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Static and Dynamic Response of Curved Concrete Frame Structures (Case Study: Jakarta International Stadium)

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Abstract

An ideally designed building should be symmetrical to mitigate eccentricities between the center of mass and the center of stiffness during seismic events. However, suppose a special design is intended to enhance the aesthetics and visual appeal of a building. In that case, it should still be engineered to perform well in static and dynamic behaviours. Jakarta International Stadium is an example of a building with a circular shape, irregular vertical geometry, and lacks expansion joints. This research investigated the static and dynamic behaviours of four structural models: the entire building without expansion joints (model ND) and the building with expansion joints (models D1, D2, and D3). The analysis included internal forces, mode shape analysis, structural displacements, inter-story drifts, and base shear forces. The analysis is conducted using the SAP2000 v22 software. The analysis results indicated that the models with expansion joints in Jakarta International Stadium generally exhibit several positive effects. These included reducing structural displacements, inter-story drifts, internal forces, and base shear forces. Furthermore, all modalities remain within the standard limits SNI 1726-2019 set.

Keywords: *Static load, dynamic behaviour, vertical irregularity, and dilation.*

INTRODUCTION

A stadium was a sports facility, with or without a roof, surrounded by seats for spectators, and used for events that required a large space, such as ceremonies, performances, large concerts, and others (Soratun, 2022). Jakarta International Stadium was a FIFA-standard stadium built with the first green building concept in Indonesia, featuring a retractable roof system (Wulandari, 2021).

An arch structure was formed by curved linear elements that spanned between two points, creating an arch. This structure generally consisted of small segments that maintained their positions due to applied loads (Ahmad, 2019). With its curved condition, the behavior of an arch structure differed from that of a straight structure. Seismic loads acting on buildings were typically considered perpendicular to the building's plan, often parallel to the portal. However, in the case of a curved plan, beams were not aligned with the seismic direction, causing the portals to be misaligned (Sudarsana et al., 2014).

One of the many impacts of earthquake disasters was damage to buildings. Earthquakes occurring on the earth's surface would shake the standing structures. One way to implement the design of a tall and elongated building to ensure its structural strength during earthquakes was by incorporating expansion joints into the structure. Implementing expansion joint systems was highly beneficial for elongated structures because the function of expansion joints could help prevent the domino effect of the seismic loads received. An expansion joint was a connection or separator in a structure intended to prevent cracks in the building caused by horizontal and vertical vibrations (Prabowo et al., 2018).

Jakarta International Stadium featured a circular-shaped building structure with a main building area of 140 thousand square meters and a height of 70 meters (Fajarta, 2021). Notably, the building does not incorporate dilatations. Therefore, an analysis of the static and dynamic behaviour of the curved concrete portal structure is essential. The analysis will cover structural displacements, story drifts, internal forces, and base shear forces for both the structure without dilatations and the structure with dilatations. Additionally, a compliance check with applicable regulations will be conducted.

RESEARCH METHOD

This research was conducted to analyze the static and dynamic response of structures with a circular shape and vertical structural irregularities, if given dilata and without expansion joints. The analysis will be carried out using SAP2000 software. The research stages are illustrated in Figure 1.

