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Analysis of Structural Behavior with Stage Construction Analysis Method Compared to Conventional Analysis on Tegalalang Bali Real Estate Building

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Abstract

Conventional structural analysis methods have shortcomings because they assume construction is complete, leading to overestimation in columns and walls. Deformation occurs due to self-weight, altering heights during casting, alongside creep (inelastic deformation from constant loads) and shrinkage (volume change from water loss). Thus, stage construction analysis (SCA) is essential. Analysis followed SNI requirements for shear force (V), vibration period (T), displacement (δ), and stress ratio. Structural elements were grouped by construction stages and contours. In SCA, dead and additional dead loads are defined non-linearly, matching stages. SCA increases displacement/deformation by 43% (x-direction), 39% (y), and 44% (z), iron work volume by 7%, and internal forces, reducing column capacity by 27.7% on average. Differences from conventional methods arise because SCA models groups per construction stages, using Nonlinear Stage Construction Load Case for self-weight and dead loads, unlike Static Linear Load Case.

Keywords : *Stage Construction Analysis, Cost, Quality, Structural Analysis.*

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Introduction

Structural analysis of low-rise buildings is usually carried out using a completed structural model without regard to the construction process (Nguyen et al., 2021; Liao & Liu, 2020). During the construction period, creep and shrinkage will occur (Gong et al., 2020; Zhang et al., 2021). Creep is an inelastic deformation caused by a constant load (Muthukumaran et al., 2020; Xie et al., 2021). Shrinkage is a phenomenon that occurs in concrete where over time, concrete will lose water content so that it will experience volume changes (Al-Mahaidi et al., 2020; Raziq & Malek, 2020).

Generally, construction stage analysis is performed to simulate the crucial stages of a structure under construction and, if necessary, to derive the deformations and forces at each stage (Chen et al., 2015; Elansary et al., 2021; Gao et al., 2020; Negendahl, 2015). Furthermore, this analysis is also used to consider the cumulative Impact of element forces and deformations from one stage to another. (Ha & Lee, 2013). In reality, the dead load from the structure's own weight develops progressively as the building is built floor by floor and external loads are also applied to the partially completed structure. The difference in load application between the real-world situation and the assumption of the structural model - full loading at completion - leads to differences in internal load distribution and deformation in the structural elements.

Several previous studies have investigated the application of stage construction analysis in various structural contexts. Ha and Lee (2013) conducted an advanced construction stage analysis of high-rise buildings, specifically examining the effects of creep and shrinkage of concrete on structural behavior during construction phases. Their findings demonstrated that ignoring construction sequences can lead to significant discrepancies in predicted structural responses, particularly in tall structures where time-dependent material properties play a crucial role. Elansary et al. (2021) performed staged construction analysis of reinforced concrete buildings with different lateral load resisting systems, comparing shear walls, moment frames, and dual systems. Their research revealed that the choice of lateral load resisting system significantly affects the magnitude of construction stage effects, with shear wall systems showing the most pronounced differences between staged and conventional analysis. The study emphasized that conventional analysis methods tend to underestimate deformations and internal forces in vertical elements by 20-35%. Girija Das and Praseeda (2016) compared conventional and construction stage analysis of a reinforced concrete building, focusing on mid-rise structures. Their work highlighted that construction stage analysis provides more realistic predictions of column shortening and differential settlements, which are critical for maintaining structural integrity and serviceability. They found that ignoring construction sequences could result in inaccurate reinforcement detailing, particularly in columns and shear walls. More recently, Zucca et al. (2018) analyzed a mixed structure building in Milan using construction stage analysis, examining the interaction between steel and concrete elements during phased construction. Their study demonstrated that the sequence of connecting different structural materials significantly impacts load distribution and stress development.

These studies collectively establish that construction stage analysis provides more accurate structural predictions than conventional methods. However, several research gaps remain. First, most existing studies focus on high-rise buildings or specific structural systems, with limited attention to low-to-mid-rise resort or villa-type buildings common in tropical regions. Second, there is insufficient research examining the comprehensive trade-offs between improved structural accuracy and increased construction costs in practical applications. Third, the combined effects of construction sequencing, topographical variations (contours), and localized loading conditions in sloped terrain have not been adequately addressed. This research aims to address these gaps by applying SCA to a real estate project in Tegalalang, Bali, which features multiple building masses on sloped terrain, providing insights into both technical performance and economic implications.

