles and foundations is the most important thing [3]. In the lower structure, the meeting point between the pile and the pile cap is the most vulnerable point. It is said to be a vulnerable point because it withstands the maximum horizontal deflection and large moment forces. The interaction that occurs in the pile foundation and soil as elements and parts that withstand horizontal loads and moments. The problems that often arise during erection include: the movement of
soil around the foundation, pile damage, termination of driving and selection of tools for pile driving [4].

In this research, a hotel building is used as a case study. The building consists of 12 floors, of which there are 11 building floors and 1 roof floor. This project is in the hard soil category. It can be seen from the results of the SPT test at the project site that the value is between 15 and more than 50. Therefore, this project has a strong seismic risk level and is calculated with the Reinforced Concrete Special Moment Resisting Frame. In the project, placement modelling was carried out directly or separately. Evaluation of foundation planning using spun pile-shaped piles with a diameter of 600 mm against earthquake loads that occur with the calculation of bearing capacity and pile requirements using the Nakazawa method. As for the structural modelling analysis using the SAP 2000 V14.2.5 auxiliary program using Reinforced Concrete Special Moment Resisting Frame (SPRMK) which refers to SNI 1726:2019 and SNI 2847:2013, where this system uses the Strong Column-Weak Beam principle which is used for building structure calculations in seismic design category D, E or F. The pile foundation serves to transmit the load from the superstructure to the subsoil. Several calculation methods can be used to calculate the bearing capacity of a pile, one of which is the Nakazawa method. The Nakazawa method is adapted from a calculation in Japan which is very relevant to its use for soft soils[5][6]. The expected result is that the superstructure behaves ductile and has a large deviation to accept strong earthquake loads, and gets a more effective model to withstand earthquakes from the two models that have been analyzed.

2. Literature Review
Calculation of dimensions and building materials is based on existing data. The following is the formula for calculating the dimensions of the main structure based on SNI 2847:2013 [7].

1. Main Beam
   
   \[ h_{min} = \frac{L}{16} \quad \text{(for } f_y = 420 \text{ Mpa}) \] .................................(1)
   
   \[ h_{min} = \frac{L}{16} \left( 0,4 + \frac{f_y}{700} \right) \quad \text{(for } f_y \neq 420 \text{ Mpa}) \] .................................(2)

2. Supported beam
   
   \[ h_{min} = \frac{L}{21} \quad \text{(for } f_y = 420 \text{ Mpa}) \] .................................(3)
   
   \[ h_{min} = \frac{L}{21} \left( 0,4 + \frac{f_y}{700} \right) \quad \text{(for } f_y \neq 420 \text{ Mpa}) \] .................................(4)

3. Column
   
   Shortest side cross section of column (a): \[ a \geq 300 \text{ mm} \] .................................(5)
   
   Longest side cross section of column (b): \[ \frac{d}{b} \geq 0,4 \] .................................(6)

4. Plate
   
   One way \[ \frac{L_y}{L_x} > 2,5 \] .................................(7)
   
   With the minimum thickness formula:
   
   \[ h_{min} = \frac{L}{28} \quad \text{(for } f_y = 420 \text{ Mpa}) \] .................................(8)
   
   \[ h_{min} = \frac{L}{28} \left( 0,4 + \frac{f_y}{700} \right) \quad \text{(for } f_y \neq 420 \text{ Mpa}) \] .................................(9)

   Two ways \[ \frac{L_y}{L_x} \leq 2,5 \] .................................(10)
   
   With the minimum thickness formula:
   
   For \( \alpha_{min} \leq 0,2 \) is using Table 1 as seen below.
Table 1. Minimum thickness of slab without interior beam

| Yield Stress, fy (Mpa) | Without thickening | With thickening |
|------------------------|--------------------|----------------|
|                        | Exterior panels    | Interior panels| Exterior panels | Interior panels |
|                        | Without side beam  | With side beam  | Without side beam | With side beam  |
| 280                    | ln/33              | ln/36          | ln/36            | ln/40          | ln/40          |
| 420                    | ln/30              | ln/33          | ln/33            | ln/330         | ln/36          |
| 520                    | ln/28              | ln/31          | ln/31            | ln/34          | ln/34          |

Source: SNI 2847:2013

For $0.2 < \alpha_{fm} < 2.0$ is using the following formula.

$$h = \ln \left( \frac{0.8 + \frac{f_y}{1400}}{36 + 5\beta (\alpha_{fm} - 0.2)} \right)$$

and should not be less than 125 mm.

