

Implementation of Knock-Down Precast Concrete System for Earthquake-Resilient School Designs

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ARTICLE INFO

Kata Kunci: Natural Disasters, Precast Concrete, Earthquake, RISHA, School

Received : 3 December

Revised : 20 January

Accepted: 21 February

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ABSTRACT

Earthquakes are among the deadliest natural disasters, causing extensive infrastructural damage around the world. This study aims to design earthquake-resistant schools using the knock-down precast concrete system RISHA (Rumah Instan Sederhana Sehat), offering flexibility, ease of assembly, and rapid deployment for post-disaster reconstruction. The methodology involves designing two school units (108 m² and 132 m²) and performing a comparative analysis of construction time and costs between RISHA and conventional methods. Each unit comprises 910 components, costing \$3,375 (20 days) and \$4,005 (23 days), respectively. Results show that RISHA saves approximately 7.6% in costs and reduces construction time by 15–17 days, demonstrating its potential as an efficient solution for post-disaster educational facilities

INTRODUCTION

Earthquakes have become a frequent threat in Indonesia, which greatly impacts the country's infrastructure and its sectors. In Indonesia, earthquakes occur annually in various regions, making civilian populated areas vulnerable to damage, hindering the country's structural development process, and threatening the future of the younger generation.

An earthquake is a physical phenomenon marked by vibrations of the earth at varying intensities. Tectonic earthquakes have a much larger scale compared to other types, resulting in more significant impacts on buildings (Siswanto et al, 2018).

Manado, the main capital of North Sulawesi, has experienced several earthquakes that could affect local residence and existing structures. For instance, from April 12-18, 2024, 81 tectonic earthquakes were recorded, according to the Meteorology, Climatology, and Geophysics Agency (Indonesian: Badan Meteorologi, Klimatologi, dan Geofisika, abbreviated BMKG), as in Figure 1. In 2023, a 6.2 magnitude earthquake struck the northwest of Halmahera in North Maluku, causing severe damage to infrastructure and residential buildings in Manado.

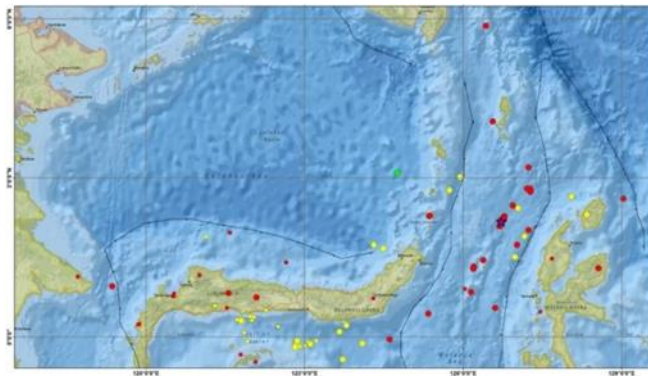


Figure 1. Earthquake Epicenter Distribution Throughout North Sulawesi Regions

One of the infrastructures affected by earthquakes is educational institutions like schools. Schools are formal educational institutions that serve as learning spaces for children and teenagers. As shown in Figure 2, here is an example of a school damaged by an earthquake.



Figure 2. School in Cianjur, West Java, That Collapsed after Being Shaken by Earthquake

Therefore, the government immediately intervened to help the children fulfill their educational needs by constructing new permanent or temporary institutions, like schools. However, the construction methods sometimes require a lot of time and money, so a new construction method is needed. The use of knock-down precast concrete components, such as Simple and Healthy Instant Home (Indonesian: Rumah Instan Sederhana Sehat, abbreviated RISHA), can be a solution in building schools with relatively efficient prices and construction times.