The urgency of this research stems from the rapid development of resort and villa construction in the Tegalalang area of Bali, where complex topography and increasing building heights demand more accurate structural analysis methods. Tegalalang has experienced significant growth in real estate development over the past decade, with numerous multi-story structures being constructed on sloped terrain. The region's geological conditions, characterized by volcanic soil and varying elevations, combined with seismic activity risks in Bali, necessitate careful consideration of construction sequencing effects on structural performance. Furthermore, the high economic value of resort properties in this tourism-dependent region makes structural safety and long-term serviceability critical concerns. Structural failures or excessive deformations could result not only in safety hazards but also significant economic losses and reputational damage to the tourism industry. Therefore, understanding whether SCA provides substantial benefits in this context is essential for informing construction practices and building code development in similar environments.

Tegalalang Bali Real Estate Building is located in Tegalalang village, Tegalalang sub-district, Gianyar district, Bali province (-8.4605768, 115.2363946). The research subject has a land area of ± 1.5 hectares, utilized for several building masses including villas, restaurants, swimming pools, and infrastructure facilities. This project presents a unique case study due to its multi-functional building complex situated on variable terrain with significant elevation changes, making it an ideal candidate for examining the practical implications of construction stage analysis in real-world conditions.

The novelty of this research lies in three key aspects. First, it provides a comprehensive comparative analysis of SCA versus conventional methods specifically for resort-type multi-building complexes on sloped terrain, a building typology that has received limited attention in the SCA literature. Second, this study uniquely integrates technical performance metrics (deformation, internal forces, capacity ratios) with economic analysis (cost implications and work volume changes) to provide a holistic evaluation of SCA implementation feasibility. Third, the research explicitly examines how topographical variations and phased construction of multiple interconnected structures influence the effectiveness of SCA, contributing practical knowledge for similar developments in tropical resort regions. Unlike previous studies that focus primarily on technical accuracy, this research addresses the practical decision-making question: is the improved accuracy of SCA worth the additional analysis complexity and potential cost increases in mid-rise resort construction?

Therefore, this research will analyze the structure of the conventional method with the SCA method to find out how the difference in deformation, demand/capacity, and volume of structural work between the SCA method and the conventional method. In addition, it is also to find out how much the SCA method affects the cost and quality of structural work. So that it is obtained what factors affect the difference in the results of the structural design of the SCA method with the conventional method.

Research Method

The steps in this study begin with the preparation of the background and formulation of the problems that occur, then collect data in the form of primary data and secondary data and literature review, then carry out SCA. The following steps in this research as a whole can be described by the flowchart below.

