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Haunch Beams Behavior and Performance in High-Rise Buildings with Spectrum and Pushover Response

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Abstract: Indonesia is located in an active tectonic zone with high seismic potential, so that high-rise building structures are very vulnerable to earthquake loads. One alternative to improve structural performance is the use of haunch beams, a non-prismatic beam model with varying stiffness in length. This study examines the effectiveness of haunch beams in improving the seismic performance of the SRPMK system, a 60 m high building without shear walls and with varying column dimensions along the building height. Prismatic beams (50/35) and haunch beams (100/35) with varying lengths of 1/5L, 1/4L, and 1/3L were used in the beam-column connection. The analysis was carried out using the response spectrum method and the nonlinear static pushover method. The results of the pushover analysis study, with the 1/3L haunch beam configuration, provided better structural performance in controlling drift and displacement, especially in high-rise buildings with columns that taper upwards. The nonlinear static procedure method (pushover) showed that the 1/3L haunch beam variant showed the most effective performance. Pushover X, displacement 0.384 m, base shear 18813.17 kN, drift 1.24% ≤ 2%, category IO-LS range, pushover Y, displacement 0.271 m, base shear 18343.3 kN, drift 0.83% ≤ 1%, limit category IO. Smaller drift values indicate increased stiffness of the frame system. B-Haunch 1/3 L provides better structural performance in controlling drift and displacement, especially in tall buildings with columns that taper upwards. Smaller drift values indicate increased stiffness of the frame system. The addition of shear walls later will increase stiffness, making the building structure safer in resisting lateral loads.

Keywords: Haunch Beam; Lateral load resistance; Inter-Story Drift; Response Spectrum; Pushover

1. Introduction

The Indonesia lies at the convergence of four major tectonic plates the Indo-Australian, Eurasian, Pacific, and Philippine plates making it one of the world's most seismically active regions [1][2]. This geographical condition exposes buildings to high seismic risks, where improper structural planning may lead to collapse and casualties. Earthquake loads are highly irregular and random in duration, causing both vertical and lateral displacements in structures [3]. The dynamic response of a structure depends on three main elements: mass, stiffness, and damping. Increased seismic intensity leads to nonlinear inelastic soil and structural responses, requiring accurate modeling to evaluate structural safety [4].

The use of haunch beams over prismatic beams is carried out as a more effective beam modeling alternative to obtain a stiffer and more effective structure capable of withstanding the lateral loads that occur, by eliminating the calculation of shear walls. In earthquake-resistant design, the principle of strong-column weak-beam is essential, with beam stiffness contributing to column stability. Large inter-story drifts may induce plastic hinges in beams, while column or beam damage can significantly reduce structural strength [5][6][7]. To enhance lateral resistance, modifications such as haunch beams non-prismatic members with variable stiffness are employed at beam-column joints [8][9][10]. Compared to prismatic beams, haunch beams offer better efficiency in reducing deflection and optimizing material use [11][12][13].

Seismic design methodologies include equivalent static analysis, response spectrum analysis, and time history analysis, each providing simplified approaches to evaluate earthquake effects on building response [14][15]. This study focuses on the effectiveness of haunch beams in reinforced concrete structures without shear walls, using response spectrum and time history analyses to assess their role in resisting lateral loads.conditions.

2. Research Method

2.1. Research location

The structural model in this study was designed for a reinforced concrete building located in Yogyakarta, Indonesia, which is categorized as a medium soil site (Site Class SD). Yogyakarta is one of the regions most exposed to seismic hazards due to its proximity to the Indo-Australian and Eurasian subduction zone. To represent seismic loading, the study employed secondary data consisting of response spectrum and time history records from major international earthquakes with magnitudes comparable to the seismic hazard in Yogyakarta. The selected ground motion data were scaled to match the target design spectrum for the site, ensuring that the structural analysis realistically reflected local seismic conditions.

2.2. Building Technical Data

The structure is designed with reinforced concrete, where the strength of the material refers to the requirements for earthquake-resistant structures. The technical data of the designed building are summarized in Table 1.

