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PENGARUH SISTEM DILATASI TERHADAP KINERJA SEISMIK GEDUNG RUMAH SAKIT 7 LANTAI BERDENAH U

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ABSTRACT

Berikut adalah perbaikan abstrak dalam bahasa Inggris yang telah disesuaikan dengan konten dokumen Anda, dengan mencantumkan metode elemen hingga, penggunaan perangkat lunak analisis struktur, serta standar SNI 1726:2019 dan SNI 2847:2019.ABSTRACTThe increasing demand for healthcare facilities in urban areas has led to the construction of multi-story hospital buildings with complex and irregular floor plan configurations, such as U-shaped layouts. This type of irregularity may result in unfavorable seismic responses due to uneven mass and stiffness distribution, which can induce torsional effects and stress concentration during earthquake events. This study aims to analyze the influence of expansion joint systems on the seismic performance of a seven-story U-shaped hospital building. The research adopts a quantitative approach through numerical simulation based on three-dimensional structural modeling using finite element-based software. Seismic analysis is performed using the equivalent static lateral load method in accordance with SNI 1726:2019 for earthquake resistance and SNI 2847:2019 for structural concrete requirements. Two structural models are compared: a monolithic model without expansion joints and a model incorporating strategically placed expansion joints between building masses. The evaluated parameters include lateral displacement, inter-story drift, internal force distribution, and global structural stability. The analysis results indicate that the implementation of expansion joints can reduce inter-story drift by up to approximately 30%, decrease maximum shear forces, and significantly improve the dynamic performance of the structure by mitigating torsional effects. These findings confirm that expansion joint systems are effective in enhancing the seismic resilience of essential facilities. This study contributes to seismic-resistant design strategies for hospitals to ensure structural safety and post-earthquake functional continuity

Keywords: *seismic performance, expansion joint system, hospital building, U-shaped plan, finite element method, inter-story drift, SNI 1726:2019.*

ABSTRAK

Berikut ini adalah revisi abstrak dalam bahasa Inggris yang telah disesuaikan dengan isi dokumen Anda, termasuk metode elemen hingga, penggunaan perangkat lunak analisis struktural, serta standar SNI 1726:2019 dan SNI 2847:2019. ABSTRAK Peningkatan permintaan akan fasilitas kesehatan di daerah perkotaan telah mendorong pembangunan gedung rumah sakit bertingkat dengan konfigurasi lantai yang kompleks dan tidak teratur, seperti tata letak berbentuk U. Ketidakteraturan semacam ini dapat menyebabkan respons gempa yang tidak menguntungkan akibat distribusi massa dan kekakuan yang tidak merata, yang dapat menimbulkan efek torsi dan konsentrasi tegangan selama peristiwa gempa. Studi ini bertujuan untuk menganalisis pengaruh sistem sambungan ekspansi terhadap kinerja gempa bangunan rumah sakit bertingkat tujuh berbentuk U. Penelitian ini menggunakan pendekatan kuantitatif melalui simulasi numerik berdasarkan pemodelan struktural tiga dimensi menggunakan perangkat lunak berbasis elemen hingga. Analisis gempa dilakukan menggunakan metode beban lateral statis setara sesuai dengan SNI 1726:2019 untuk ketahanan gempa dan SNI 2847:2019 untuk persyaratan beton struktural. Dua model struktural dibandingkan: model monolitik tanpa sambungan ekspansi dan model yang memasukkan sambungan ekspansi yang ditempatkan secara strategis antara massa bangunan. Parameter yang dievaluasi meliputi perpindahan lateral, pergeseran antar lantai, distribusi gaya internal, dan stabilitas struktural global. Hasil analisis menunjukkan bahwa implementasi.

Kata kunci: kinerja gempa, sistem sambungan ekspansi, gedung rumah sakit, rencana berbentuk U, metode elemen hingga, pergeseran antar lantai, SNI 1726:2019.