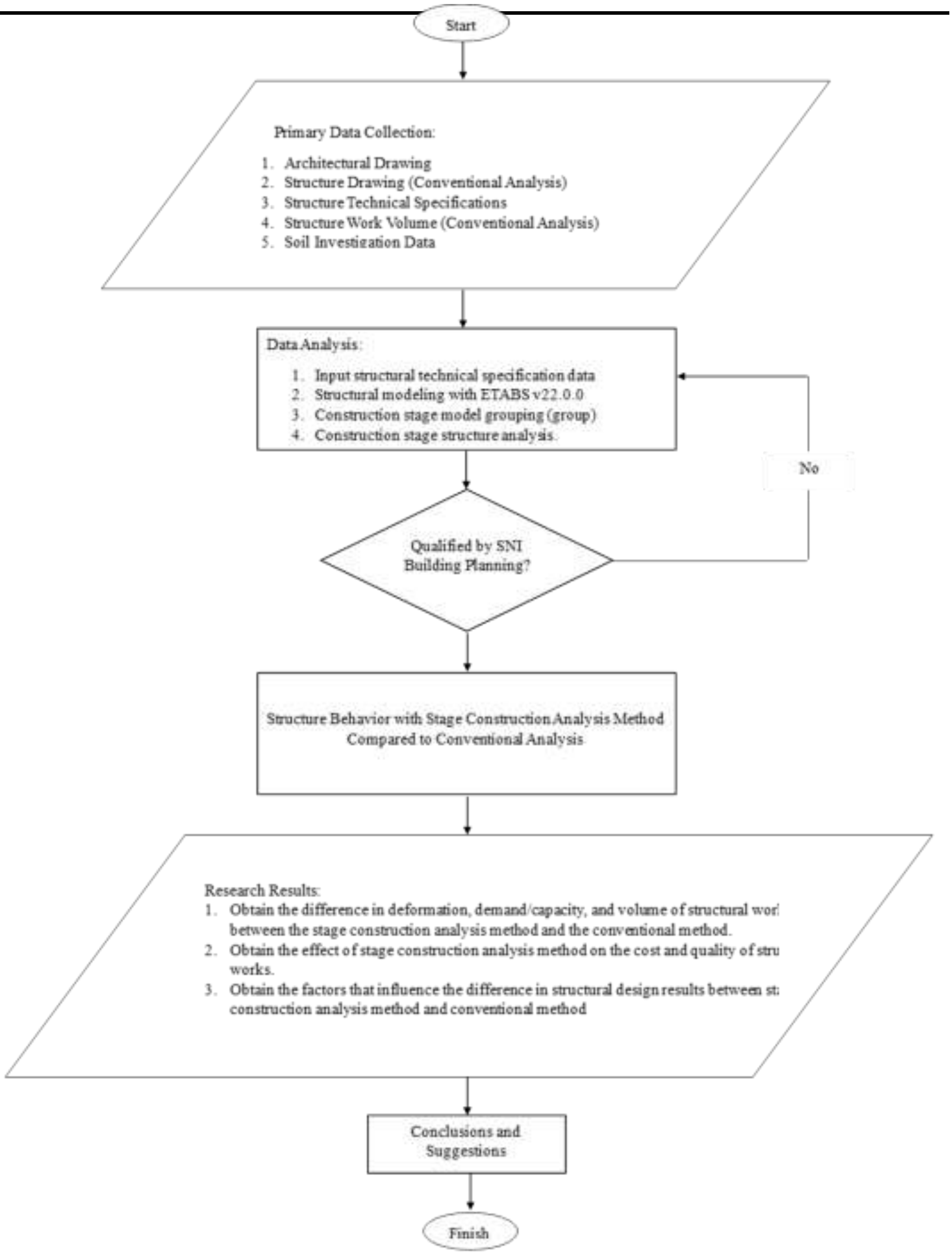

Figure 1. Research Flowchart

The analysis stage begins with the collection of data on the Tegalalang Bali Real Estate Swimming Pool Building project as a guideline, including architectural drawings, structural drawings, and material specifications related to material quality. Materials were then defined in the ETABS program, including concrete elastic modulus (Ec), concrete compressive strength (f'c), steel elastic modulus (Es), longitudinal reinforcing steel yield strength (fy), and tranverse reinforcing steel yield strength (fys). The structural dimensions are then defined which are taken according to the existing dimensions in the project data obtained.

In the next step, the structure is then modeled as an open frame, where in the ETABS program beams and columns are modeled using the frame menu, while plates and stairs are modeled using the slab menu. The material definition used in this SCA research uses the same data as the conventional method, so that the Impact of the SCA method can be known more accurately.

After modeling the structure and inputting the working structural loads, the structural element group was conducted. The structural element group is carried out by selecting structural elements that will become 1 group where each group is assumed in the design to have the same construction sequence. The following is how to assign groups in ETABS v22.0.0.

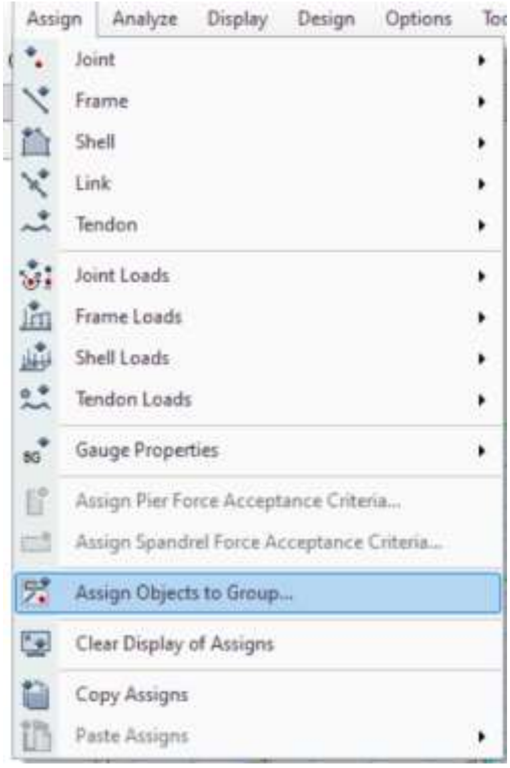

Figure 2. Assign Objects to Group

The loading on the structural model was calculated manually based on SNI 1727-2020 Minimum design loads and related criteria for buildings and other structures, including dead loads, live loads and earthquake loads. Dead loads are calculated automatically by the ETABS program, earthquake loads use response spectrum, made by entering S1, Ss and soil classification data in the ETABS program.