Table 1. Building Technical Data

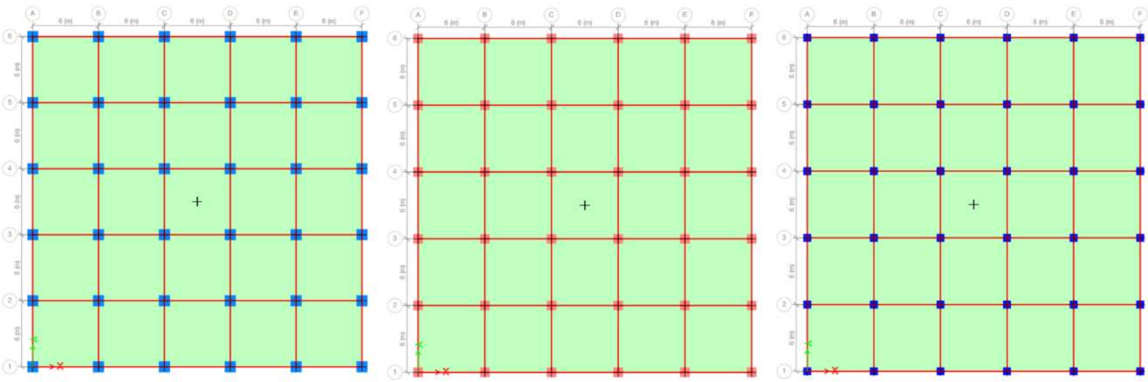
Parameter	Specification
Building type	High-rise reinforced concrete building
Total area	13,500 m²
Height	60 m (15 stories, 4 m each)
Structural system	Special Moment Resisting Frame (SMRF)
Column K1 (1st–5th floor)	100 × 100 cm, f'_c = 40 MPa
Column K2 (6th–10th floor)	85 × 85 cm, f'_c = 40 MPa
Column K3 (11th–15th floor)	70 × 70 cm, f'_c = 40 MPa
Beam (prismatic)	50 × 35 cm, f'_c = 35 MPa
Beam (haunch)	100 × 35 cm, f'_c = 35 MPa
Slab	Reinforced concrete, f'_c = 35 MPa
Reinforcing steel	f_y = 400 MPa

2.3. Structural Modeling

The structural analysis was carried out using software, which is widely recognized for the modeling and analysis of high-rise reinforced concrete structures. The software was selected because of its ability to simulate complex structural behavior under dynamic loading, including modal response spectrum and nonlinear time history analysis. In this study, a 60-meter-high reinforced concrete building was modeled with 15 stories and a 6-meter span between columns. The structural system adopted was a Special Moment Resisting Frame (SMRF), designed according to earthquake-resistant design standards (SNI 1726:2019 and SNI 2847:2019). The modeling process included:

1. Geometry Modeling defining column and beam dimensions based on technical building data. Columns were designed with varying dimensions (1000×1000 mm, 850×850 mm, and 700×700 mm depending on the floor level), while beams consisted of prismatic sections (500×350 mm) and haunch beams (1000×350 mm). The floor slabs were modeled as rigid diaphragms to distribute lateral loads.
2. Material Properties input values for reinforced concrete compressive strength were f'_c = 40 MPa (columns) and f'_c = 35 MPa (beams and slabs), with reinforcing steel yield strength of f_y = 400 MPa.
3. The application of seismic loads using the Static Analysis and Dynamic Response Spectrum Analysis methods based on the target design spectrum scaled to Yogyakarta with medium soil conditions (Site Class SD).
4. Haunch Beam and Prismatic Beam Configurations, with beam variations modeled with haunch length variants of 1/3L, 1/4L, and 1/5L (where L = 6 m). Each configuration is analyzed to compare its effectiveness in reducing interstory shifts and increasing lateral stiffness.
5. Analysis generated results for modal analysis, inter-story drift, lateral displacement, and internal forces under static, response spectrum, and time history loadings. These outputs were compared to evaluate compliance with drift limits specified in seismic codes and to identify the most effective haunch beam configuration.

The structural model of the 15-story reinforced concrete building was developed to evaluate the seismic performance under different haunch beam configurations. The floor plan layout of the building, from the base level up to the 15th floor, is illustrated in Fig. 1.



Base,2,3,4,5 Floor | 7,8,9,10 Floor | 12,13,14,15 Floor

Fig. 1. Layout Base Floor – 15Th Floor

While the roof plan with a water tank load is presented in Fig. 2. These layouts provide the basic geometric representation of the structure, including column positions, beam spans, and the overall floor dimensions.