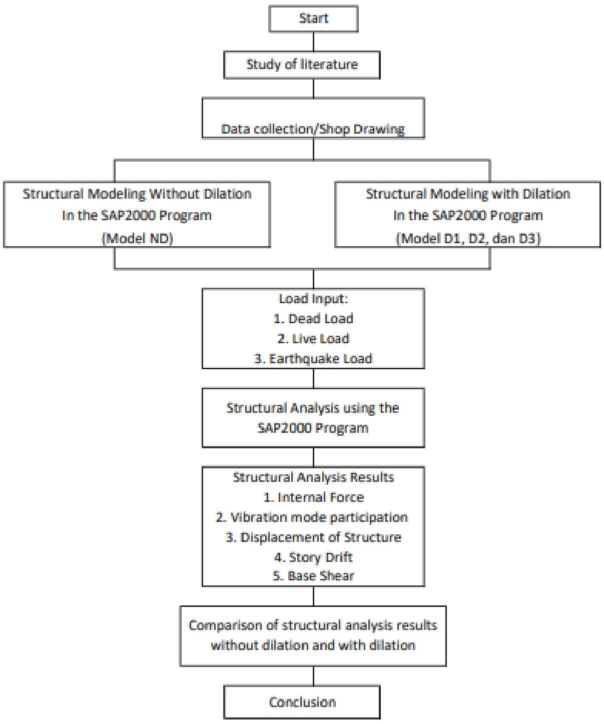

Figure 1. Research flowchart

The materials used will be in accordance with secondary data, namely :

- Concrete (fc') for Beams and Slabs = 35MPa
- Concrete (fc') for Columns = 45MPa
- Reinforcement Steel Quality = BJTS 52 & BJTS 42

The load used in the calculation and input is in per metric unit. In Table 1 bellow is the data for each load based on SNI 1727:2020 (Badan Standardisasi Nasional, 2020).

Table 1. Load data

Item	Definition	Referensi
Dead Load	The dead load is automatically alculated by the SAP2000 program	SNI 1727 :2020
Live Load	7,66 kN/m2	SNI 1727 :2020
Addition Dead Load	11,796 kN/m2	SNI 1727 :2020
Seismic Load	Using the Indonesian Spectra Design application http://rsa.ciptakarya.pu.go.id/2022/	SNI 1726 :2019

The structure will be modeled in 3D using AutoCAD software, before analyzed using the structural engineering application SAP2000 v22, creating four models : the non-dilatation model (ND) as show in Figure 2, and the dilatation model D1, model D2, and model D3 as show in Figure 3, 4 and 5.