Next, the estimation of beam and column dimensions was checked on the reinforced concrete and steel structural models by looking at the stress ratio value ≤ 1.0 on the structural elements. The check is carried out based on SNI requirements which include shear force (V), vibration period (T), displacement (δ), and stress ratio. Based on the structural modeling, structural element groups were then conducted. The structural element group is carried out by considering the construction stages and contours. In structural analysis using SCA method, dead load and additional dead load are defined non-linearly so that they can be adjusted to the construction stage based on the previously defined model group.

Based on the element groups that have been carried out, the definition of the Nonlinear Stage Construction Load Case is then carried out, as follows.

General
Load Case Name: DL NL
Load Case Type: Nonlinear Staged Construction
Mass Source: MsSrc1
Analysis Model: Default

Initial Conditions
● Zero Initial Conditions - Start from Unstressed State
○ Continue from State at End of Nonlinear Case (Loads at End of Case ARE Included)

Stage Definition

Stage Number	Stage Name	Duration, Days	Provide Output	User Comment	Number Operations
1	Stage1	0	Yes		2
2	Stage2	0	Yes		2
3	Stage3	0	Yes		2
4	Stage4	0	Yes		2
5	Stage5	0	Yes		2
6	Stage6	0	Yes		2

Other Parameters
Geometric Nonlinearity Option: None
Results Saved: Start/End of Each Stage
Floor Cracking Analysis: No Cracked Analysis
Nonlinear Parameters: Default - Iterative Event-to-Event
☐ Material Properties Are Time Dependent

Figure 3. Load Case Nonlinier Stage Construction

Results and Discussion

Based on the data description carried out previously, then in this study obtained research findings that will answer research problems and show that research objectives have been achieved, interpret or confirm the results of research findings, then provide explanations, integrate research findings into a collection of knowledge that has been tested, modify existing theories, or can also compile into new theories, explain the implications of the research results including the limitations of the research findings including will be described as follows.

Tabel 1. SCA deformation and conventional analysis

Story	**Conventional**			***SCA***		
	Displacement			***Displacement (step number 25)***		
	δe_X	δe_Y	δe_Z	δe_X	δe_Y	δe_Z
	(mm)	**(mm)**	**(mm)**	**(mm)**	**(mm)**	**(mm)**
5	0.468	0.867	-0.54	0.627	1.153	-0.713
4	0.075	0.157	-3.278	0.151	0.285	-6.48
3	0.188	0.15	-0.422	0.38	0.27	-0.803
2	0.047	0.025	-0.288	0.085	0.043	-0.565
1	0.028	0.02	-0.135	0.048	0.033	-0.269