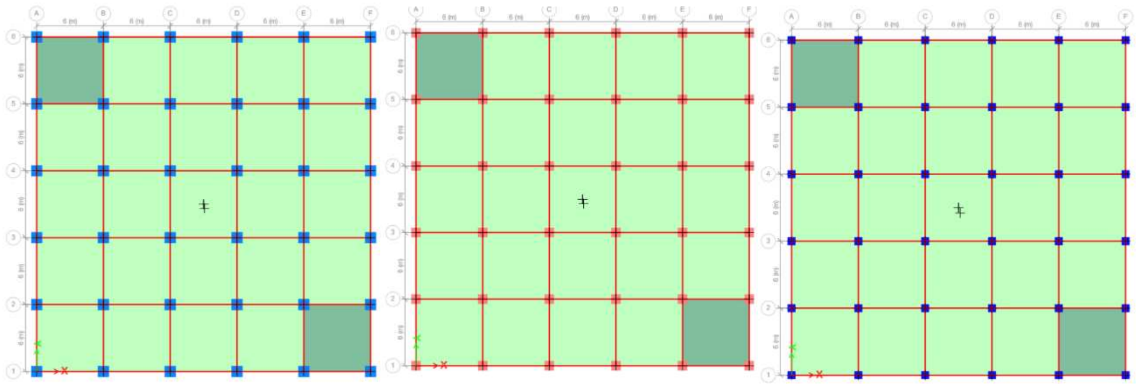


Fig. 2. Water Tower Floor Layout

To represent the research variable, a haunch beam configuration was introduced into the structural model. The haunch beam was modeled at the beam-column joints with varying lengths (1/3L, 1/4L, and 1/5L, of the total span). The schematic representation of the haunch beam geometry and its inclination angle relative to the prismatic beam is shown in Fig. 3. This configuration allowed systematic comparison of how different haunch lengths influenced structural stiffness and inter-story drift under seismic loading.

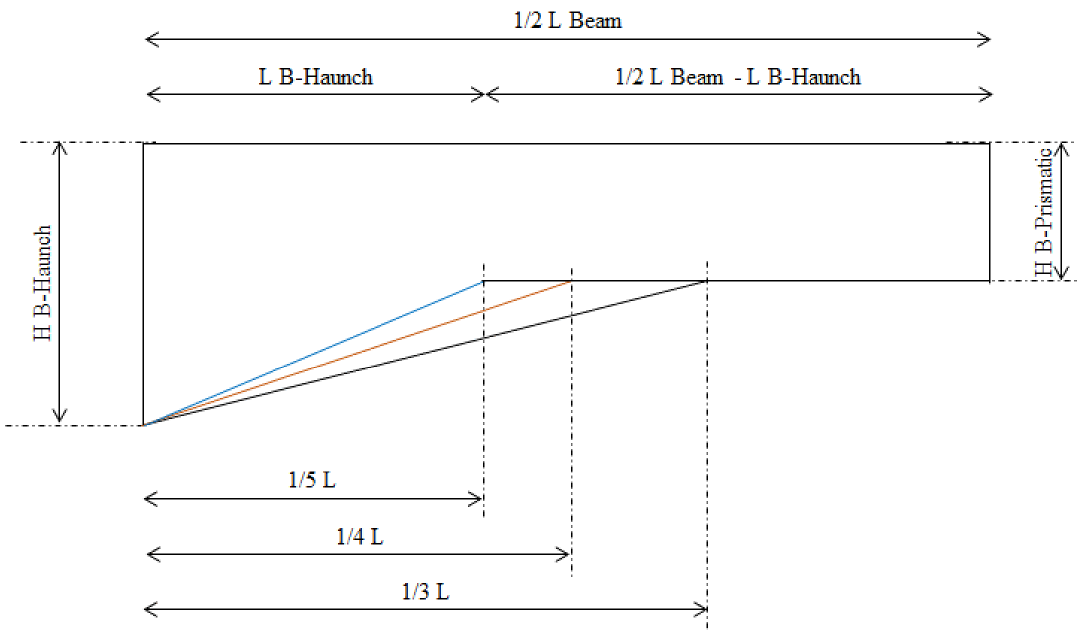


Fig. 3. Haunch Block Model Cut

3. Result and Discussion

3.1 Inter-Story Drift of Prismatic Beams (500/350)

The initial analysis was conducted on the building model using prismatic beams (500/350 mm) as the baseline reference. Several analysis methods were applied, including static analysis, response spectrum, and time history analysis, to evaluate inter-story drift performance.

a. Static Analysis (X-S, Y-S)

The inter-story drift response under static lateral loading indicated that significant displacements occurred from the 3rd to the 15th story, both in the X and Y directions. The maximum drift values exceeded the permissible limits, demonstrating that the prismatic beam configuration without haunch modification was insufficient to resist lateral loads effectively

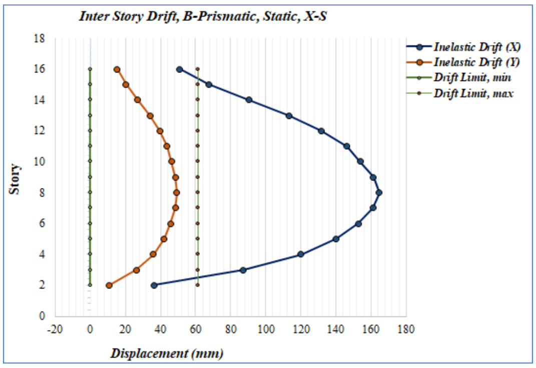


Fig. 4. Prismatic, Static, X-S

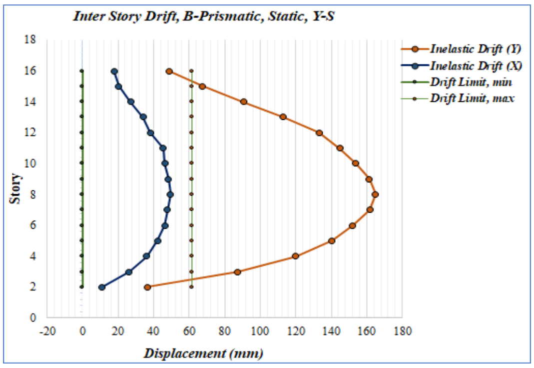


Fig. 5. Prismatic, Static, Y-S

b. Response Spectrum Analysis (X-D, Y-D)
   The dynamic analysis using response spectrum revealed that excessive drift occurred between the 3rd and 14th stories. Similar to the static model, the displacement exceeded the code requirements, confirming the inadequacy of the prismatic configuration under design-level earthquake loading