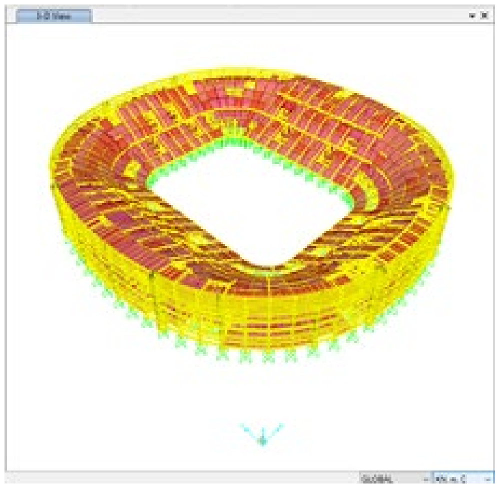

Figure 2. Structural Modeling of Model ND

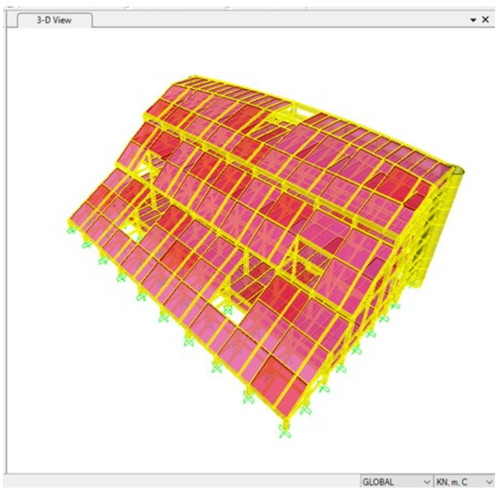

Figure 3. Structural Modeling of Model D1

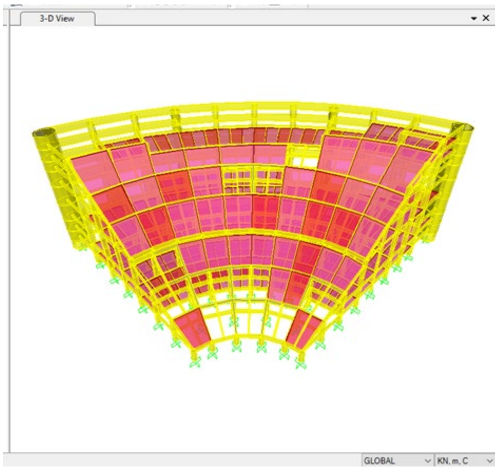

Figure 4. Structural Modeling of Model D2

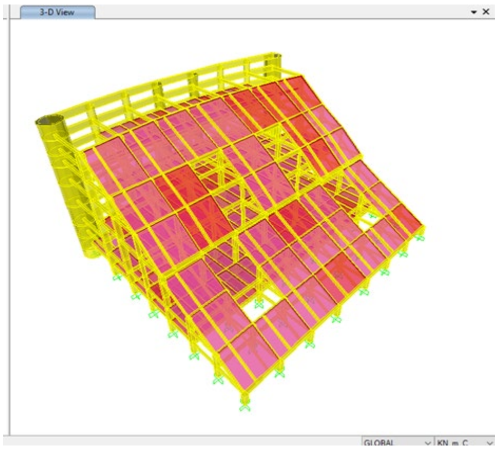

Figure 5. Structural Modeling of Model D3

RESULTS AND DISCUSSION

The internal Forces Due to Static Loads in stucture of stadium, can be seen in table 2 and Figure 6.

Table 2. Internal force of static loads

Internal Forces	Non dilation	Dilation		
	Model ND	Model D1	Model D2	Model D3
Shear *(kN)*	20,33	20,26	13,99	13,31
Momen *(kN m)*	53,93	53,48	37,99	37,33
Aksial *(ton)*	1657,8	1655,4	1344,7	1192,9

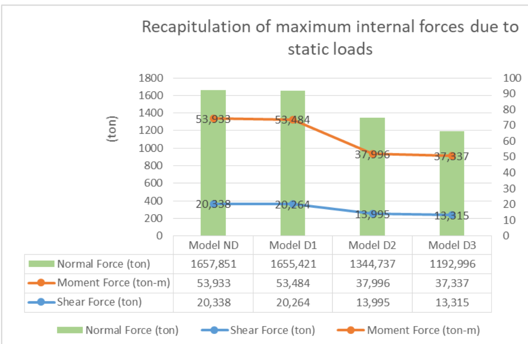

Figure 6. Internal force due to static load

The tabel 2 and figure 6 shows the conclusion that the internal force due to static loads shows that the dilatation in models D1, D2, and D3 have smaller internal forces compared to the non dilatation in the ND model. Internal forces that occur due to dynamic loads as show in table 3.

Table 3. Internal forcse of static loads

Internal Forces	Non dilation	Dilation		
	Model ND	Model D1	Model D2	Model D3
Shear *(kN)*	24,963	24,331	15,83	14,825
Momen *(kN m)*	57,293	57,266	46,519	42,004
Aksial *(ton)*	1731,6	1729,7	1423,3	1359,7

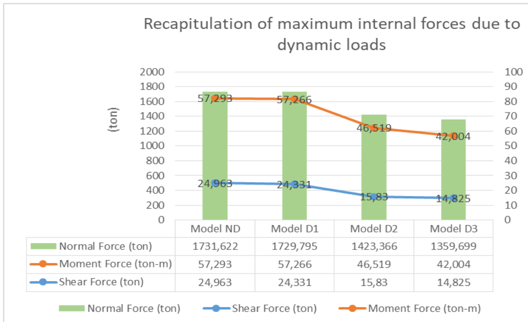

Figure 7. Internal force due to dynamic load

The table 3 and figure 7 shows the conclution that the effect of dilatations in models D1, D2, and D3 results some like static load there is smaller internal forces compared to the non-dilatation model ND.

Displacement of Structure Due to Static Load After conducting the analysis using SAP2000 v22,

The results of these calculations can be seen in Table 4 and Figure 8 for displacement in X direction static load and Table 5 and Figure 8 for displacement in X direction static load.