1. INTRODUCTION

The high demand for healthcare facilities in urban areas has encouraged the development of multi-story hospital buildings with large capacity and increasingly complex architectural designs. To accommodate spatial and functional requirements, designers frequently adopt irregular floor plan geometries, such as U-shaped, L-shaped, or T-shaped layouts. While these configurations offer architectural advantages, they pose significant structural challenges, particularly in terms of load distribution when subjected to lateral actions. This issue is critically relevant in Indonesia, which is situated at the meeting point of four major tectonic plates—the Eurasian, Indo-Australian, Pacific, and Philippine Sea plates. This unique geological position makes Indonesia one of the most seismically active regions globally, necessitating strict adherence to national standards such as SNI 1726:2019 for earthquake-resistant design and SNI 2847:2019 for structural concrete requirements. Furthermore, Permen PUPR No. 14/2017 mandates that hospital infrastructures must maintain high performance and functionality post-disaster, as they are classified as essential facilities.

Previous studies have shown that irregular plan configurations significantly influence seismic behavior, with Kumar (2025) reporting that U-shaped configurations lead to uneven distribution of shear forces and bending moments, resulting in poor seismic performance in certain elements. Plan irregularity increases torsional demand and energy dissipation requirements, often necessitating additional deformation control systems. In this context, expansion joints have been recognized as an effective strategy to mitigate these adverse effects. By subdividing the building mass into smaller, more symmetric segments, expansion joints reduce torsional concentration and improve load distribution. Raheem (2025) demonstrated that well-designed expansion joint systems can significantly reduce peak acceleration, base shear forces, and inter-story drift in buildings with geometric irregularities.

Using a numerical modeling approach, this study quantitatively evaluates the influence of expansion joint systems on the seismic performance of an irregular U-shaped building subjected to earthquake loading. The analysis focuses on comparing the dynamic response of a seven-story hospital building modeled with and without expansion joints to provide practical recommendations for resilient structural design in essential facilities. This study specifically addresses three research questions: (1) how a U-shaped floor plan influences the structural behavior of multi-story buildings; (2) the extent to which expansion joint systems can improve the seismic performance of hospital buildings; and (3) the comparison of seismic performance between structural models with and without expansion joints in terms of drift and internal force response.

2. LITERATURE REVIEW

2.2.1 Seismic Behavior of Buildings with Irregular Plan Configuration

Plan irregularity is one of the most critical factors influencing the seismic performance of multi-story buildings. Irregular floor plan configurations, such as U-shaped, L-shaped, and T-shaped layouts, result in nonuniform distribution of mass and stiffness, which may lead to torsional effects when subjected to seismic loads. This torsional response causes uneven demand on structural elements, increasing the risk of local damage and overall structural instability. (1727, 2020)

Several studies have highlighted that buildings with irregular plans tend to experience higher lateral displacement and inter-story drift compared to regular-plan buildings. The eccentricity between the center of mass and the center of rigidity is a primary source of torsional motion, which amplifies seismic demand on columns and beams located at the perimeter of the structure. Consequently, plan irregularity is commonly associated with reduced seismic reliability if not adequately addressed during the design stage. (Rafiqi, Ratih Hurriyati, 2018)

2.2.2 Seismic Performance of U-Shaped Building Structures

Among various irregular configurations, U-shaped buildings present specific challenges due to their re-entrant corners and discontinuous stiffness distribution. These geometric characteristics intensify stress concentration at the re-entrant regions, making them vulnerable to cracking and excessive deformation during earthquake events. (Wardiana et al., 2024)

Previous research indicates that U-shaped buildings generally exhibit higher torsional irregularity and larger inter-story drift ratios than compact or symmetric buildings. The dynamic interaction between the wings of the U-shaped plan often results in differential movement, which can significantly increase internal forces in connecting elements. As a result, special attention is required in the structural design of U-shaped buildings, particularly for essential facilities such as hospitals that must remain operational after seismic events. (Kumar et al., 2025)

2.2.3 Expansion Joint Systems as a Seismic Mitigation Strategy

Expansion joints, also referred to as seismic separation joints, are structural design elements intended to divide a building into independent segments that can move freely relative to one another during seismic excitation. By separating building masses, expansion joints help reduce torsional coupling, control deformation demand, and minimize stress concentration caused by plan irregularity.