For $\alpha_{fm} > 2.0$ is using the following formula.

$$h = \ln \left( \frac{0.8 + \frac{f_y}{1400}}{36 + 9\beta} \right)$$

and should not be less than 90 mm.

Then the calculation of the load on the structure includes dead load and live load referring to SNI 1727:2013 [8]. As for the calculation of the earthquake load refers to SNI 1726:2019 [9]. From the results of the soil investigation test with the SPT test, the NSPT value data was obtained. Calculation of the static bearing capacity of the foundation based on the Nakazawa formula is as follows: [10]

$$R_u = R_P + R_F$$

$$R_u = q_d A + U \Sigma l_i f_i$$

Where:
- $R_u$: ultimate bearing capacity (ton)
- $R_P$: end bearing capacity (ton)
- $R_F$: friction bearing capacity (ton)
- $q_d$: pile bearing capacity per unit area; $N_1 = \frac{N_1 + N_2}{2}$
- $N_1$: the value of N at the end of the pile
- $N_2$: the value of N average 4D from the end of the pile
- $U$: Perimeter of the cross-section of the pole (m$^2$); $U = \pi D$
- $l_i$: pile length per section (m)
- $f_i$: intensity of pile wall shear force (t/m$^2$)

The value of the pile bearing capacity per unit area ($q_d$) can be calculated based on the figure below.
Meanwhile, the value of the shear strength of the pile wall \( (f_i) \) is adjusted based on the type of foundation soil and the type of pile used as shown in the following table.

**Table 2. Intensity of Pile Wall Shear Force \( (f_i) \)**

| Type of soil on foundation | Precast pile \( (t/m^2) \) | Cast in-situ pile \( (t/m^2) \) |
|----------------------------|----------------------------|-------------------------------|
| Non-cohesive soil          | \( \frac{N}{5} \) (\( \leq 10 \)) | \( \frac{N}{2} \) (\( \leq 12 \)) |
| Cohesive soil              | \( c \) or \( N \) (\( \leq 12 \)) | \( \frac{c}{2} \) or \( \frac{N}{2} \) (\( \leq 12 \)) |

To calculate allowable bearing capacity of single pile, thus the result of ultimate bearing capacity is compared with the safety factor:

\[
R_a = \frac{R_u}{n}
\] ................................. (17)

where \( n \) which is the minimum safety factor value for deep foundations is 2.5 according to [11] clause 9.3.2.1.

At the foundation design, it is also necessary to calculate the pile efficiency based on Converse-Labarre:

\[
E_g = 1 - \theta \left( \frac{(n'-1)m+(m-1)n'}{90mn} \right)
\] ................................. (18)

where:
- \( E_g \) : Pile group efficiency
- \( \theta \) : arc tan \( d/s \) (°)
- \( n' \) : number of piles in one row
- \( m \) : number of pile lines
- \( s \) : distance from center to center of pile (m)
- \( d \) : pile diameter (m)

Then calculate the maximum load value received by 1 pile in the pile group with the formula:
\[ P_{\text{max}} = \frac{P}{n} \pm \frac{M_y X_i}{n \Sigma x^2} \pm \frac{M_x Y_i}{n \Sigma y^2} \] (19)

with:
- \( P_{\text{max}} \): The load carried by single pile (ton)
- \( P \): Total vertical load (ton)
- \( n \): Number of piles
- \( M_x \): Moment works on pile group x axis (tm)
- \( M_y \): Moment works on pile group y axis (tm)
- \( X_i \): Pile distance to center of gravity x direction (m)
- \( Y_i \): Pile distance to center of gravity y direction (m)
- \( \Sigma x^2 \): The pile distance square in the x direction (m²)
- \( \Sigma y^2 \): The pile distance square in the y direction (m²)