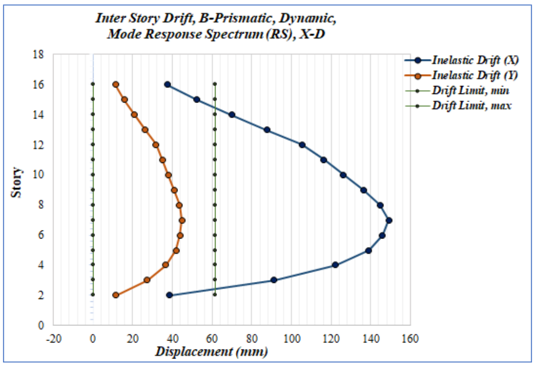


Fig. 6. B-Prismatic, RS, X-D

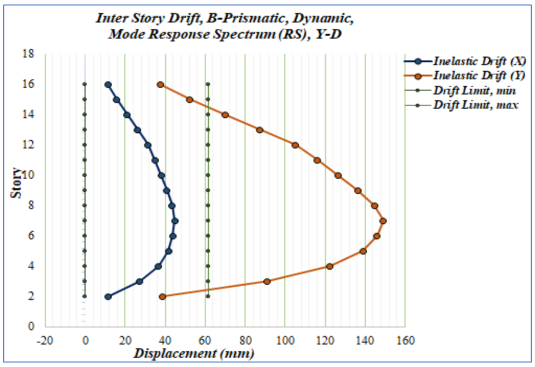


Fig. 7. B-Prismatic, RS, Y-D

Overall, the analysis of the prismatic beam configuration (50/35 cm) consistently showed that the building failed to satisfy the inter-story drift requirements across multiple analysis method

3.2 Inter-Story Drift of Haunch Beams (1000/350, 1/5L)

The next configuration applied haunch beams with dimensions 1000/350 mm and haunch length equal to 1/5 of the total beam span. This model was analyzed using static, response spectrum, and time history approaches.

a. Static Analysis (X-S, Y-S)
   The static analysis indicated that the 1/5L haunch configuration met the inter-story drift requirements in both the X and Y directions. Compared to the prismatic, this configuration provided better lateral stiffness at the lower and mid-level stories. The inter-story drift response under static lateral loading indicated that significant displacements occurred from the 6rd to the 9th story, both in the X and Y directions

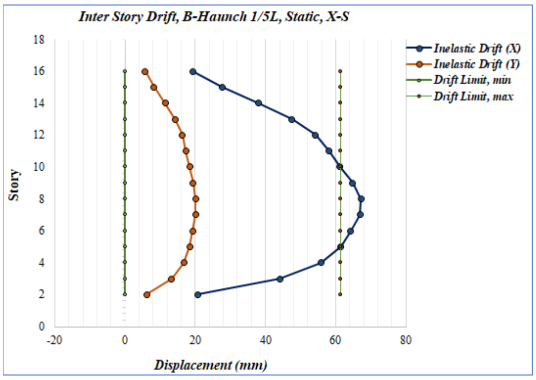


Fig. 8. B-Haunch 1/5 L, Static, X-S

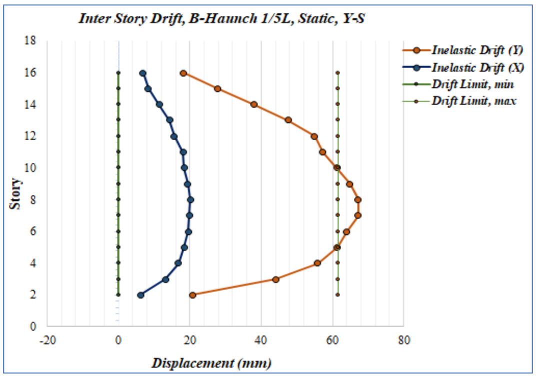


Fig. 9. B-Haunch 1/5 L, Static, Y-S

b. Response Spectrum Analysis (X-D, Y-D)
The response spectrum analysis confirmed that the drift limits were satisfied throughout the structure. Both X and Y directions showed controlled displacements, indicating that the 1/5L haunch provided sufficient stiffness under dynamic spectrum loading

