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Development and Analysis of an Innovative Precast Concrete U-Shell Beam

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Abstract

Precast concrete offers several advantages compared to conventional systems; precast concrete structure technology has become a strategy to enhance standardization, quality control, labor efficiency, and reduce environmental impact and construction pollution. The U-Shell precast beam is a reinforced concrete beam with a 'U' shape designed to enhance practicality and expedite the construction process as it does not require additional formwork and shoring during implementation. The U-Shell beam functions as a permanent formwork, and its design follows either monolithic or conventional methods. In multi-story buildings, using U-Shell beam can increase practical value, reduce costs, and improve time efficiency because they do not require additional formwork and scaffolding in the implementation application. This research involves the development of U-Shell precast beams, structure loading considering various loads, modeling using computer program to determine the structural reactions on each element, reinforcement design for the U-Shell beam structure, and analysis of the lifting and assembly of U-Shell precast beam. The building selected for reviewing U-Shell beams is the Building with a Special Moment Resisting Frame System. From the results of the analysis, the researcher drew several conclusions regarding the reinforcement design for the U-Shell beam under both conditions. In the condition before composite, the number of installed main reinforcements is 6 with a diameter of 13 mm, while in the condition after composite, the number increases to 8 with a diameter of 16 mm. Lifting reinforcement requires a diameter of 10 mm. The difference in reinforcement between before composite and after composite conditions is because before the composite the beam is still receiving self-load, whereas for the after composite condition the change in moment occurs. After all, the beam has received self-load and other loads. The development and analysis of an innovative precast concrete U-Sheel beam has complied with strength and serviceability.

Keywords: Design; Development; Precast system; U-shell beam

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1. Introduction

Precast concrete offers several advantages compared to conventional (cast-in-place) systems. Essentially, this system involves casting components (fabrication) at specific locations, whether it's on the ground surface, in a factory, or on the project site's ground floor, which are then assembled to form a complete structure [1]. Precast concrete structures are recognized as assemblies of monolithic elements manufactured to fabrication standards and then transported to the construction site for assembly [2]. In the last decade, precast concrete structure technology has emerged as a strategy to enhance standardization, quality control, labor efficiency, and reduce environmental impact and construction pollution [3][4]. Realization of precast structures is still relatively limited, especially earthquake-resistant precast structures, as evidenced by research conducted by [5] on precast structures that collapsed due to earthquakes. Therefore, there is a need for significant development in terms of precast structural elements.

Innovations have been plentiful in precast products, one of which is the U-Shell beam, commonly referred to as U-Shaped, representing a development and innovation in precast beams frequently applied in Indonesia. The U-Shell precast beam is a reinforced concrete beam with a 'U' shape designed to enhance practicality and expedite the construction process as it does not require additional formwork and shoring during implementation. The U-Shell beam functions as a permanent formwork, and its design follows either monolithic or conventional methods. The structural behavior of the U-Shell beam in precast method is analysed both before composite (U-Shell beam) and after becoming composite (complete beam) [6]. U-Shell precast beams support their own weight as well as construction loads during the assembly of structural elements [7]. U-Shell beam is combination of precast concrete and cast-in-place concrete systems. While the basic planning of U-Shell beams is like planning beams using conventional methods, the difference lies in the need to calculate the installation conditions when the concrete is still easily workable. Therefore, in the planning of U-Shell beams, it is necessary to consider the reinforcement capacity to prevent cracking. The precast U-

Shell method requires specific analysis and design considerations that are not accounted for in the analysis of monolithic or conventional concrete [5].

The use of U-Shell Precast Beams has been widely applied, especially in multi-story buildings. In high-rise buildings, this method can reduce costs and improve time efficiency. The application of U-Shell Beams is illustrated in Figure 1 [8]. The application method of U-Shell beams can be carried out as a whole or partially, with partial applications typically focused on the column face area to facilitate assembly between beam and column elements, as seen in the research [9][10][5]. During implementation, lifting U-Shell precast beams using a tower crane will affect the moments acting on the beam before it is assembled into the structure. U-Shell precast beams must be designed considering the loads and moments during both lifting and assembly. Additionally, the position of the lifting cable for U-Shell beams must also be considered, as it serves as the support for the tower crane. If the cable position is not properly accounted for, it can lead to imbalance and pose a risk of the beam breaking at the support point [11].