LITERATURE REVIEW

Simple and Healthy Instant Home (Rumah Instan Sederhana Sehat [RISHA])

Simple and Healthy Instant Home, also in Indonesian: Rumah Instan Sederhana Sehat, abbreviated RISHA, is a precast concrete system using a knock-down concept, where the construction process does not require mixing concrete on-site but rather a firm connection between two structural panels using bolts. In this technology, the main structural components consist of 3 panels, namely: type 1 structural panel (P1), type 2 structural panel (P2), and node or specialized joint (P3), as shown in Figure 3.

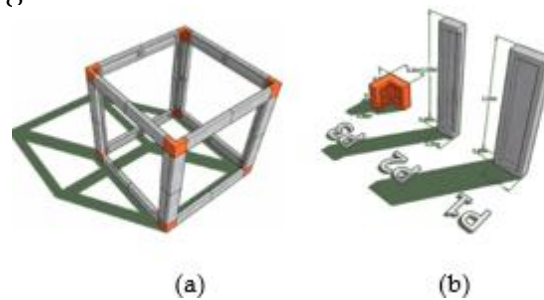


Figure 3. RISHA's 3 X 3 M Structural Module (A) and Each of Their Respective Components (B)

The three RISHA panels are part of the structural frame system (PUSKIM, 2015). Conceptually works like Legos, the construction can be completed at a much higher rate of time, which can be assembled and disassembled, as well as RISHA. This method of construction is highly suitable for construction in disaster-affected areas due to its rapid implementation and cost efficiency, making it an ideal solution for providing infrastructure, such as housing for displaced individuals or schools for children, at a faster rate of time (Lestari, 2020). Figure 4 is an example of house construction using methods of RISHA, from early construction to its final result.



Figure 4. An Example of House Construction Using Methods of Risha, From Early Construction (A) to Its Final Result (B)

The advantages of this method include shorter work implementation time, budget cost reduction of up to 10% (relative), better quality, being environmentally friendly, being more resistant to earthquakes, relatively light construction, and being able to be assembled and disassembled in situ. Based on test results (compression test, shear test, bending test, and full building test on the RISHA building, two floors), which have been carried out in the laboratory and field, it shows that RISHA's building has reliability against earthquake loads up to zoning area 6 (i.e., the highest earthquake risk area in Indonesia). Figure 5 showcased the component's strength against lateral load during lateral load test.

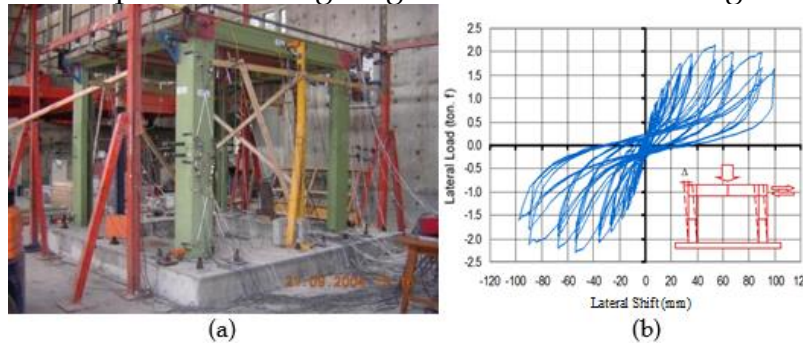


Figure 5. RISHA's 3 X 3 M Structural Module When Tested in Laboratory for Structure and Construction Against Lateral Load and Lateral Shift (A), To Its Final Result (B)

However, some of the drawbacks include the limited number of floors, because the maximum for RISHA buildings is 2 floors; the span between columns is limited to a maximum of 3 meters; each room module measures 3×3 m, so a sheer level of understanding of the structure is needed when designing buildings; and because the components refer to modular sizes, the size and model of the floor plan is very rigid, so if you have a site with a size outside the module or want to design with a unique model, then the processes will be difficult (Punuindoong et al, 2022).

METHODOLOGY

The research method used is a qualitative approach and a quantitative approach. Literature study activities were also carried out to better understand the next proper steps for the study.