Table 4. Static Displacement in X direction

Floor	Displacement in X direction (mm)			
	Without diation	Dilation		
	Model ND	Model D1	Model D2	Model D3
Lt. 9	1,417	2,113	0,791	1,015
Lt. 8	1,727	2,341	0,827	1,082
Lt. 7	1,892	2,442	0,869	1,138
Lt. 6	1,959	2,579	0,846	1,116
Lt. 5	1,766	2,386	0,654	0,930
Lt. 4	0,941	1,246	0,404	0,544
Lt. 3m	0,286	0,366	0,197	0,241

Lt. 3	0,037	0,037	0,087	0,103
Lt. 2	0,003	0,003	0,017	0,022

Table 5. Static Displacement in Y direction

Floor	**Displacement in Y direction (mm)**			
	Without diation	Dilation		
	Model ND	Model D1	Model D2	Model D3
Lt. 9	0,565	0,698	0,413	0,451
Lt. 8	0,650	0,892	0,470	0,507
Lt. 7	0,807	1,075	0,524	0,605
Lt. 6	0,982	1,135	0,548	0,655
Lt. 5	0,729	0,985	0,386	0,454
Lt. 4	0,345	0,541	0,245	0,245
Lt. 3m	0,114	0,204	0,123	0,123
Lt. 3	0,056	0,059	0,056	0,056
Lt. 2	0,030	0,015	0,012	0,012

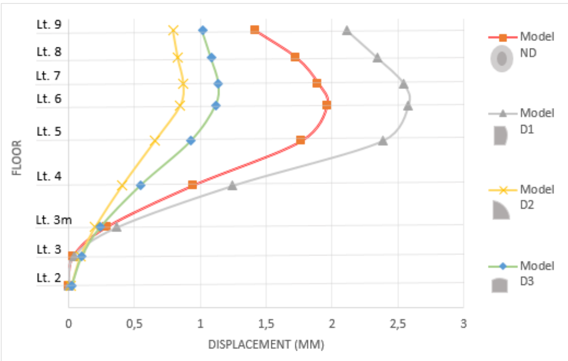

Figure 8. Static Displacement in X direction

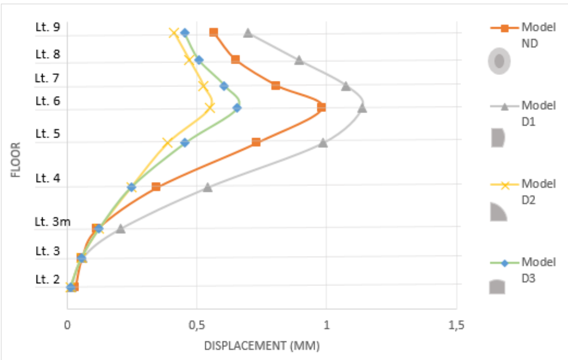

Figure 9. Static Displacement in Y direction

Figure 8 shows the displacement in the X direction due to static loads shows that the largest displacement occurs on fl-6 for each model, and the largest displacement occurs in model D3 and some condition for displacement in Y direction largest displacement occurs in model D3 show in Figure 9.

The result analisys for displacement of Structure of dynamic Load can be seen in Table 6 and Figure 10 for displacement in X direction dynamic load and Table 7 and Figure 11 for displacement in X direction dynamic load.

Table 6. Dynamic Displacement in X direction

Floor	**Displacement in X direction (mm)**			
	Without diation	Dilation		
	Model ND	Model D1	Model D2	Model D3
Lt. 9	39,024	33,456	27,171	21,373
Lt. 8	37,998	32,426	25,065	20,083
Lt. 7	36,323	30,834	22,937	18,528
Lt. 6	34,417	29,086	20,888	16,907
Lt. 5	31,039	26,099	17,159	13,801
Lt. 4	23,871	19,986	11,605	9,293
Lt. 3m	13,512	11,262	6,348	5,210
Lt. 3	6,467	5,379	3,137	2,847
Lt. 2	1,339	1,117	0,738	0,677