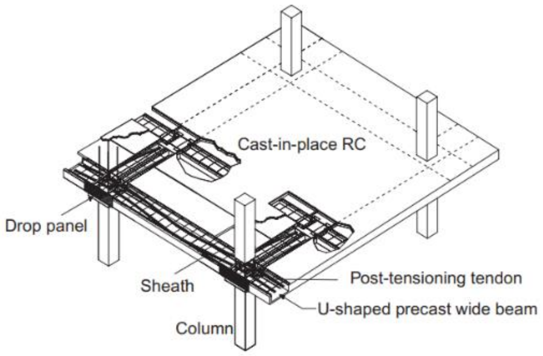
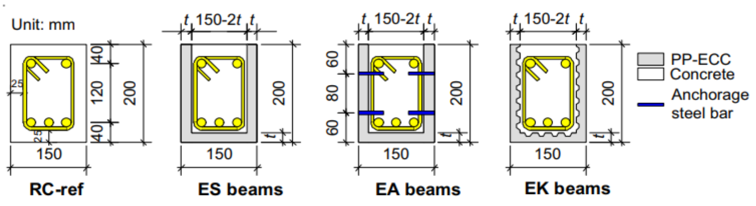


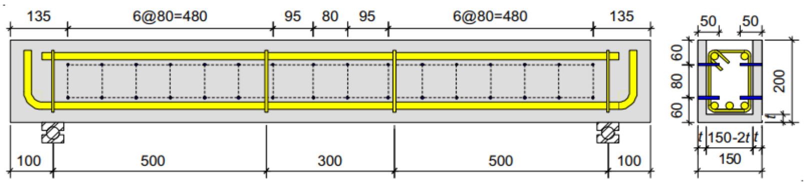
Figure 1. Precast U-Shell Beam Application in Building Construction [8]

In this study, the development of U-Shell precast beam will be conducted. Structure loading will be carried out to various loads, followed by modeling using computer program to determine structural reactions in each element. Subsequently, the reinforcement design for U-Shell beam structures will be performed, an analysis will be conducted on the lifting and assembly of U-Shell precast beam. The building chosen for reviewing U-Shell beams is the Building with a Special Moment Resisting Frame System.

Development related to U-Shell precast beams has been extensively conducted, including research carried out by [12] that compared the capacity analysis of conventional beam-column connection elements with the precast system using U-Shell beams. Furthermore, research conducted by [13] involved the development of U-Shell precast beams with ECC material, considering shell thickness parameters of 15, 20, and 25 mm. Subsequently, testing was conducted to investigate shear behavior and failure mechanisms. The design of U-Shell precast beams and reinforcement in the study conducted by [13] is illustrated in Figure 2.



(a) Cross section and reinforcements of all beams.



(b) Arrangement of anchorage steel bars in EA beams.

Figure 2. Cross section and reinforcement details [13]

Here introduce the paper, and put a nomenclature if necessary, in a box with the same font size as the rest of the paper. The paragraphs continue from here and are only separated by headings, subheadings, images and formulae. The section headings are arranged by numbers, bold and 11 pt. Here follows further instructions for authors.

Furthermore, research conducted by [14] involved the development of U-Shell beams with Reactive Powder Concrete (RPC) material, aiming to investigate the mechanical properties of RPC and the flexural capacity of U-Shell beams. The test results revealed that the use of U-Shell beams with RPC material and thicker shells proved effective in delaying the cracking moment of U-Shell shells. This study also obtained results regarding moment capacity, hysteresis curves, and failure modes of the beam elements. The detailed configuration of several specimens tested in this study can be seen in Figure 3.