The implementation begins with designing a concept for school buildings using RISHA components. The concept was made, which was then used to create the structural drawings and 3D images using AutoCAD software. The drawings from AutoCAD software can be used as a reference in calculating the work volume so that the required costs can be obtained.

After designing and making structural drawings, we proceed with calculating the work volume and the budget plan in the form of a Bill of Quantities (BOQ), as well as the work duration needed to complete this construction, using Microsoft Excel as its software. The work duration needed to complete the construction using the RISHA method was calculated from Eq. 1:

$$T_{(Hours)} = \frac{V}{P} \dots\dots\dots (1)$$

Where in this equation:

$T_{(Hours)}$: time required to complete the task in hours;

V : volume of work which obtained from number of panels, by calculating total amount of components used;

P : productivity rate, where the average efficiency of component installation by workers is 3 panels per hour (PUSKIM, 2015).

To convert the time required to complete (T) from hours to days, the calculation was made from Eq. 2:

$$T_{(Days)} = \frac{T_{(Hours)}}{LH} \dots\dots\dots (2)$$

Where LH is the labor hours, which in Indonesia are around 7 hours average in one day.

Material Data

The material specifications that were used in each of RISHA's components are as follows.

1. Concrete Material

- Concrete Compressive Strength (f_c'): 21,7 MPa
- Weight of concrete volume (γ_c): 2.400 kg/m³
- Modulus of elasticity (ϵ_c): 21.894 MPa

2. Reinforcement Bar Materials

- Main Rebar Size: Ø8 mm
- Stirrups Rebar Size: Ø6 mm

Component and Reinforcement Details

The detailed pictures of RISHA components, from their rebar detailing images to their real-life examples, can be seen from Figure 6 to Figure 8.

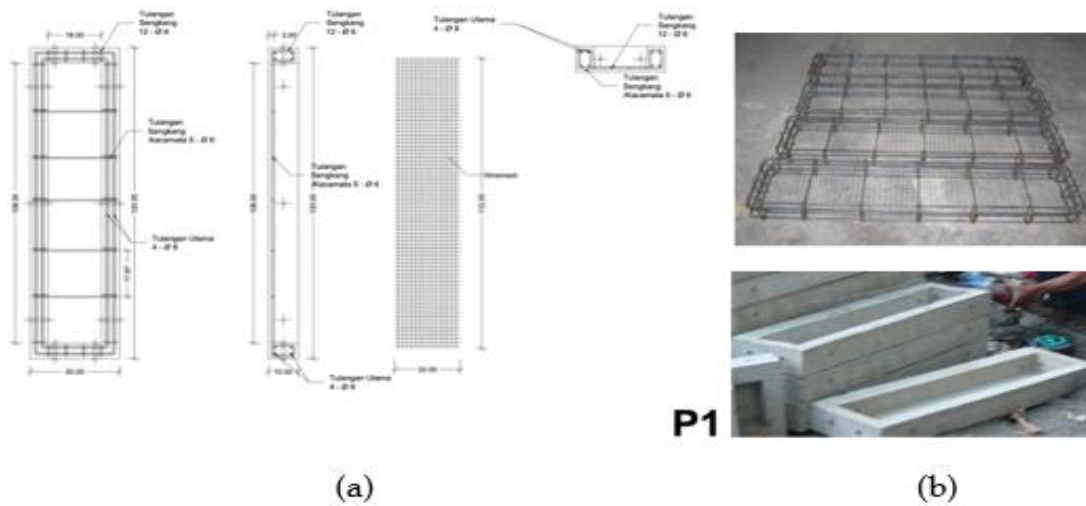


Figure 6. Component and Reinforcement Details for P1, Consists of its Rebar Detailing (A) and Real-Life Example (B)