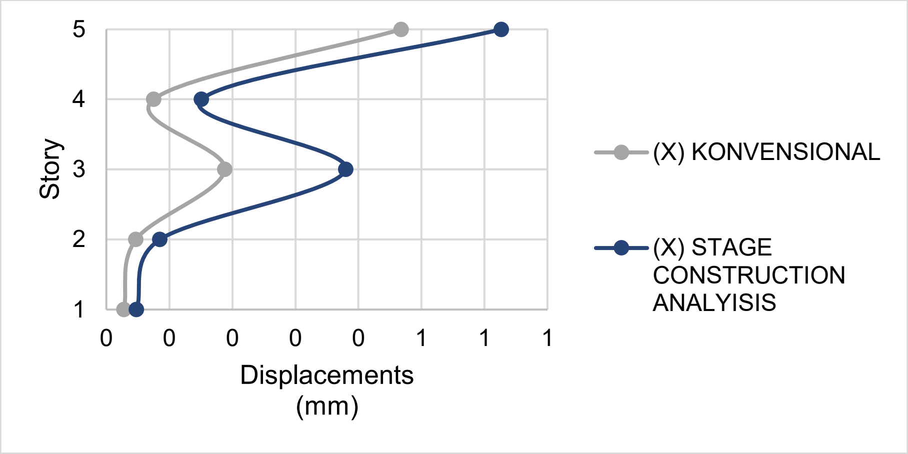

Figure 1. SCA deformation and conventional analysis X direction

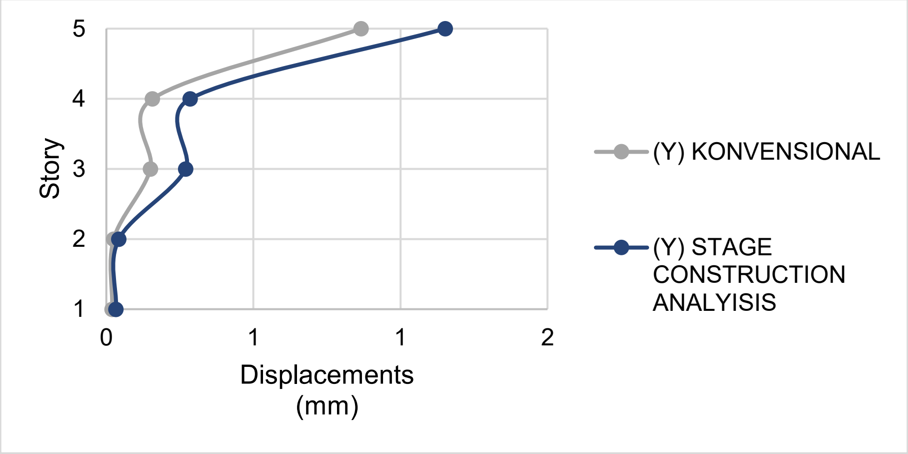

Figure *2*. SCA deformation and conventional analysis Y direction

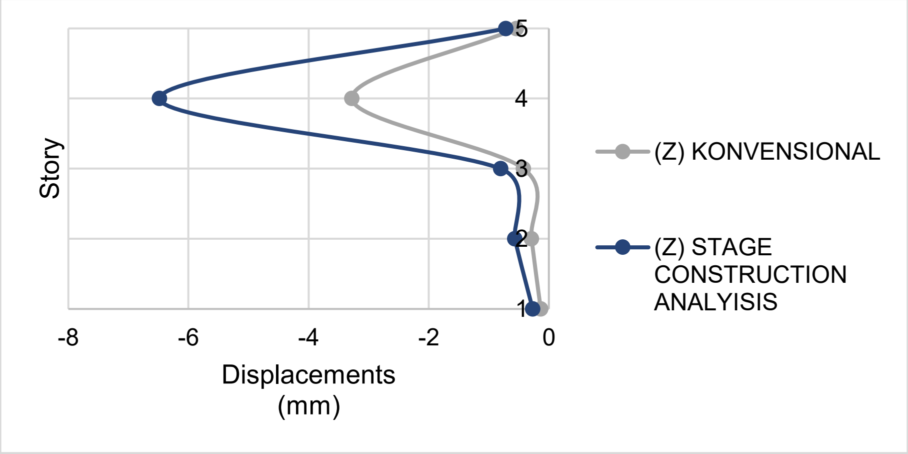

Figure 3. SCA deformation and conventional analysis Z direction

Based on the deformation tables and graphs of stage construction analysis and conventional analysis, it is found that the deformation in x, y, and z directions is larger than that in the conventional method of structural analysis. SCA has the Impact of increasing the displacement/deformation in the x direction by 43%, y direction by 39%, and z direction by 44%.