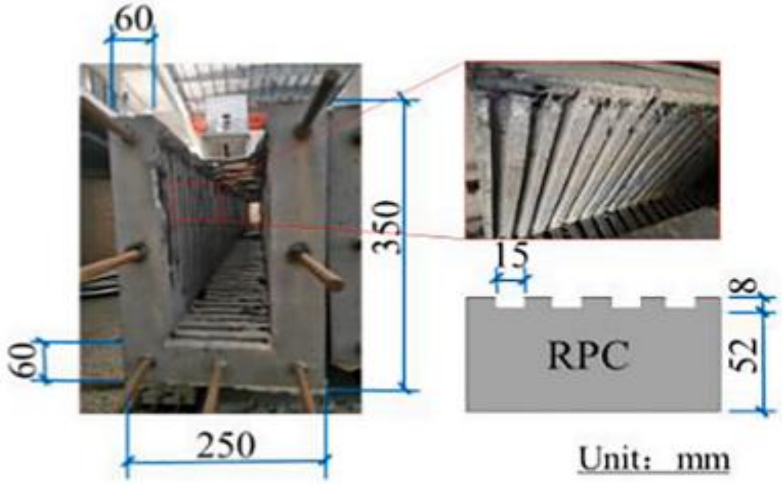


Figure 3. Details of the RPC permanent formwork [14]

The development of U-Shell beams is widely applied in research on precast beam-column connections. In a study conducted by [15], U-Shell beams were implemented in UHPC (Ultra-High-Performance Concrete) connections designed to withstand seismic loads. U-Shell beams were applied to the column face, and the research results indicated that the use of UHPC with U-Shell achieved a ductility 4% greater than that of conventional specimens. The installation scheme of UHPC with U-Shell beams in the study by [15] is illustrated in Figure 4.

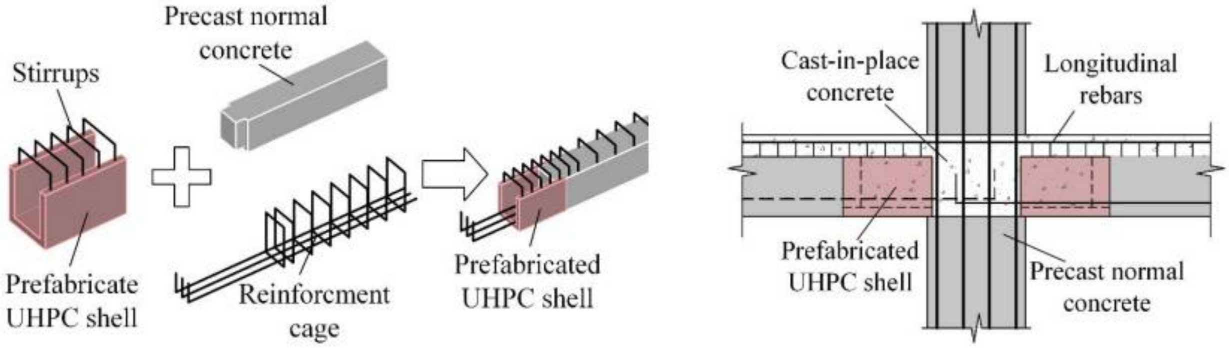


Figure 4. Schematic of the novel precast beam-to-column connection [15]

2. Materials and Method

In this study, several stages will be undertaken to achieve the results. These include data collection, system structural, and soil data related to the building that will be used as a reference in planning and design. Subsequently, a preliminary design of U-Shell precast beam will be conducted, allowing for load analysis, modeling, structural reaction analysis, reinforcement design for U-Shell precast beams, and assembly analysis.

2.1. Structural Data

Structural data is required to support the research when remodeling the structural elements of U-Shell precast beams. The geometric data of the building/floor plan can be seen in Figure 5.