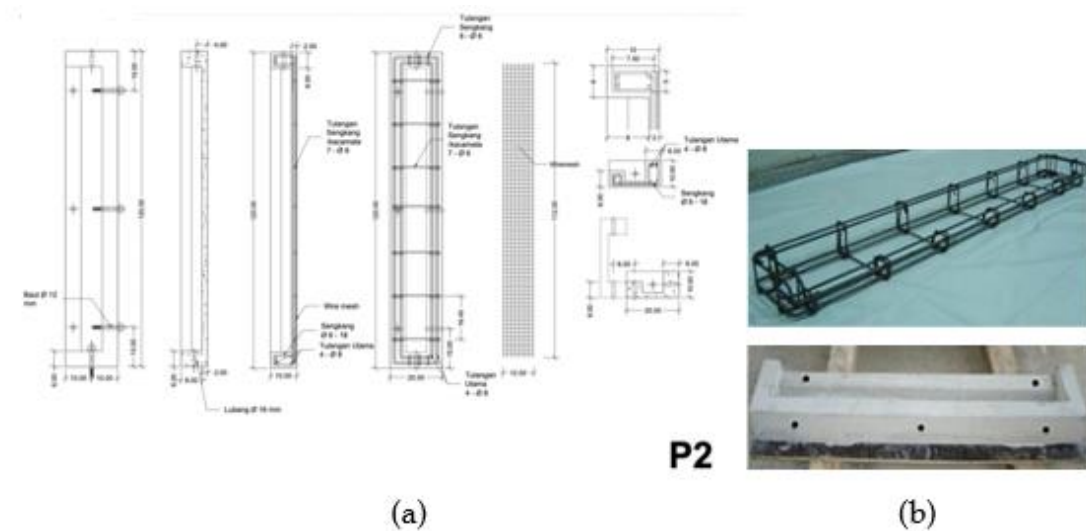


Figure 7. Component and Reinforcement Details for P2, Consists of its Rebar Detailing (A) and Real-Life Example (B)

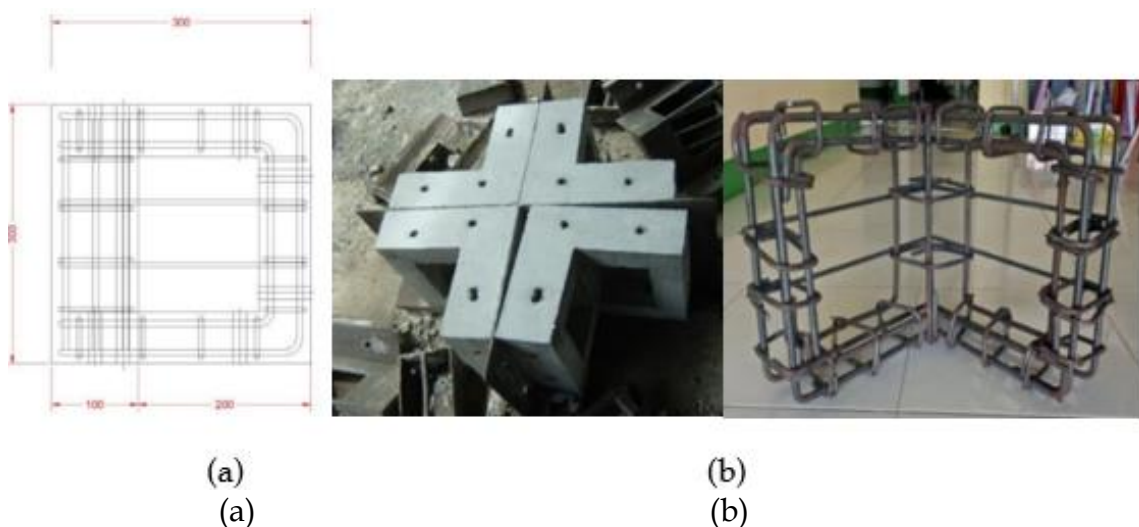


Figure 8. Component and Reinforcement Details for P3, Consists of its Rebar Detailing (A) and Real-Life Example (B)

Reinforcing Joint Elements

Each RISHA panel requires a strong connector, which utilizes dry joints such as bolts, nuts, and metal strips, as shown in Figure 9.