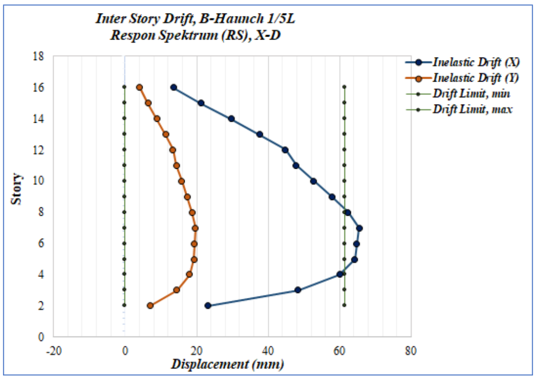


Fig. 10. B-Haunch 1/5 L, RS, X-D

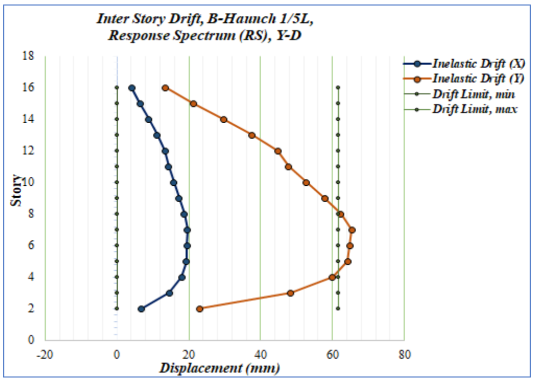


Fig. 11. B-Haunch 1/5 L, RS, Y-D

In conclusion, the 1/5L haunch beam model demonstrated significant improvement over the prismatic. The dynamic analysis using response spectrum revealed that excessive drift occurred between the 5rd and 8th stories While the model successfully satisfied drift requirements under static and response spectrum analysis, some upper stories still exhibited excessive drift in time history simulations, indicating partial effectiveness.

3.3 Inter-Story Drift of Haunch Beams (1000/350, 1/4L)

The fourth configuration employed haunch beams with dimensions 1000/350 mm and haunch length equal to 1/4 of the total beam span. This model was analyzed using static, response spectrum, and time history methods.

a. Static Analysis (X-S, Y-S)
The inter-story drift response under static lateral loading indicated minimum that displacements occurred from the 7th to 8th story, both in the X and Y directions This indicates that the 1/4L haunch configuration provided sufficient stiffness to control lateral displacement under static conditions

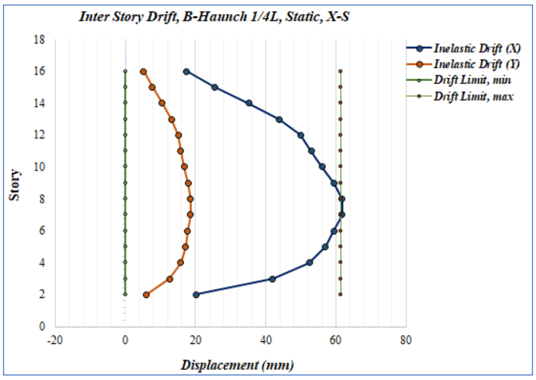


Fig. 12. B-Haunch 1/4 L, Static, X-S

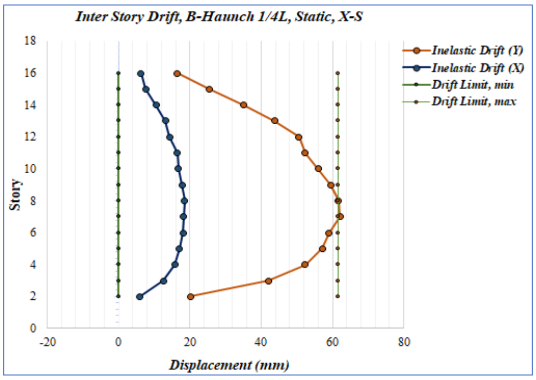


Fig. 13. B-Haunch 1/4 L, Static, Y-S

b. Response Spectrum Analysis (X-D, Y-D)
The response spectrum analysis further confirmed the effectiveness of this configuration. The results in both X and Y directions indicated that the drift remained within permissible limits across all stories, making the 1/4L haunch more reliable compared to previous models.