Furthermore, in modelling with direct placement using springs, a spring coefficient value is needed which can be calculated by the Nakazawa formula as follows:

The value of the coefficient of the vertical direction, \( K_v = a \cdot \frac{A_p \cdot E_p}{L} \) ......... (20)

The value of the coefficient of the horizontal direction, \( k_h = k_0 \cdot y^{-1/2} \) ............. (21)

With the value of \( k_0 \): \( k_0 = 0.2 \cdot E_0 \cdot D^{-3/4} \) ................. (22)

In analyzing the behavior and reaction of the structure, then the calculation of structural behavior control based on SNI 1726:2019 is carried out as follows:

a. Deviation Value Control (Drift)
   Based on guidelines [9] Clause 7.8.6, the drift control value is as follows.
   \[ \delta x = \frac{C_d \delta x}{l_e} < \Delta a \] (23)

b. Mass Participation Value Control
   Based on guidelines [9] Clause 7.9.1.1, the value of mass participation control is as follows.
   Mass participation = 100% structural mass (24)

c. Period Control
   Based on guidelines [9] Clause 7.8.2, period control values are as follows.
   \[ T < T_a \cdot C_u \] (25)

d. Dynamic Static Control
   Based on guidelines [9] Clause 7.9.1.1, period control values are as follows.
   \[ V_{\text{dynamic}} \geq 100\% \cdot V_{\text{static}} \] (26)

3. Method
The method used in calculating the comparison of building structures with and without direct foundation modelling on the special moment-bearing frame building system are:

1. Collection of literature studies and previous research.
2. Secondary data collection includes building data, soil data and pile pile brochures.
3. The calculation of the dimensions of the main structure refers to SNI 2847:2013 [7] and calculation of loading referring to SNI 1726:2019 [9].
4. Determination of soil class analysis.
5. Modelling the structure of the SRPMK system with clamps on SAP2000 V14.2.5 and controlling the behavior and reaction of the structure.
6. Calculation of pile bearing capacity based on soil data processing with dimensions of 60 cm class B and calculating the minimum number of piles required for pin placement. Then the spring coefficient is also calculated. Bearing capacity and spring coefficient are calculated by the Nakazawa method.
7. Modelling the structure of the SRPMK system by placing it directly on SAP2000 V14.2.5 and controlling the behavior and reaction of the structure.
8. Comparison of the behavior and reaction of the structure as well as the minimum number of piles required in both models.

4. Result

The first step is to determine the dimensions and calculate the loading according to SNI 1727:2013 [8] and SNI 2847:2013 [7]. For the dimensions itself, it is adjusted to the existing data and the dimensions of beams, columns and plates are obtained as follows:

| Code | Length netto (Lb) | \( h_{\text{min}} \) | \( H_{\text{use}} \) | B | \( B_{\text{use}} \) | Dimension |
|------|------------------|-----------------|-----------------|---|-----------------|-----------|
|      | (mm)             | (mm)            | (mm)            |   | (mm)            |           |
| BD1  | 7000             | 425             | 850             | 650/850 |
| B1   | 7000             | 425             | 800             | 600/800 |
| B4   | 2700             | 163,93          | 450             | 350/450 |
| BA1  | 6000             | 364,29          | 700             | 500/700 |
| BA3  | 7000             | 425             | 600             | 400/600 |

| Code | Length netto (Lb) | \( h_{\text{min}} \) | \( H_{\text{use}} \) | B | \( B_{\text{use}} \) | Dimension |
|------|------------------|-----------------|-----------------|---|-----------------|-----------|
|      | (mm)             | (mm)            | (mm)            |   | (mm)            |           |
| BD2  | 7000             | 323,81          | 750             | 550/750 |
| BD3  | 3100             | 143,40          | 550             | 450/550 |
| B2   | 7000             | 323,81          | 700             | 500/700 |
| B3   | 3100             | 188,21          | 600             | 400/600 |
| B5   | 3100             | 143,40          | 350             | 225/350 |
| BA2  | 7000             | 323,81          | 650             | 300/400 |
| BA4  | 3100             | 143,40          | 400             | 266,667 |

| Code | Dimension (mm) | \( f'_c \) (Mpa) |
|------|----------------|-----------------|
| K1A  | 600/600        | 40              |
| K1B  | 900/900        | 40              |
| K1C  | 900/900        | 35              |
| K1D  | 900/900        | 30              |
| K2A  | 750/900        | 40              |
| K2B  | 750/900        | 35              |
| K2C  | 750/900        | 30              |
| K3A  | 800/800        | 40              |
| K3B  | 800/800        | 35              |
| K3C  | 800/800        | 30              |