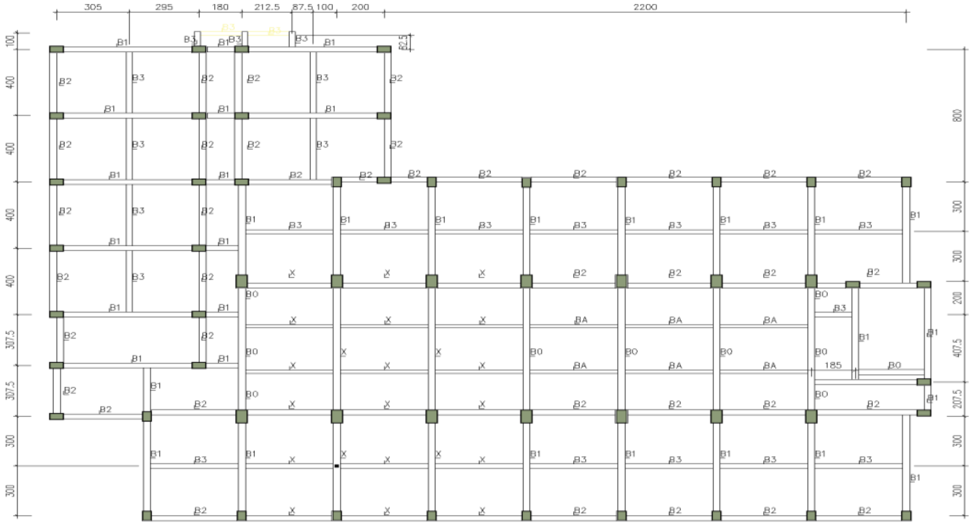


Figure 5. Beam Layout

Quality of Materials
Concrete : 35 MPa
Reinforcement : 400 MPa
Building Data
Location : Surabaya, East Java
Section Area : 850.65 m^2
Number of Floor : 5 Stories
Material : Reinforced Concrete
Site Class of Soil : C
Structural System : SMRF
Dimensions of Existing Beams
Beam Height : 50 cm
Beam Wide : 30 cm
Beam Span : 5.4 m

2.2. Soil Data

In this research, soil data is needed to determine the classification value of soil sites in the area to be reviewed in the form of NSPT data (Surabaya). Soil data can be seen in Table 1.

Table 1. NSPT Data

Depth (m)	**Type of Soil**	**N-SPT**	**N-Avg**	**Fi (t/m^2)**
0.00	Silty Sand	0	0	0
-1.00	Silty Sand	0	1	0
-2.00	Silty Sand	6	6	1.2
-3.00	Silty Sand	11	11	2.2
-4.00	Silty Sand	13	13	2.6
-5.00	Silty Sand	16	15	3.2
-6.00	Silty Sand	13	13	2.6
-7.00	Sandy Silty Clay	10	10	10
-8.00	Sandy Silty Clay	7	8	7
-9.00	Sandy Silty Clay	11	11	11
-10.00	Silty Sand	16	15	3.2

-11.00	Silty Sand	17	17	3.4
-12.00	Silty Sand	18	18	3.6
-13.00	Silty Sand	19	19	3.8
-14.00	Clayy Silt Sand	20	20	4
-15.00	Clayy Silt Sand	21	21	4.2
-16.00	Clayy Silt Sand	23	23	4.6
-17.00	Clayy Silt Sand	25	25	5
-18.00	Clayy Silt Sand	27	29	5.4
-19.00	Clayy Silt Sand	44	44	8.7
-20.00	Clayy Silt Sand	60	57	10
-21.00	Clayy Silt Sand	60	60	10
-22.00	Clayy Silt Sand	60	60	10
-23.00	Clayy Silt Sand	60	60	10
-24.00	Clayy Silt Sand	60	60	10
-25.00	Clayy Silt Sand	60	60	10
-26.00	Clayy Silt Sand	60	60	10
-27.00	Clayy Silt Sand	60	60	10
-28.00	Clayy Silt Sand	60	60	10

2.3. *Preliminary Design*

The preliminary design is the first step to determine the dimensions of the building structure. The purpose of this preliminary design is to establish the cross-sectional dimensions of the structural elements that will be redesigned in the building. In the planning of beam dimensions, the determined parameters are the height and width of the beam, which can be calculated based on equations 1 and 2.

$$\text{Beam Height } (h) = \frac{l}{16}\ x\ (0.4 + \frac{fy}{700}) \qquad (1)$$

$$\text{Beam Wide } (b) = \frac{1}{2}h - \frac{2}{3}h \qquad (2)$$

Where fy is mutu baja (MPa) and l is the beam length.

2.4. *Structure Loading*

The analysis of loading in this research refers to the loading regulations [16][17][18], including:

1. Dead Load

According to [17], dead load is the load caused by the self-weight of the building, such as beams, columns, and slabs. In addition to the loads caused by the main structure of the building, the identification of dead loads is also obtained from additional elements in the structure that are fixed and inseparable, such as walls, roof floors, and planned architectural and structural components. In this study, the calculation of dead loads from materials will be performed using the computer program. By inputting material data and planned dimensions, the program will automatically determine the weight of the material. The dead load applied in the load design is detailed in Table 2.

Table 2. Dead Load

Material	**Load (kg/m^2)**
Ceramic Tile	24
Cement Floor (1cm)	21
ME	25
Plafond	18
Brick Wall	250

2. Live Load

Live load is the load generated due to the use and activities in the building and is not part of the building's structure. Each space function in the building will have a different load. The live load in this study is detailed in Table 3.