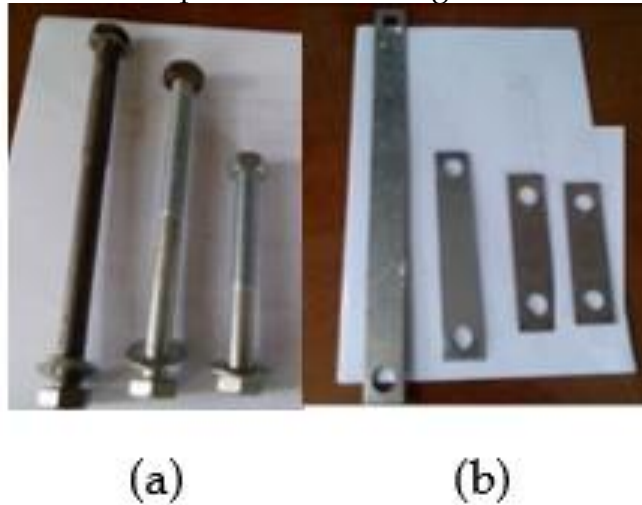


Figure 9. Connector Elements For RISHA Panels That Consist of: Bolts, Nuts (A), and Metal Plates (B)

Each panel connection uses two joints, with each panel having two connection holes at its ends. The size of the bolts used depends on the panel's specifications. The panels have been tested and researched, showing that using beams consisting of three panels and adding reinforcing connector elements is the best option to enhance the stiffness of RISHA beams (Carissa et al, 2023).

RESULT AND DISCUSSION

Initial Planning Data for the Design

For the design, the school consists of two separate units within one single area that has an approximate land area of around 1625 m². Each school unit consists of three classrooms for different grades and one restroom, with one additional room specifically for the teachers.

The number of components varies on each unit, with a total of 910 components being used; that includes P1 (520 panels), P2 (184 panels), and P3 (206 panels). The information for each unit is as follows.

1. The first unit, with a building area of around 108 m², consists of three classrooms and one restroom, with a total of 417 components being used, which includes P1 (238 panels), P2 (84 panels), and P3 (95 panels).
2. The second unit, with a building area of around 132 m², consists of three classrooms, one teacher's room, and one restroom, with a total of 493 components being used, which includes P1 (282 panels), P2 (100 panels), and P3 (111 panels).

3D Design Render and Floor Plan

The following are the pictures of the school's design, starting from 3D rendering to its details.