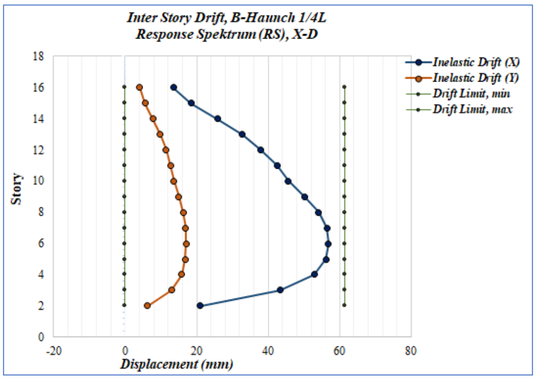


Fig. 14. B-Haunch 1/4 L, RS, X-D

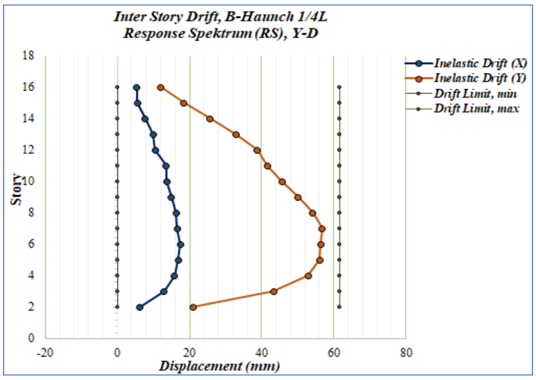


Fig. 15. B-Haunch 1/4 L, RS, Y-D

In summary, the 1/4L haunch beam configuration demonstrated the best overall performance among all variations. It consistently satisfied the inter-story drift requirements under static, response spectrum, and time history analyses, with only limited exceedances in the RS-matched model.

3.4 Inter-Story Drift of Haunch Beams (100/35, 1/3L)

The final configuration tested was haunch beams with dimensions 1000/350 mm and haunch length equal to 1/3 of the total beam span. This model was analyzed under static, response spectrum, and time history loadings.

a. Static Analysis (X-S, Y-S)
The static analysis showed that the inter-story drift requirements were satisfied in both X and Y directions. This indicates that the 1/3L haunch provided sufficient stiffness to control displacement under static seismic loading.

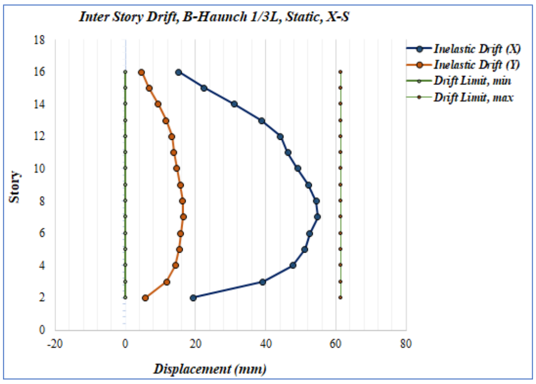


Fig. 16. B-Haunch 1/3 L, Static, X-S

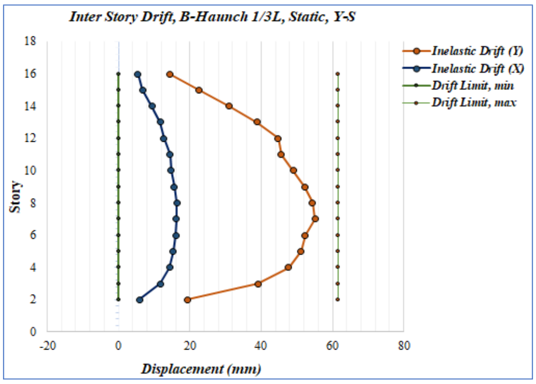


Fig. 17. B-Haunch 1/3 L, Static, Y-S

b. Response Spectrum, Dinamyc Analysis (X-D, Y-D)
Under response spectrum dinamic analysis, the drift values in both X and Y directions also met the allowable limits. The results suggest that the 1/3L haunch configuration is effective in enhancing lateral resistance under dynamic spectrum loading.

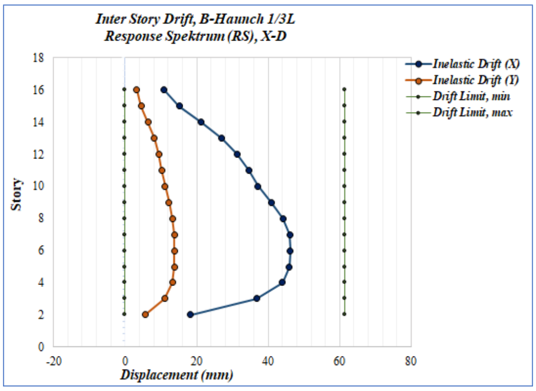


Fig. 18. B-Haunch 1/3 L, RS, X-D

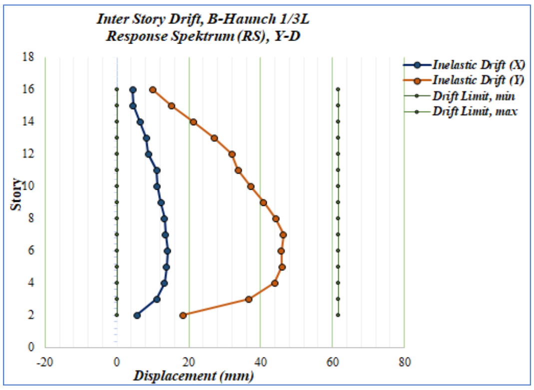


Fig. 19. B-Haunch 1/3 L, RS, Y-D

Overall, the 1/3L haunch configuration performed well under static and response spectrum analyses. The 1/3L model exhibited highlighting consistent performance, improve protect of seismic behavior optimally.