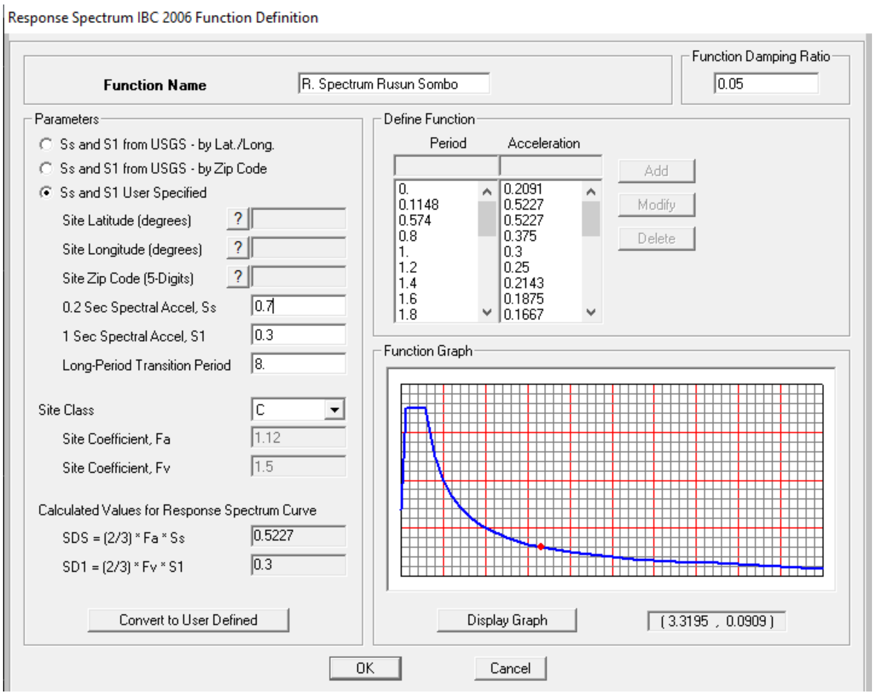
Table 3. Live Load

Function	**Load (kg/m^2)**
Private Room	192
Public Room	479

Roof	479
Garage	192
Stair	133
Restaurant	479

3. Seismic Load

Seismic load is the load that acts on the building structure caused by the movement of the ground that affects the building structure. In this study, seismic loading using the response spectrum function will be conducted with the assistance of computer program. The response spectrum will be presented in the form of a graph showing the vibration period of the structure against the maximum response damping ratio and a specific earthquake. The Design Response Spectrum, analyzed based on [18], is illustrated in Figure 6. Analysis of the design response spectrum using the computer program to obtain the Design Response Spectrum diagram. The following are the results of the spectrum response design for Semampir, Surabaya with site class C soil type.



Response Spectrum IBC 2006 Function Definition

Function Name R. Spectrum Rusun Sombo

Function Damping Ratio 0.05

Parameters

○ Ss and S1 from USGS - by Lat./Long.
○ Ss and S1 from USGS - by Zip Code
● Ss and S1 User Specified

Site Latitude (degrees)
Site Longitude (degrees)
Site Zip Code (5-Digits)
0.2 Sec Spectral Accel, Ss: 0.7
1 Sec Spectral Accel, S1: 0.3
Long-Period Transition Period: 8.

Site Class: C
Site Coefficient, Fa: 1.12
Site Coefficient, Fv: 1.5

Calculated Values for Response Spectrum Curve
SDS = (2/3) * Fa * Ss: 0.5227
SD1 = (2/3) * Fv * S1: 0.3

Define Function

Period	Acceleration
0.	0.2091
0.1148	0.5227
0.574	0.5227
0.8	0.375
1.	0.3
1.2	0.25
1.4	0.2143
1.6	0.1875
1.8	0.1667

Function Graph

(3.3195 , 0.0909)

Figure 6. Response Spectrum Design

2.5. *Structural Modeling Using Computer Program*

The structural modeling in this study will be carried out in 3D, and the modeling steps are conducted to obtain outputs/force reactions within the structure.