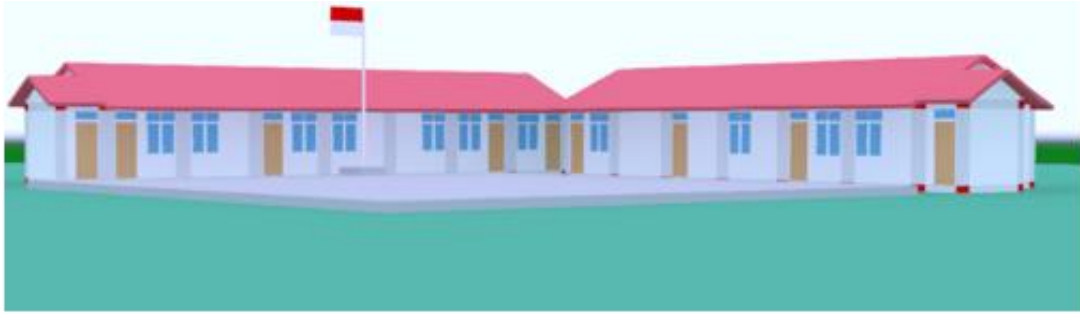


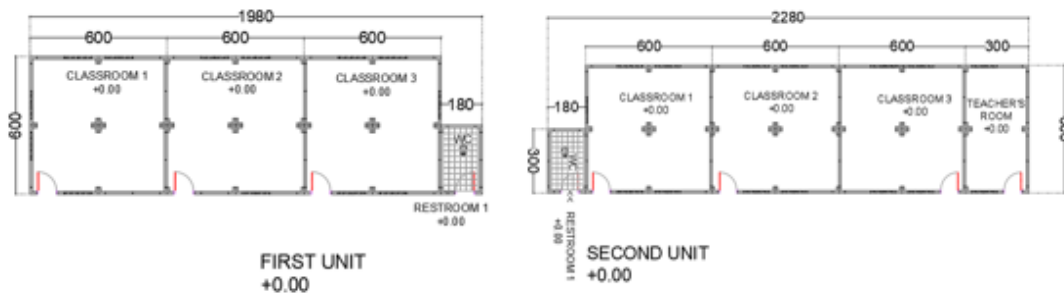
Figure 10. 3D Render of the Earthquake-Resilient School Using Method of RISHA that Consist of two units, which is SECOND Unit (Left) and the First Unit (Right)



(a)

(b)

Figure 11. 3D Render of the School's First Unit (A) and the Second Unit (B)



(a)

(b)

Figure 12. Structural Floor Plan Drawings of the School's First Unit (A) and the Second Unit (B)

Calculation of Cost Budget Plan and Installation Time of RISHA Panels

The bill of quantities (BOQ) for all the panels for each school unit, along with the connecting components, was obtained using Manado City's year 2022 release of Unit Price Analysis. The price result will be converted from Indonesian currency (Rupiah) to United States Dollar (USD). Results of the budget calculation, which can be seen in Table 1 and Table 2, are as follows.

Table 1. Bill of Quantities For Unit 1 Building Structure Budgets

Name of Items	Quantity	Unit	Unit Price (Rp)	Total Price (Rp)
Panel 1	238	Pcs	Rp104,175.20	Rp24,793,697.60
Panel 2	84	Pcs	Rp80,868.79	Rp6,792,978.36
Panel 3	95	Pcs	Rp80,924.67	Rp7,687,843.65
D12 bolts 4" long	266	Ls	Rp4,500.00	Rp1,197,000.00
D12 bolts 7" long	544	Ls	Rp7,500.00	Rp4,080,000.00
Metal plates 8 cm	168	Ls	Rp12,000.00	Rp2,016,000.00
Metal plates 13 cm	283	Ls	Rp15,000.00	Rp4,245,000.00
Metal plates 30 cm	33	Ls	Rp25,000.00	Rp825,000.00
Ø12 steel anchor 40 cm long	96	Pcs	Rp19,900.00	Rp1,910,400.00
TOTAL				Rp53,547,919.61
ROUNDED				Rp53,550,000.00

Table 2. Bill of Quantities for Unit 2 Building Structure Budgets

Name of Items	Quantity	Unit	Unit Price (Rp)	Total Price (Rp)
Panel 1	282	Pcs	Rp104,175.20	Rp29,377,406.40
Panel 2	100	Pcs	Rp80,868.79	Rp8,086,879.00
Panel 3	111	Pcs	Rp80,924.67	Rp8,982,638.37
D12 bolts 4" long	332	Ls	Rp4,500.00	Rp1,494,000.00
D12 bolts 7" long	642	Ls	Rp7,500.00	Rp4,815,000.00
Metal plates 8 cm	197	Ls	Rp12,000.00	Rp2,364,000.00
Metal plates 13 cm	347	Ls	Rp15,000.00	Rp5,205,000.00
Metal plates 30 cm	38	Ls	Rp25,000.00	Rp950,000.00
Ø12 steel anchor 40 cm long	114	Pcs	Rp19,900.00	Rp2,268,600.00
TOTAL				Rp63,543,523.77
ROUNDED				Rp63,550,000.00

The total budgets needed for both units were then converted from Indonesian Rupiah (IDR) to United States Dollar (USD). Additionally, the estimation of construction time for assembling the structure with RISHA was also carried out using Eq. 1 and Eq. 2. The results can be seen in Table 3.