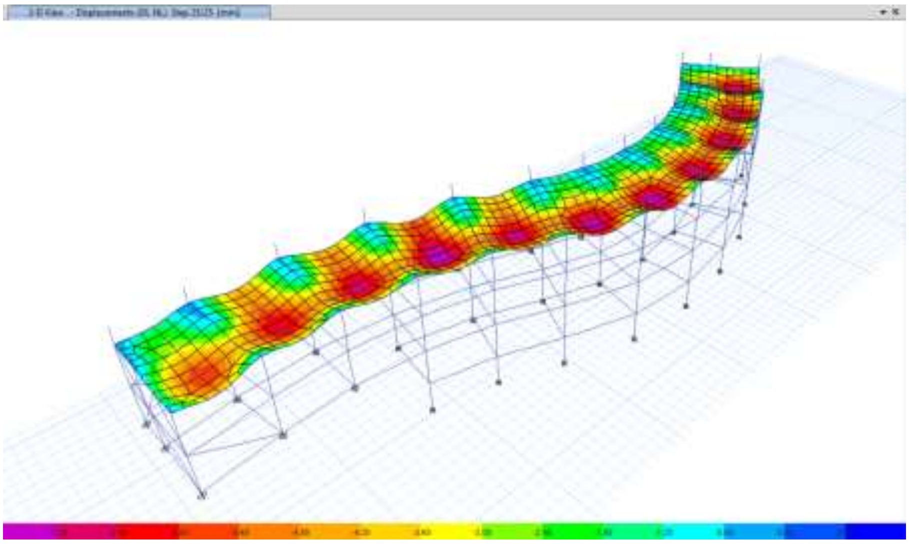

Figure 4. ***Deformed Shape Step Number 25***

The deformation of the structure at step 25 can be seen in the figure, where deformation occurs at step 25. Where there is deformation due to self-weight and additional dead load in model group 12 and deformation in the previous model group.

In this study, the overall volume of concrete and column reinforcement did not change because to get accurate influence results, the structural cross section must have the same dimensions so that the base reaction in the earthquake analysis used has the same value. It is known that the volume of iron work in conventional analysis is 8,5305.9 kg, while the SCA produces an iron work volume of 9,0968.9 kg. So that in this study the SCA method was found to have an Impact on increasing the volume of ironwork by 7%.

Based on the structural analysis using the SCA method, the structural demand/capacity of the column and foundation structural elements is obtained, as follows.

Tabel 2 Column Demand/Capacity Impact

Column	Dimensions		Reinforcement Installed			Reinforcement Area (mm2)	Demand/Capacity		Impact %
	b (mm)	h (mm)					Convention	SCA	
K1	750	750	26	D	22	10638.32	0.599	0.698	14.18%
K2	600	600	20	D	22	7598.8	0.442	0.686	35.57%
K3	550	550	16	D	22	6079.04	0.004	0.006	33.33%

Based on the table, it is known that Stage Construction Analysis has an Impact on reducing the average column capacity by 27.7%.

Tabel 3 Impact of SCA on Foundation Support Reactions

Story	Label	Impact FX	 FY	 FZ	 MX	 MY	 MZ
		%	%	%	%	%	%
Story2	1	8%	3%	11%	0%	0%	3%
Story2	2	2%	2%	32%	2%	0%	2%
Story2	3	3%	3%	37%	-1%	1%	3%
Story2	4	4%	11%	46%	9%	1%	3%
Story2	5	8%	0%	16%	1%	1%	2%
Story2	6	2%	3%	36%	1%	2%	2%
Story2	10	1%	9%	48%	5%	0%	2%
Story2	11	0%	6%	47%	8%	1%	2%
Story2	12	4%	1%	42%	3%	0%	2%
Story2	13	1%	2%	42%	2%	0%	2%
Story2	16	0%	1%	41%	3%	1%	0%
Story2	19	0%	1%	40%	2%	2%	0%
Story2	22	1%	1%	39%	3%	1%	1%
Story2	25	3%	1%	39%	3%	1%	1%
Story2	28	2%	1%	39%	3%	2%	2%
Story2	31	2%	1%	39%	3%	2%	2%
Story2	34	4%	2%	30%	2%	4%	1%
Story2	37	0%	0%	9%	2%	2%	1%
Story1	14	2%	4%	47%	21%	54%	0%
Story1	17	5%	2%	47%	10%	15%	0%
Story1	20	8%	2%	47%	4%	9%	0%
Story1	23	18%	4%	46%	3%	5%	1%
Story1	26	7%	4%	46%	4%	4%	1%
Story1	29	3%	4%	46%	3%	4%	2%
Story1	32	4%	4%	46%	1%	4%	2%
Story1	35	7%	5%	45%	2%	4%	2%
Story1	38	13%	11%	34%	4%	3%	1%
Base	15	12%	24%	48%	6%	-1%	2%
Base	18	0%	25%	48%	22%	1%	1%
Base	21	11%	26%	47%	19%	4%	1%
Base	24	4%	35%	47%	79%	2%	1%
Base	27	4%	26%	47%	36%	3%	1%
Base	30	6%	20%	47%	10%	3%	2%
Base	33	8%	14%	46%	3%	4%	2%
Base	36	7%	8%	33%	1%	4%	2%
Base	39	7%	4%	17%	2%	4%	2%
Average		**5%**	**8%**	**39%**	**8%**	**4%**	**2%**

Based on the table, it is known that structural analysis using the SCA method provides a significant increase in the axial force (Fz) received by the foundation by 39%.