Numerous studies have demonstrated that the application of expansion joints in irregular buildings can significantly improve seismic performance. Properly designed expansion joints reduce peak floor acceleration, base shear forces, and inter-story drift by limiting the transfer of seismic forces between adjacent structural segments. In U-shaped buildings, expansion joints are particularly effective in separating the wings of the structure, allowing each segment to respond independently to earthquake motion. (Abdel et al., 2025)

However, the effectiveness of expansion joints strongly depends on their location, width, and structural detailing. Inadequate placement or insufficient separation distance may lead to pounding between adjacent segments, which can exacerbate structural damage. Therefore, numerical evaluation is essential to optimize the configuration of expansion joint systems in irregular buildings. (Akhir, 2023)

2.2.4 Numerical Modeling and Finite Element Analysis in Seismic Evaluation

Finite element–based numerical modeling has become a widely accepted approach for evaluating the seismic performance of building structures. This method enables detailed representation of structural geometry, material properties, and boundary conditions, allowing engineers to simulate realistic seismic response under various loading scenarios.

Through numerical modeling, key seismic performance indicators such as lateral displacement, inter-story drift, internal force distribution, and global stability can be quantitatively assessed. Comparative modeling of structures with and without expansion joints provides valuable insight into the effectiveness of seismic mitigation strategies. Previous studies confirm that numerical simulation is a reliable and efficient tool for assessing seismic behavior, particularly during the preliminary and evaluation stages of structural design. (Pinanggih & Yogaswara, 2021)

2.2.5 Research Gap

Although extensive research has been conducted on seismic behavior of irregular buildings and the application of expansion joints, studies focusing specifically on U-shaped hospital buildings with medium-rise configurations remain limited. In addition, comparative evaluations using equivalent static seismic analysis based on Indonesian seismic design standards are still relatively scarce. Therefore, further investigation is required to quantify the influence of expansion joint systems on the seismic performance of U-shaped hospital buildings and to provide design-oriented recommendations applicable to local seismic conditions. (Sipil & Indonesia, 2020)

3. RESEARCH METHODOLOGY

This research is conducted as a case study on a seven-story reinforced concrete hospital building with a U-shaped floor plan located in a seismically active region. The study applies a quantitative approach through numerical simulation to evaluate the influence of expansion joint systems on the seismic performance of the selected building. A three-dimensional structural model of the case study building is developed using finite element–based structural analysis software, representing the actual geometric configuration, structural system, and functional characteristics of the hospital. Two structural configurations are analyzed: the existing monolithic structure without expansion joints and an alternative configuration incorporating expansion joints at critical locations between building masses.

Seismic analysis is performed using the equivalent static earthquake load method in accordance with SNI 1726:2019. The seismic parameters, including site classification, importance factor for hospital buildings, and seismic response factors, are defined based on the provisions of the standard and applied consistently to both structural configurations. Gravity loads and seismic loads are combined following the prescribed load combinations, and structural responses are obtained under identical loading conditions. This approach ensures that the observed differences in seismic behavior are attributable solely to the presence of the expansion joint system.

The seismic performance of the case study building is evaluated based on lateral displacement, inter-story drift, internal force distribution within structural elements, and overall structural stability. A comparative assessment between the models with and without expansion joints is conducted to quantify the effectiveness of the expansion joint system in mitigating torsional effects and controlling deformation demand. The results of this case study are used to formulate design-oriented insights and recommendations for improving the seismic resilience of U-shaped hospital buildings subjected to earthquake loading.

4.ANALYSIS AND DISCUSSION

4.1 Initial Design Data

The following are the initial structural design data for the case study is :

a. Building Function : Hospital
b. Building Configuration : U-shaped floor plan (U-layout)
c. Building Height : 32 m
d. Building Length : 72.5 m
e. Building Width : 56 m
f. Number of Stories : 7 stories
g. Concrete Strength (f'c) : 35 MPa
h. Reinforcing Steel BJTS 420B : 420 MPa
i. Reinforcing Steel BJTP 280 : 280 MPa

4.2 Design of the Seven-Story U-Shaped Hospital Building

The following Tabel 1 Response Spectrum Parameters

Table 1. Response Spectrum Parameters

Parameter Respons Spektra		
Kategori Risiko		IV
Faktor Keutamaan	I_e	1.5
Klasifikasi Situs		SC (Tanah Keras-Batuan Lunak)
Percepatan Gempa MCER terpetakan untuk Periode Pendek	S_s	1.1209
Percepatan Gempa MCER terpetakan untuk Periode 1 detik	S_1	0.4928
Faktor Amplifikasi Periode Pendek	F_a	1.2
Faktor Amplifikasi Periode 1 detik	F_v	1.5
Percepatan Desain pada Periode Pendek	SDS	0.8967
Percepatan Desain pada Periode 1 detik	SD1	0.4928
Parameter Periode	T0	0.1099
	Ts	0.5496
Parameter Sistem Rangka Pemikul Momen Khusus (SRPMK)		