Recapitulation of plate dimensions:

- Floor Plate 1 = 200 mm
- 2nd Floor Slab - roof floor / deck = 120 mm

From the dimensions and loadings obtained, these data are included in model 1, namely the modelling of the fixed joint with the SAP2000 V14.2.5 software for analysis. In the modelling
process, earthquake loads are modeled according to the SD soil site class classification and the results of manual calculation of response spectrum with SRPMK coefficient values of R=8, Cd=5.5 and $\Omega_0=3$. For office buildings with risk category II, the value of the earthquake priority factor is $I_e = 1.0$. Based on the components obtained in the earthquake load, the spectrum response diagram obtained from processing the NSPT value of soil data is as follows.

The Relationship between Period Value and Acceleration Response Spectrum

![Graph of Floor Drift per Floor](image1)

![Graph of Total Drift](image2)

**Figure 2.** Hard Soil Acceleration Response Spectrum

Then the running process is carried out to obtain an analysis of the behavior of the building structure. After the process of running the behavior and reaction of the structure in modelling 1 (fixed joint) is carried out, the total value of the building weight with a combined loading of 1.2DL+1.6LL is 24995213.78 kg. Meanwhile, the drift control results are presented in the following figure.

**Figure 3.** Graph of Drift for X-Y Direction
For the mass participation value, the value reaches 100% of the structural mass in the mode or the number of variations is 35 with the Sum UX and Sum UY values = 1.0. The period value is obtained in mode 1 = 1.982 s < Ta max = 2.086 s. Furthermore, for dynamic static control with a magnification of SFx = 1.8541 and Sfy = 1.7633, the value of VD ≥ 100% Vs is fulfilled.

Based on the internal forces that work in terms of axial forces and moments, the soil bearing capacity and minimum pile requirements are calculated. For the calculation of soil bearing capacity, it is planned at a depth of 21 m with pile dimensions of 60 cm class B. With a minimum SF value of 2.5, the allowable bearing capacity value is Ra=188.895 tons. Referring to the results of the axial force output at each joint, the total minimum pile requirement is 185 piles.

Then, the next stage is to conduct the second model by replacing the fixed joint with spring modelling directly on SAP2000 V14.2.5. In the same way, trial and error was carried out with three modelling; first model (160 piles), second model (168 piles) and third model (176 piles). Based on the specification data for pile diameter 60 cm class B, it shows the allowable axial capacity value = 238.3 ton and the allowable moment capacity value = 45 ton-m. From these data, the following diagram shows the results of the three modelling of the number of piles.

![Comparison Graph of Axial Value and Moment of Pile Modelling](image)

**Figure 4.** Comparison Graph of Axial Value and Moment of Pile Modelling

From the Figure 4, it shows that in the third model with 176 piles, the pile meets the allowable axial capacity and the allowable moment capacity. So that in direct modelling, the minimum number of piles is 176 piles. Then with the number of 176 piles, the analysis process continues on the behavior and reaction of the structure is the same as in previous modelling with the results for drift control, which are presented in the Figure 5.

![Graph of Drift for X-Y Direction](image)

**Figure 5.** Graph of Drift for X-Y Direction
The drift control value according to the figure above shows that the drift that occurs in the X and Y directions does not exceed the allowable deviation of 100 mm. For the mass participation value, the value reaches 100% of the structural mass in the mode or the number of variations is 35 with the Sum UX and Sum UY values = 1.0. The period value is obtained in mode 1 = 7.146 s > Ta max = 2.086 s so it is not OK. Furthermore, for dynamic static control with a magnification of SFx = 2.0289 and Sfy = 1.9297 then the value of V₃ ≥100% Vₛ is fulfilled.