Table 7. Dynamic Displacement in Y direction

Floor	**Displacement in Y direction (mm)**			
	Without diation	Dilation		
	Model ND	Model D1	Model D2	Model D3
Lt. 9	31,087	38,797	17,624	18,536
Lt. 8	29,144	36,697	15,765	17,743
Lt. 7	27,064	34,062	14,018	17,190
Lt. 6	24,924	31,279	12,455	16,621
Lt. 5	20,774	25,469	9,888	15,154
Lt. 4	14,312	16,643	6,467	11,632
Lt. 3m	8,045	9,321	3,397	6,727
Lt. 3	4,086	5,301	1,636	3,343
Lt. 2	0,994	1,218	0,376	0,751

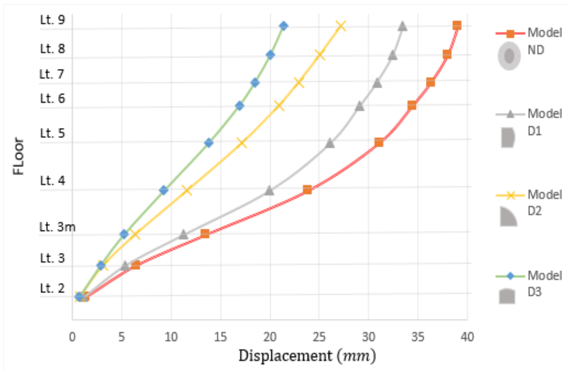

Figure 10. Dynamic displacement in X direction

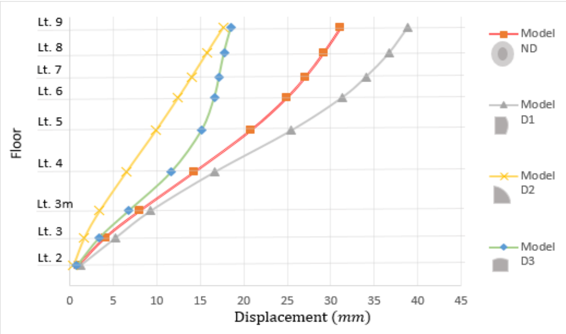

Figure 11. Dynamic displacement in Y direction

Table 6 and Figure 10 shows the compare displacements between the non-dilatation model ND and the dilatation in X directions models D1, D2, and D3, the largest displacement occurs in model ND wich is 39,024 mm and Table 7 and figure 11 shows the displacement in Y direction occurs in model D1 wich is displacement 38,797 mm.

The Story drift structure of dynamic loads accordance with SNI 1726:2019, the deviation limit (Δa) that applies to structures with risk category III is 0.020 hsx. In KDS D, the level deviation cannot exceed Δa/ρ, with ρ = 1.3. The results of these calculations can be seen in Table 8 and Figure 12 for a story drift in X direction dynamic load and Table 9 and Figure 13 for an story drift in X direction dynamic load :

Table 8. Story drift in X direction dynamic load

Floor	Story drift in X direction (mm)			
	Without diation	Dilation		
	Model ND	Model D1	Model D2	Model D3
Lt. 9	4,516	4,533	9,267	5,675
Lt. 8	7,370	7,006	9,361	6,844
Lt. 7	8,386	7,689	9,017	7,132
Lt. 6	14,863	13,145	16,406	13,667
Lt. 5	31,536	26,895	24,438	19,835
Lt. 4	45,583	38,389	23,132	17,966
Lt. 3m	30,994	25,883	14,128	10,396
Lt. 3	22,563	18,755	10,553	9,548
Lt. 2	5,893	4,913	3,249	2,980