Koefisien Modifikasi Respons	*R*	8
Faktor Kuat Lebih Sistem	Ω_0	3
Faktor Pembesaran Defleksi	C_d	5.5
Parameter Sistem Ganda		
Koefisien Modifikasi Respons	*R*	7
Faktor Kuat Lebih Sistem	Ω_0	2.5
Faktor Pembesaran Defleksi	C_d	5.5

Sumber : Hasil Analisa

4.3 Dynamic Response Analysis

1. Dynamic Response Analysis

The following Table 2 Dynamic Response Analysis Results

Table 2. Dynamic Response Analysis Results

Model	Translasi Arah Y	Translasi Arah X	Rotasi
1	1.09878	0.72357	0.60670
1a	1.13726	0.83209	0.74397
1b	1.60124	1.45670	1.37532
1c	1.60136	1.45749	1.37542

Sumber : Hasil Analisa

2. Seismic Analysis of the Superstructure

The following Table 3 Dynamic Seismic Analysis Results

Table 3. Dynamic Seismic Analysis Results

Model	T_X (Detik)	$V_{dinamik\ X}$ (kN)	T_Y (Detik)	$V_{dinamik\ Y}$ (kN)
1	0.919	14866.14	0.734	18617.12
1a	0.919	10937.65	0.832	12084.01
1b	0.440	11847.72	0.440	11847.72
1c	0.440	11847.72	0.440	11847.72

Sumber : Hasil Analisa

3. Inter-Story Drift

The following Table 4 Inter-Story Drift Results

Table 4. Inter-Story Drift Results

Story	**MODEL 1**			**MODEL 1a**			**MODEL 1b**			**MODEL 1c**		
	Inelastic Drift		**Drift Limit**	**Inelastic Drift**		**Drift Limit**	**Inelastic Drift**		**Drift Limit**	**Inelastic Drift**		**Drift Limit**
	ΔX	**ΔY**		**ΔX**	**ΔY**		**ΔX**	**ΔY**		**ΔX**	**ΔY**	
	(mm)	**(mm)**	**(mm)**	**(mm)**	**(mm)**	**(mm)**	**(mm)**	**(mm)**	**(mm)**	**(mm)**	**(mm)**	**(mm)**
8	16.053	7.113	30.769	15.440	4.297	30.769						
7	15.730	13.141	30.769	14.355	10.223	30.769						
6	18.363	15.231	30.769	16.709	13.435	30.769						
5	20.999	14.315	30.769	18.421	12.412	30.769						
4	22.282	13.783	30.769	18.517	13.988	30.769						
3	20.339	10.648	30.769	18.524	11.840	30.769	0.124	0.105	30.769	0.124	0.105	30.769
2	11.099	8.320	30.769	17.222	9.420	30.769	0.200	0.157	30.769	0.200	0.157	30.769

1	6.868	4.737	30.769	11.403	5.324	30.769	0.237	0.163	30.769	0.237	0.163	30.769

Sumber : Hasil Analisa

4. P–Delta Effect Verification

   The evaluation of the P–Delta effect indicates that the structure is not significantly affected by P–Delta effects. The stability criteria are satisfied, and second-order effects do not govern the structural response under the applied seismic loading.

5. Torsional Irregularity Check

   The torsional irregularity assessment indicates the presence of horizontal (plan) irregularity, which leads to eccentricity between the center of mass and the center of rigidity. This condition induces torsional response in the structure under seismic loading.

4.5 Structural Element Design Results

1. Slab Design

   The following Table 5 Summary of Slab Reinforcement Design Results

Table 5. Summary of Slab Reinforcement Design Results

Pelat	**Lx (m)**	**Ly (m)**	**Tebal (mm)**	**Arah**	**Tumpuan**		**Lapangan**	
					Atas	**Bawah**	**Atas**	**Bawah**
Pelat Heliped	7	7	340	X	D28-200	D28-200	D28-200	D28-200
				Y	D28-200	D28-200	D28-200	D28-200
Pelat Atap	7	7	220	X	D19-200	D19-200	D19-200	D19-200
				Y	D19-200	D19-200	D19-200	D19-200
Pelat Lantai	7	7	280	X	D22-200	D22-200	D22-200	D22-200
				Y	D22-200	D22-200	D22-200	D22-200