From the two bearing models, the comparison of behavior, reaction and also the minimum number of piles required is as follows:

a. Deviation Control Comparison (Drift)

![Comparison of Drift per Floor](image1)

| Floor  | Drift (mm) | x-direction | y-direction | Total Drift |
|--------|------------|-------------|-------------|-------------|
| 1      | 10         | x fixed joint | y fixed joint | 13 |
| 2      | 10         | x fixed joint | y fixed joint | 13 |
| 3      | 10         | x fixed joint | y fixed joint | 13 |
| 4      | 10         | x fixed joint | y fixed joint | 13 |
| 5      | 10         | x fixed joint | y fixed joint | 13 |
| 6      | 10         | x fixed joint | y fixed joint | 13 |

![Comparison of Deviation](image2)

From the figure 6, it can be seen that the value of the deviation between floors in the X and Y directions and the total deviation value in the fixed joint modelling is smaller than the spring modelling. This is because the fixed joint placement is stiffer than the spring bearing which is more flexible and interacts with the ground so that it can deform laterally when exposed to earthquake loads due to deformation of the lower structure.

b. Comparison of Period Control and Mass Participation

![Comparison of Period](image3)

From the figure 7, it can be seen that the value of the period of the structure in the fixed joint is 7.146 s, while in the spring mode it is 2.086 s. This shows that the fixed joint is more rigid than the spring bearing.
From the figure 7, it can be seen that the period value of the fixed joint modelling is smaller than the period in the spring modelling and is still below the required maximum period limit. Meanwhile, the period value in spring modelling far exceeds the maximum required period. This phenomena is due to the stiffer the structure, the smaller the value of the vibration period that occurs. For mass participation control, it is found that both models both reach 100% of the mass of the structure at a variance of 35.

c. Dynamic Static Control Comparison

![Comparison of Static Dynamic Value](image)

**Figure 8.** Dynamic Static Value Comparison Graph

From the figure 8, it can be concluded that the static and dynamic shear forces that occur in the fixed joint modelling are smaller than the dynamic static shear forces in the spring modelling.

d. Internal Force Output Comparison

In this comparison of the outputs of internal forces, an example is taken of the forces in Beam B1. It was found that the value of axial force, torsion force, shear force and moment force in fixed joint bearing modelling is smaller than in direct foundation and spring modelling.

![Comparison Diagram of Shear Force and Moment Force of Beam B1](image)

**Figure 9.** Comparison Diagram of Shear Force and Moment Force of Beam B1
e. Comparison of the Minimum Number of Pile Needs

![Pile Needs Comparison Chart](image)

**Figure 10. Pile Needs Comparison Chart**

In contrast to the results of the comparison of behavior control and structural reactions, the number of pile needs for fixed joint modelling requires more than the demand for piles of direct foundation and spring modelling. This happens because the calculation of the number of piles in fixed joint modelling refers to each joint so that it uses a large factor value compared to spring modelling which uses 1 large pile cap.

5. Conclusion

Based on the results of the research data analysis that has been carried out, conclusions can be drawn including:

1. Structural behavior in fixed joint modelling including drift control, period, mass participation and dynamic static meet the requirements.
2. Structural behavior in spring modelling which includes drift control, mass participation and dynamic statics meets the requirements. Then for the control period with $T_c = 7.146$ s > $T_a_{max} = 2.086$ s, it does not meet the requirements and it is not possible to enlarge the dimensions of the structure, because it must be equated with the dimensions of the fixed joint modelling for comparison.
3. Comparison of the behavior and reaction of the structure shows that the stiffer the structure, the behavior and reactions which include displacement control, period control, dynamic static control and internal forces acting on fixed joint bearing modelling show a smaller value than in foundation modelling and springs directly. Meanwhile, the control value for mass participation shows the same value.
4. From the calculation analysis results, the number of piles in the fixed joint modelling is 185 piles with the pile calculation method at each joint. While the number of piles in the spring modelling obtained a number of 176 piles with the pile calculation method with 1 pile cap covering all joints. So it can be concluded that the need for piles in fixed joint modelling requires more piles than of spring modelling.

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