Table 2. Recapitulation of Inter-Story Drift Results

Beam Type	Static Analysis	Response Spectrum	Overall Performance
Prismatic (50/35)	Not satisfied (floors 3–15 exceeded limits)	Not satisfied (floors 3–14 exceeded limits)	Weak – high drift at multiple levels
Haunch 1/5L (100/35)	Not satisfied (floors 6–9 exceeded limits)	Not satisfied (floors 5–8 exceeded limits)	Good – better than 1/5L, still some upper-floor drift
Haunch 1/4L (100/35)	Enough satisfied (floors 7,8 exceeded limits)	Satisfied (X and Y directions)	Better than 1/5L, moderate, strong in spectrum
Haunch 1/3L (100/35)	Satisfied (X and Y directions)	Satisfied (X and Y directions)	Good – strong in static and spectrum,

3.5 Work Performance by Interstory Drift Ratio

The linear static pushover method provides a relatively simple yet effective approach to estimate the inelastic capacity of a building structure, especially regular buildings. Inter-story displacements are calculated and compared with performance limits. Immediate Occupancy (IO), Life Safety (LS), Collapse Prevention (CP).

Inter-story drift is calculated and compared against the following performance limits, Immediate Occupancy (IO), Life Safety (LS), Collapse Prevention (CP). The maximum drift value is evaluated against the recommended limits in FEMA 440, ASCE 41, or the Indonesian National Standards Agency (SNI) for earthquake resistance. Using interstory drift ratio to evaluate structural performance the general drift limit between floors.

Table 3. Interpretation Interstory Drift of Performance Criteria

Perfomance Level	Drift Limit (≈)
Immediate Occupancy (IO)	≤ 1%
Life Safety (LS)	≤ 2%
Collapse Prevention (CP)	≤ 4%

Table 4. Interstory Drift Ratio B-Haunch 1/4L

B-H 1/4 L		PUSHOVER-X					PUSHOVER-Y				
Story	Elevation (mm)	Displacement (mm)	Δ Relative (mm)	Drift (Ratio)	Drift (%)	Perfor-mance	Displace-ment (mm)	Δ Relative (mm)	Drift (Ratio)	Drift (Ratio)	Perfor mance
Roof	60	441.54	3.331	0.0008	0.08%	IO	313.78	3.2	0.0008	0.08%	IO
15	56	438.21	5.309	0.0013	0.13%	IO	310.58	5.13	0.0013	0.13%	IO
14	52	432.90	7.652	0.0019	0.19%	IO	305.45	7.392	0.0018	0.18%	IO
13	48	425.25	10.184	0.0025	0.25%	IO	298.06	9.782	0.0024	0.24%	IO
12	44	415.06	13.138	0.0033	0.33%	IO	288.28	12.379	0.0031	0.31%	IO
11	40	401.93	15.770	0.0039	0.39%	IO	275.9	14.255	0.0036	0.36%	IO
10	36	386.16	20.362	0.0051	0.51%	IO	261.64	17.648	0.0044	0.44%	IO
9	32	365.79	26.830	0.0067	0.67%	IO	244	22.502	0.0056	0.56%	IO
8	28	338.96	34.377	0.0086	0.86%	IO	221.49	28.033	0.0070	0.70%	IO
7	24	304.59	42.336	0.0106	1.06%	IO-LS	193.46	33.309	0.0083	0.83%	IO
6	20	262.25	48.083	0.0120	1.20%	IO-LS	160.15	36.157	0.0090	0.90%	IO
5	16	214.17	52.203	0.0131	1.31%	IO-LS	124	37.283	0.0093	0.93%	IO
4	12	161.96	55.156	0.0138	1.38%	IO-LS	86.712	36.066	0.0090	0.90%	IO
3	8	106.81	55.810	0.0140	1.40%	IO-LS	50.646	30.979	0.0077	0.77%	IO
2	4	51.00	50.998	0.0127	1.27%	IO-LS	19.667	19.667	0.0049	0.49%	IO
Base	0	0.00	0.000	0	0.00%	IO	313.78	3.2	0.0008	0.08%	IO

Criteria B-Haunch 1/4L, Push X, drift 1.40% ≤ 2%, max level story 3th, performance in range IO-LS category, displacement max 0.441 m, and base share 18653.79 kN (result as Shear vs Monitored Displacement ASCE 41-13 NSP). Need of damage control, meaning the structural elements are beginning to experience significant inelastic deformation. Push Y drift 0.93% ≤ 1%, max level story 5th, range IO category, displacement max 0.314 m, and base share 18160.24 kN (result as Shear vs Monitored Displacement, and ASCE 41-13 NSP). Need of damage control meaning the structural elements are beginning to experience significant inelastic deformation.