2.6. *Reinforcement Capacity Design*

Reinforcement analysis is conducted to ensure that the reinforcement to be used meets the standards. In the planning of structural elements such as beams, the nominal moment value (Mn) must be greater than the ultimate moment (Mu). This is planned so that when the beam receives the ultimate load, the beam does not experience structural failure. The following equation (3) and (4) is used to obtain the value of Mn [19]:

$$M_n = \varphi M_n = M_n^- + M_n^+ \qquad (3)$$

$$M_n = (A_s.f_y - A_s'.f_s') \times (d - a) + A_s \times f_s'(d^+ - d^-) \qquad (4)$$

The reinforcement analysis is considered under two conditions: before composite and after composite. Under the condition before composite, there are two sub-conditions: not overtopping and already overtopping. The condition before composite occurs during the initial casting, where the precast component and the topping component cannot yet unite to carry the load. The condition after composite occurs when the topping and precast slab elements have worked together to bear the load, and the placement of the slab is considered as a clamping condition. Additionally, deflection control will be conducted in this analysis.

2.7. *Lifting Analysis*

As explained in the precast beam/U-Shell concept, the beam is fabricated in advance. Therefore, it must be designed to withstand the lifting process without damage. The strength of the lifting reinforcement must ensure the beam element's safety from any potential damage.

3. Results and Discussion

3.1. *Preliminary Design*

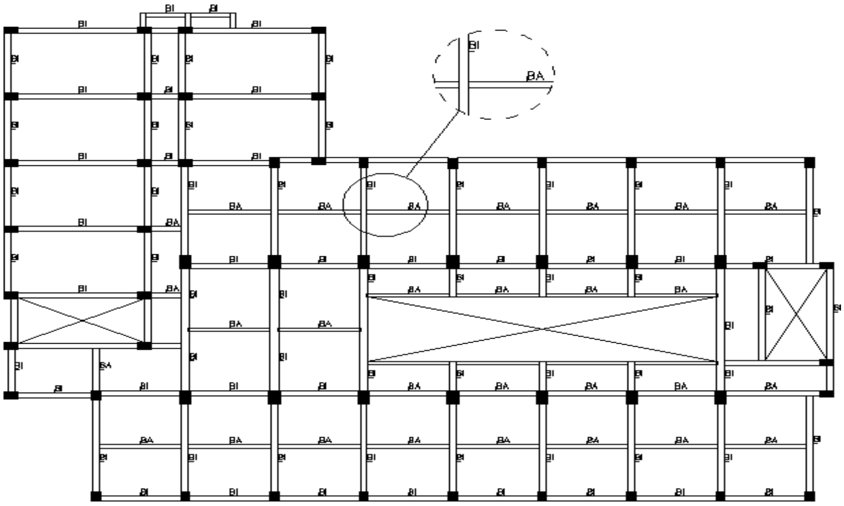


Figure 7. Beam Layout

In this study, only the main beam is being reviewed. The main beam under consideration can be seen in Figure 7. The dimensions of the beam in this study are planned as a simply supported beam with a span of 5400 mm, concrete strength of 35 MPa, and steel strength of 400 MPa. The planning is as follows:

$$\text{Beam Height } (h) = \frac{5400}{16}\ x\ \left(0.4 + \frac{400}{700}\right) = 327.8 \approx 700 \text{ mm} \tag{5}$$

$$\text{Beam Wide } (b) = \frac{1}{2}\ x\ 700 = 350 \text{ mm} \tag{6}$$

By planning the longest span in the beam's floor plan, the dimensions of the main U-Shell beam are determined to be 35 cm in width and 70 cm in depth.

3.2. *Structure Modelling Using Computer Program*

Based on the planning data, the structure of the Apartment building is modeled, and loading is applied to the structure. The structural modeling of the building can be seen in Figure 8.