Table 3. Total Budget (IDR to USD) and Construction Time for Both Units

Units	Total Budgets (IDR to USD)	Construction Time (Days)
1	\$3,375.00	20 Days
2	\$4,005.00	23 Days

Comparison Between Conventional Method and Method of RISHA

In order to showcase the efficiency of using RISHA components in terms of budget plan and work duration, we decided to calculate the cost budget plan and its duration on the same two units of school, but with the conventional method, and run a comparison between the two methods in terms of cost and work efficiency. The results of the budget calculation and the durations for the conventional method can be seen in Table 4 and Table 5.

Table 4. Bill of Quantities for Unit 1 Structure Budgets Using Conventional

1	Formwork installation for ground beams (15 × 20 cm)	24.8	M ²	Rp401,911.06	Rp9,983,470.73	3
2	Reinforcement for ground beams (15 × 20 cm)	729.82	kg	Rp216,515.71	Rp158,016,982.76	4
3	Concrete casting for ground beams (f _c 14.5 MPa)	1.91	M ³	Rp1,541,059.15	Rp2,940,340.86	1
4	Formwork installation for columns (15 × 15 cm)	41.4	M ²	Rp602,147.67	Rp24,928,913.54	2
5	Reinforcement for columns (15 × 15 cm)	1102.6	kg	Rp216,515.71	Rp238,729,771.49	6
6	Concrete casting for columns (f _c 14.5 MPa)	1.6	M ³	Rp1,541,059.15	Rp2,392,494.33	1
7	Formwork installation for tie beams (15 × 20 cm)	39.15	M ²	Rp619,309.22	Rp24,245,955.96	2
8	Reinforcement for tie beams (15 × 20 cm)	818.59	kg	Rp216,515.71	Rp177,238,381.43	4
9	Concrete casting for tie beams (f _c 14.5 MPa)	2.99	M ³	Rp1,541,059.15	Rp4,604,684.74	1
10	Excavation for foundation	50.88	M ³	Rp160,770.00	Rp8,179,977.60	3
11	Stone masonry work for foundation	24.17	M ²	Rp1,270,916.00	Rp30,715,497.89	8
TOTAL					Rp681,976,471.34	
ROUND					Rp681,976,472.00	35 Days
IDR To USD					\$42,965.00	

Table 5. Bill of Quantities for Unit 2 Structure Budgets Using Conventional Method

No	Description	Quantity	Units	Unit Price (Rp)	Total Price (Rp)	Construction Time (Days)
1	Formwork installation for ground beams (15 × 20 cm)	37.9	M ²	Rp401,911.06	Rp15,216,352.73	2
2	Reinforcement for ground beams (15 × 20 cm)	1108.5	kg	Rp216,515.71	Rp240,006,926.65	6
3	Concrete casting for ground beams (f _c 14.5 MPa)	2.9	M ³	Rp1,541,059.15	Rp4,465,989.42	1
4	Formwork installation for columns (15 × 15 cm)	46.8	M ²	Rp602,147.67	Rp28,180,510.96	3
5	Reinforcement for columns (15 × 15 cm)	1092.5	kg	Rp216,515.71	Rp236,551,346.31	6
6	Concrete casting for columns (f _c 14.5 MPa)	1.8	M ³	Rp1,541,059.15	Rp2,704,558.81	1
7	Formwork installation for tie beams (15 × 20 cm)	52.0575	M ²	Rp619,309.22	Rp32,239,689.72	3
8	Reinforcement for tie beams (15 × 20 cm)	1108.5	kg	Rp216,515.71	Rp240,006,926.65	6
9	Concrete casting for tie beams (f _c 14.5 MPa)	2.9	M ³	Rp1,541,059.15	Rp4,465,989.42	1
10	Excavation for foundation	77.28	M ³	Rp160,770.00	Rp12,424,305.60	5
11	Stone masonry work for foundation	36.71	M ²	Rp1,270,916.00	Rp46,652,784.53	6
TOTAL					Rp862,915,380.79	
ROUND					Rp862,915,381.00	40 Days
IDR To USD					\$54,364.00	