Sumber : Hasil Analisa

2. Beam Design

   The following Table 6 Summary of Beam Reinforcement Design Results

Table 6 Summary of Beam Reinforcement Design Results

Kode	**Dimensi (mm)**	**Lokasi**	**Tulangan Longitudinal**		**Tulangan Transversal**		**Tul. Torsi**
			Tumpuan	**Lapangan**	**Tumpuan**	**lapangan**	
G1	300 x 600	Atas	6D22	2D22	D13-150	D13-200	6D13
		Bawah	4D22	6D22			
BA1	300 x 500	Atas	4D16	2D16	D10-150	D10-200	2D13
		Bawah	3D16	3D16			
BA2	300 x 500	Atas	4D16	2D16	D10-150	D10-200	2D13
		Bawah	3D16	3D16			

Sumber : Hasil Analisa

3. Column

The following Tabel 7 Summary of Column Reinforcement Design Results

Tabel 7 Summary of Column Reinforcement Design Results

Kode	**Dimensi kolom (mm)**	**Tulangan Pokok**	**Tulangan Geser**	
			Tumpuan	**lapangan**
K1	600 x 800	22D25	D16-100	D16-150
K2	600 x 1000	24D25	D16-100	D16-150
K3	300 x 300	8D25	D16-100	D16-150
K4	600 x 800	20D25	D16-100	D16-150
K5	600 x 800	24D25	D16-100	D16-150

Sumber : Hasil Analisa

4. Shearwall

The following Table 16 Summary of Shearwall Reinforcement Design Results

Tabel 1 Summary of Shearwall Reinforcement Design Results

Tipe Dinding Geser	Tulangan Kolom			Tulangan Badan			
	Longitudinal	Transversal		Longitudinal	Transversal	confinement EBK	
		Sejajar Lebar	Sejajar Panjang			Sejajar Lebar	Sejajar Panjang
SW1	18 D22	4 D16-100	7 D16-100	2 D19-150	2 D19-150	4 D16-100	10 D16-100
SW2	18 D22	4 D16-100	7 D16-100	2 D19-150	2 D19-150	4 D16-100	8 D16-100
SW3	18 D22	4 D16-100	7 D16-100	2 D19-150	2 D19-150	4 D16-100	7 D16-100
SW4	18 D22	4 D16-100	7 D16-100	2 D19-150	2 D19-150	4 D16-100	7 D16-100

Sumber : Hasil Analisa

5. CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Based on the results of the numerical analysis and the case study conducted on the seven-story U-shaped hospital building, the following conclusions are formulated:

1. Influence of U-Shaped Configuration on Seismic Response: The U-shaped floor plan significantly influences seismic behavior by introducing plan irregularities that lead to adverse torsional effects. This configuration results in an uneven distribution of mass and stiffness, which increases lateral displacement and inter-story drift, particularly at the re-entrant corners of the structure.
2. Effectiveness of Expansion Joint Systems: The implementation of expansion joints is proven to be an effective strategy for improving seismic performance. By subdividing the building mass into more symmetric

independent segments, the system reduces torsional interaction and improves the overall dynamic response.

3. Quantifiable Performance Improvement: The analysis indicates that the expansion joint system can reduce inter-story drift by approximately 30%. Furthermore, it leads to a decrease in maximum shear forces and ensures a more uniform distribution of internal forces within the structural elements.
4. Compliance and Functional Continuity: The use of expansion joints helps the structure meet the stringent safety requirements of SNI 1726:2019. This is critical for essential facilities like hospitals, which must remain structurally sound and functional to provide emergency services immediately after an earthquake.

5.2 Recommendations

To further enhance the structural resilience of irregular multi-story buildings, this study offers the following recommendations:

1. Optimized Placement and Detailing: Structural designers should conduct rigorous numerical evaluations to determine the optimal location and width of expansion joints to prevent structural pounding between adjacent segments during high-magnitude events.
2. Focus on Re-entrant Corners: Special reinforcement detailing should be applied at re-entrant corners in U-shaped buildings to mitigate stress concentrations that remain even after the implementation of joints.
3. Advanced Dynamic Analysis: Future research should utilize Non-Linear Time History Analysis (NLTHA) to capture the more complex real-time behavior of expansion joints under specific Indonesian seismic ground motions.

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