Table 9. Story drift in Y direction dynamic load

Floor	Story drift in Y direction (mm)			
	Without diation	Dilation		
	Model ND	Model D1	Model D2	Model D3
Lt. 9	8,551	9,243	8,176	3,490
Lt. 8	9,152	11,592	7,690	2,432
Lt. 7	9,416	12,244	6,878	2,507
Lt. 6	18,257	25,566	11,291	6,455
Lt. 5	28,435	38,834	15,056	15,496
Lt. 4	27,575	32,219	13,509	21,581
Lt. 3m	17,419	19,687	7,747	14,891
Lt. 3	13,607	15,965	5,543	11,404
Lt. 2	4,373	5,359	1,656	3,305

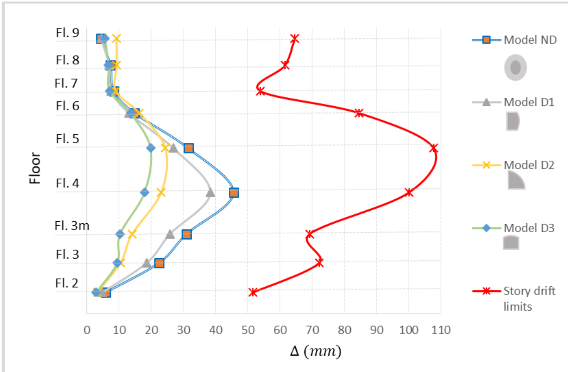

Figure 12. Story drift all model in X direction

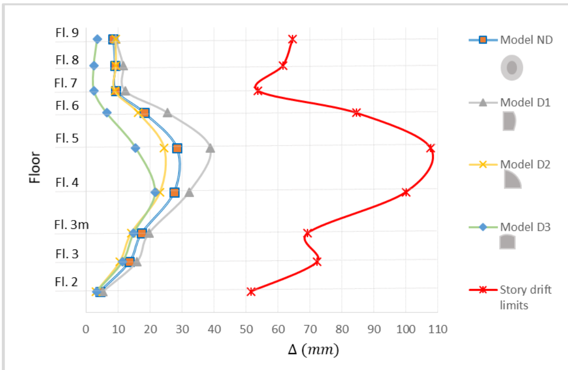

Figure 13. Story drift all model in Y direction

From the Figure 12 and Figure 13, it can be seen that the largest story drift X direction occurs on the fl-4 model ND wich is 45,583 mm and the largest story drift in Y direction occurs on the fl-5 model D1, wich is 38,834 mm. However, all models are still below the story drift limit based SNI 1726-2019.

Base shear due to dynamic load Based on the analysis results from SAP2000 v22, the values for the four types of portal structure models are as follows Figure 14.

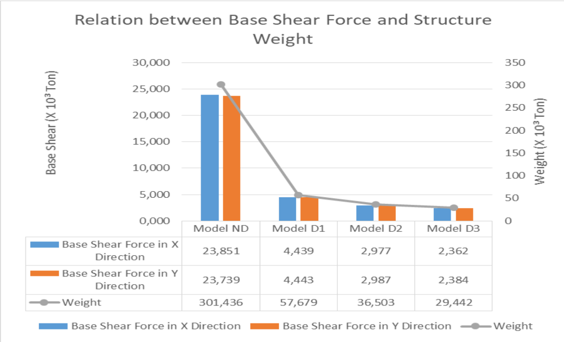

Figure 14. Base shear and structure weight

We look at the relation between the weight of the structure and the base shear in Figure 14, it can be observed that as the building's weight increases, the base shear value also increases. This is because one of the factors influencing the base shear value is the loading on the structure.

CONCLUSION

From the results of the analysis the following conclusions :

1. Analysis of the static load of the curved concrete portal structure in the dilatation modeling D1, D2, and D3 generally results in a decrease in structural displacement, internal forces, and base shear when compared to the intact model without dilatations ND.
2. The dynamic load is consistent with the due to static loads, where modeling with dilatations will result in a decrease in values for structural displacement, internal forces, and base shear, but it shows a greater influence compared to static loads.
3. All variations of building modeling, both without dilatations and with dilatations, still comply with the standards according to the permissible limits, mode participation analysis, and base shear analysis based on SNI 1726-2019.

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