Tabel 4 SCA and Conventional Structure Work Volume

NO	DESCRIPTION	CONVENTIONAL		*SCA*	
		TOTAL	UNIT	TOTAL	UNIT
1	Borpiled				
	Bp1	114.7411	m3	114.7411	m3
	D13	9927.424	kg	9927.424	kg
	D8	2959.852	kg	2959.852	kg
2	Pilecap				
	P1	6.3	m3	6.3	m3
	P2	122.5	m3	122.5	m3
	P3	18.375	m3	18.375	m3
	P1 D19	706.464	kg	706.464	kg
	P2 D19	16783.87	kg	16783.87	kg
	P3 D19	2279.06	kg	2279.06	kg
3	Sloof			0	0
	Tb1A	18.567	m3	18.567	m3
	Tb1B	7.875	m3	7.875	m3
	Tb2	1.017225	m4	1.017225	m4
	Tb1A D13	1004.103	kg	1313.058	kg
	Tb1A D10	1425.616	kg	1425.616	kg
	Tb1B D13	622.44	kg	819	kg
	Tb1B D10	604.66	kg	604.66	kg
	Tb2 D13	56.42208	kg	75.22944	kg
	Tb2 D10	80.58431	kg	80.58431	kg
4	Balok				
	B1	33.672	m3	33.672	m3
	B2	0.72	m3	0.72	m3
	B3	32.886	m3	32.886	m3
	B4	7.92	m3	7.92	m3
	B5	25.46	m3	25.46	m3
	B6	20.4	m3	20.4	m3
	B7A	12.96638	m3	12.96638	m3
	B8A	0.375	m3	0.375	m3
	B9A	11.33988	m3	11.33988	m3
	B10A	3	m3	3	m3
	B7B	18.33	m3	18.33	m3
	B8B	0.75	m3	0.75	m3
	B9B	15.4025	m3	15.4025	m3

NO	DESCRIPTION	CONVENTIONAL		*SCA*	
		TOTAL	UNIT	TOTAL	UNIT
	B10B	3.75	m3	3.75	m3
	B1 D16	2105.903	kg	2881.762	kg
	B1 D13	291.824	kg	291.824	kg
	B1 D10	1875.577	kg	2091.99	kg
	B2 D16	37.92	kg	42.66	kg
	B2 D13	6.24	kg	6.24	kg
	B2 D10	40.105	kg	40.105	kg
	B3 D16	2405.55	kg	3271.548	kg
	B3 D13	253.344	kg	253.344	kg
	B3 D10	2254.518	kg	2442.395	kg
	B4 D16	417.12	kg	469.26	kg
	B4 D13	68.64	kg	68.64	kg
	B4 D10	441.155	kg	441.155	kg
	B5 D16	1609.072	kg	2413.608	kg
	B5 D13	264.784	kg	264.784	kg
	B5 D10	1505.429	kg	1505.429	kg
	B6 D16	1289.28	kg	1933.92	kg
	B6 D13	212.16	kg	212.16	kg
	B6 D10	1206.235	kg	1206.235	kg
	B7A D16	1229.212	kg	1475.055	kg
	B7A D13	215.7605	kg	215.7605	kg
	B7A D10	1137.814	kg	1137.814	kg
	B8A D13	37.44	kg	37.44	kg
	B8A D10	22.212	kg	41.13333	kg
	B9A D13	660.4343	kg	849.1298	kg
	B9A D10	870.7008	kg	995.0866	kg
	B10A D13	162.24	kg	199.68	kg
	B7B D16	2316.912	kg	2780.294	kg
	B7B D13	305.0112	kg	305.0112	kg
	B7B D10	1608.478	kg	1608.478	kg
	B8B D13	49.92	kg	62.4	kg