Table 5. Interstory Drift Ratio B-Haunch 1/3L

B-H 1/3 L		PUSHOVER-X					PUSHOVER-Y				
Story	Elevation m	Displacement (mm)	Δ Relative mm	Drift Ratio	Drift %	Displacement (mm)	Displacement (mm)	Δ Relative mm	Drift Ratio	Drift %	Performance
Roof	60	383.68	2.71	0.0007	0.07%	IO	270.62	2.61	0.0007	0.07%	IO
15	56	380.97	4.35	0.0011	0.11%	IO	268.02	4.21	0.0011	0.11%	IO
14	52	376.62	6.25	0.0016	0.16%	IO	263.80	6.05	0.0015	0.15%	IO
13	48	370.37	8.28	0.0021	0.21%	IO	257.75	7.98	0.0020	0.20%	IO
12	44	362.09	10.62	0.0027	0.27%	IO	249.77	10.06	0.0025	0.25%	IO
11	40	351.47	12.69	0.0032	0.32%	IO	239.71	11.49	0.0029	0.29%	IO
10	36	338.77	16.83	0.0042	0.42%	IO	228.22	14.61	0.0037	0.37%	IO
9	32	321.94	22.74	0.0057	0.57%	IO	213.61	19.19	0.0048	0.48%	IO
8	28	299.20	29.69	0.0074	0.74%	IO	194.42	24.42	0.0061	0.61%	IO
7	24	269.52	37.05	0.0093	0.93%	IO	170.00	29.42	0.0074	0.74%	IO
6	20	232.47	42.35	0.0106	1.06%	IO-LS	140.58	32.11	0.0080	0.80%	IO
5	16	190.12	46.25	0.0116	1.16%	IO-LS	108.48	33.22	0.0083	0.83%	IO
4	12	143.87	49.06	0.0123	1.23%	IO-LS	75.25	32.07	0.0080	0.80%	IO
3	8	94.82	49.67	0.0124	1.24%	IO-LS	43.18	27.11	0.0068	0.68%	IO
2	4	45.14	45.14	0.0113	1.13%	IO-LS	16.07	16.07	0.0040	0.40%	IO
Base	0	0.00	0.00	0.0000	0.00%	IO	0	0.00	0	0.00%	IO

Criteria B-Haunch 1/3L, Push X, drift 1,24% ≤ 2%, max level story 3th, performance in range IO-LS category, displacement max 0.384 m, and base share 18813.17 kN (result as Shear vs Monitored Displacement ASCE 41-13 NSP). Need of damage control, meaning the structural elements are beginning to experience significant inelastic deformation. Push Y drift 0,83% ≤ 1%, max level story 5th, range IO category, displacement max 0.271 m, and base share 18343.3 kN (result as Shear vs Monitored Displacement, and ASCE 41-13 NSP). The structure is slightly inelastic, need of damage control meaning with minimal structural damage, and the building can still be used immediately.

4. Conclusions

The use of haunch beams with special moment-resistant frame system modeling is one method to increase structural stiffness to improve the performance of resisting lateral loads of buildings, by eliminating the calculation of shear walls. This study uses variants, prismatic beams, haunch beams with 1/5 L, 1/4 L, and 1/3 L. By considering the SRPMK system method without shear walls, and variations in column dimensions along the height of the building, it is concluded that using static linear analysis and response spectrum analysis methods, prismatic beams and 1/5 L beams do not meet the drift requirements, while 1/4 L and 1/3 L haunch beams meet the shift requirements criteria.

To determine performance, testing using the nonlinear static procedure (pushover) method showed that the 1/3 L girder variant demonstrated the most effective performance (referring to ASCE 41-13) in the X pushover, with a maximum displacement of 0.468 m, a base shear of 20313 kN, and a maximum drift of 1,52% of the IO-LS range, and the Y pushover, with a maximum displacement of 0.358 m, a base shear of 21536 kN, and a maximum drift of 1.09% of the IO-LS range. The 1/3 L B-Haunch provides better structural performance in controlling drift and displacement, especially in tall buildings with columns that taper upward. A smaller drift value indicates increased frame system stiffness.

The 1/3 L B-H length is considered optimal because it increases the rotational stiffness of the connection, distributes bending stresses along the beam, reduces plastic hinge concentration, and improves the overall stability of the frame. In tall buildings without shear walls, increasing connection stiffness is crucial for controlling interstory drift and reducing top displacement. This is consistent with the analysis results which show that the 1/3 L haunch beam variation produces smaller drift and displacement than the 1/4 L haunch beam. The addition of shear walls then increases stiffness, making the building structure safer in resisting lateral loads.

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