After running through the analysis, the comparison between both methods is summarized in Table 6, which consists of two units of school, with each of their total price and duration time compared.

Table 6. Total Budget and Duration Time Comparison Between Conventional and RISHA Method for Both Units

Unit 1			
Total Budget (USD)		Duration Time	
Conventional	RISHA	Conventional	RISHA
\$42,965.00	\$3,375.00	35 Days	20 Days
Unit 2			
Total Budget (USD)		Duration Time	
Conventional	RISHA	Conventional	RISHA
\$54,364.00	\$4,005.00	40 Days	23 Days

Based on the budget and time comparison between the conventional and RISHA methods for school design, the RISHA method is the most efficient in terms of budget and work duration, with a price difference of \$39,590.00 for the first unit and \$50,360.35 for the second unit. For time comparison, the method of RISHA is superior, with a difference of 15 days or 360 working hours for the first unit, and for the second unit, it is 17 days or 408 working hours.

CONCLUSION AND RECOMMENDATION

Based on the results of the discussion obtained, the research conducted provides several results, and the results are as follows.

1. The design of the earthquake-resilient school consists of two units of elementary school, using a knock-down precast concrete system named RISHA. From the designs, the school has a distinct building area for each unit, with a building area of the first unit of 108 m², whereas the second unit has a building area of 108 m². Also, the total usage of RISHA panels varies on each unit, with the first unit having a total of 417 components being used, whereas the second unit has a total of 493 components.
2. The total budget and duration time for each unit also vary depending on how large the units are. For the budgets, the first unit requires around Rp 53,550,000.00 in Indonesian currency, which is equivalent to \$3,375.00 in United States dollars (USD), whereas the second unit requires around Rp 63,550,000.00 or around \$4,005.00. For the duration needed to assemble, the first unit only needs 20 days to finish, whereas the second unit needs 23 days to finish.
3. To evaluate the efficiency of the RISHA method, a comparative analysis was conducted between the RISHA and conventional construction methods applied to the school units. The conventional method requires a budget of Rp681,976,472.00 (\$42,965.00) and a completion time of 35 days for the first unit. For the second unit, the budget was Rp862,915,381.00 (\$54,364.00), with a construction time of 40 days. In contrast, the RISHA method demonstrated cost savings of approximately \$39,590.00 for the first unit and \$50,360.35 for the second unit. Additionally, the RISHA method reduced the construction period by 15 days (360 working hours) for the first unit and 17 days (408 working hours) for the second unit.

Based on the results, it can be concluded that the school design for earthquake disaster victims using the RISHA method has a variety of advantages, such as time efficiency, more guaranteed quality, and a fairly affordable price. In addition, the school can provide a sense of security and comfort for students and teachers during the teaching and learning process.

FURTHER STUDY

This research still has limitations so further research is needed related to the topic Implementation of Knock-Down Precast Concrete System for Earthquake-Resilient School Designs in Order to Refine this research and increase insight for readers

ACKNOWLEDGMENT

The authors would like to thank the Center for Research and Community Service (Pusat Penelitian dan Pengabdian pada Masyarakat [P3M]), Manado State Polytechnic, for funding support through the 2024 Student Creativity Research (Penelitian Kreativitas Mahasiswa 2024) scheme, and also all parties who have assisted on this research.

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