NO	DESCRIPTION	CONVENTIONAL		*SCA*	
		TOTAL	UNIT	TOTAL	UNIT
	B8B D10	57.58667	kg	57.58667	kg
	B9B D13	1089.265	kg	1473.711	kg
	B9B D10	1182.638	kg	1182.638	kg
	B10B D13	234	kg	312	kg
	B10B D10	287.9333	kg	287.9333	kg
5	Kolom				
	K1	60.44063	m3	60.44063	m3
	K2	84.924	m3	84.924	m3
	K3	11.011	m3	11.011	m3
	K1 D22	5043.166	kg	5043.166	kg
	K1 D13	5028.66	kg	5028.66	kg
	K2 D22	5061.47	kg	5061.47	kg
	K2 D13	4710.451	kg	4710.451	kg
	K3 D22	525.0045	kg	525.0045	kg
	K3 D13	503.8634	kg	503.8634	kg
	Total Volume of Concrete	*631.705*	*m3*	631.7055	m3
	Total Volume of Reinforcement	*85305.9*	*kg*	90968.9	kg

Based on the analysis of the structure using the SCA method, it is known that there is an increase in the volume of structural work, so in this study it can be found that SCA cannot be carried out as an alternative for cost efficiency of structural work. It is known that the volume of iron work in SCA is 90968.9 kg, if the unit price of iron/kg is Rp.12,000, then the cost will be Rp1,091,626,773. Conventional structural analysis has an ironwork cost of Rp1,023,670,471, so there is a 7% increase in cost.

However, if structural planning using SCA can result in an improvement in the quality of the structure, it is evidenced by the fact that the structural analysis results go to the safer side, where the structural deformation, reinforcement output, foundation reaction, and forces received by the structural elements are greater than those of conventional analysis. Analysis stages that take into account the construction stages allow the structure to be analyzed at each construction stage, considering changes in stiffness, loads, and material conditions over time. This results in a more accurate model compared to conventional static analysis that ignores construction stages.

Based on the description of the research findings, it is known that the author has answered the problem formulation and research objectives. Where, structural analysis with the SCA method provides a better Impact than conventional structural analysis. This can be seen in the deformation produced in this analysis is greater than the conventional analysis where the modeling is done with groups following the construction stages so as to provide more realistic modeling and better accuracy. The internal forces and reinforcement output generated by the SCA method are also greater, making it safer for design.

In this research, there are factors that influence the difference between the structural design results of the SCA method and the conventional method, including the following:

a In the SCA method, the model group is carried out by considering the construction stage process.

b The self-weight of the structure and the additional dead load used in SCA are defined as Nonlinear Stage Construction Load Cases, in contrast to conventional analysis using Linear Static Load Cases. The Load Case is used to compare the deformation of the structure, and is also used as the load name in the load combination.

Based on the findings that have been carried out, it is known that the author's findings show the same results as previous studies. As one example in research conducted by (David & Supartono, 2023) With the title “Analysis of the Impact of Construction Stage on Deformation and Forces in Multi-Story Building Structures with Shear Walls”, it is known that there is a difference in the internal force on the beam due to the difference in shortening between the structural analysis that takes into account the construction stage and the one that does not take into account the construction stage by 80% for the moment and 58% for the shear force. Therefore, there is a difference in the amount of reinforcement by 2 pieces of 22 mm diameter reinforcement between the two structural analyses. The amount of reinforcement of the main beam at 2/3 elevation of the building is 2 pieces more when considering the construction stage but at the top of the building will be 1 piece less compared to the analysis without considering the work stage.

This is similar to the findings in this study where there is an increase in the volume of structural reinforcement. Where deformation, internal forces, cost, and quality of structural works. However, this study found that the construction stage cannot provide efficiency in the value of structural work. This is because the comparison is only carried out on the volume of beam reinforcement, while the structural elements of the column and foundation are only examined for the Impact on their capacity, where no dimensional changes are made so that a more accurate Impact can be known where the base reaction of the two methods remains the same.

Conclusion

The research concludes that stage construction analysis (SCA) significantly impacts structural behavior compared to conventional methods on the Tegalalang Bali real estate building. SCA increases displacement/deformation by averages of 43% (x-direction), 39% (y-direction), and 44% (z-direction), raises ironwork volume by 7%, and elevates internal forces, reducing average column capacity by 27.7%. These differences arise because SCA employs group modeling accounting for construction stages, with self-weight and additional dead loads defined as Nonlinear Stage Construction Load Case, unlike the conventional Linear Static Load Case. For future research, investigators could extend SCA to high-rise structures or incorporate time-dependent effects like long-term creep and shrinkage under seismic loads to validate results across diverse Indonesian building typologies.

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