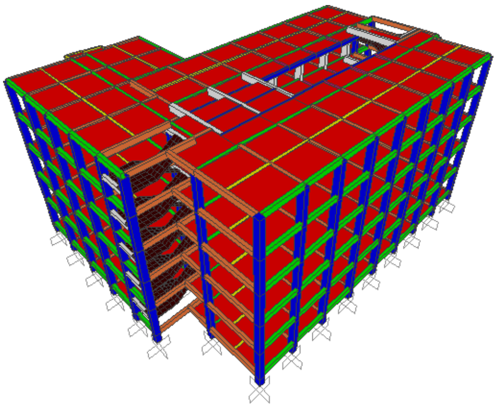


Figure 8. Structure Modelling using Computer Program

3.3. *Analysis of the Reinforcement of Precast U-Shell Beam*

Data Plan:

Beam Dimension = 35 x 70 cm
Concrete (f'_c) = 35 MPa
Reinforcement (f_y) = 400 MPa
Flexural Reinforcement = *D*13
Stirrup = ϕ 10

1. Reinforcement Analysis Before Composite

In the reinforcement planning before composite, there are two conditions. In the first condition, the beam is not yet filled with overtopping, and the loads include the self-weight of the main precast beam, the self-weight of the secondary precast beam, the self-weight of the precast slab, and the live load. In the second condition, the beam is already filled with overtopping but has not fully composite with the column structure, so its placement is still treated as a hinge placement.

a. First Condition (Not Yet Overtopping)

Beam Dimension = 35/57 cm
Length Span = 540 cm
Concrete (f'_c) = 35 MPa
Reinforcement (f_y) = 400 MPa
Concrete Strength in 7 days (f'_c) = 65% x (f'_c) = 22.75 MPa

The loads that occur when not yet overtopping include the self-weight of the main precast beam, the self-weight of the secondary precast beam, the self-weight of the precast slab, and the weight of the workers. The detailed loading conditions that occur when not yet overtopping are as follows:

$$Q_u = 1.2\,DL + 1.6\,LL = 1.2\ (471) + 1.6\ (100) = 725.2\ \text{Kg.m} \tag{7}$$

$$M_u = (1/8 \times Q_u \times L^2) + (P_u \times \frac{Lu}{2}) \tag{8}$$

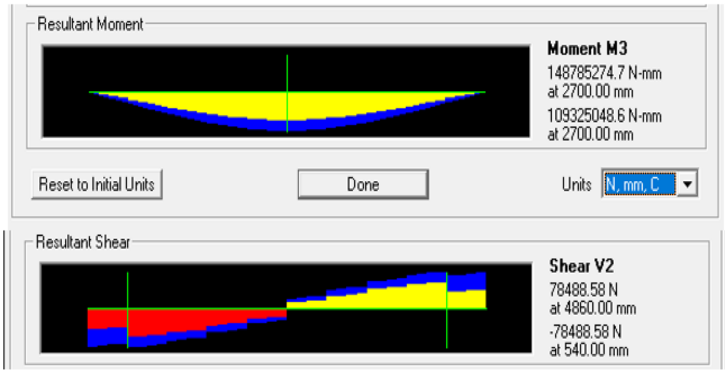
$$= (1/8 \times 725.2 \times 5.4^2) + (174 \times \frac{5.4}{2}) \tag{9}$$

$$= 3113.154\ \text{Kg.m} \tag{10}$$

b. Second Condition (Already Overtopping)

Beam Dimension = 350/700 mm
Concrete (f'_c) = 35 MPa
Reinforcement (f_y) = 400 MPa
Flexural Reinforcement = *D*13
Stirrup = ϕ 10
Concrete Strength in 14 days (f'_c) = 88% x f'_c = 30.8 MPa

In this condition, flexural and shear reinforcement will be calculated using the computer program. The ultimate moment and ultimate shear that occur in the reviewed beam can be seen in Figure 9.



```
Moment M3
148785274.7 N-mm
at 2700.00 mm
109325048.6 N-mm
at 2700.00 mm

Shear V2
78488.58 N
at 4860.00 mm
-78488.58 N
at 540.00 mm
```

Figure 9. Ultimate Moment and Ultimate Shear Output from Computer Program

Based on the forces analyzed in both the first and second conditions, the recapitulation results of the reinforcement of U-Shell beam before composite are presented in Table 4.

Table 4. Summary of U-Shell Beam Reinforcement Before Composite

Forces	**Flexural Reinforcement**	
M_u	**Top**	**Bottom**
148785274.7 N.mm	3*D*13	3*D*13
V_u	**Transversal Reinforcement**	
78488.58 N	ϕ 10 – 200	

2. Reinforcement Analysis After Composite

In the analysis of the reinforcement after composite, it is assumed that the beam has become the main structure and is already carrying all the loads working on the beam. Similarly, the placement of the beam after composite is considered a clamped placement. The floor plan of the beam under review can be seen in Figure 10.

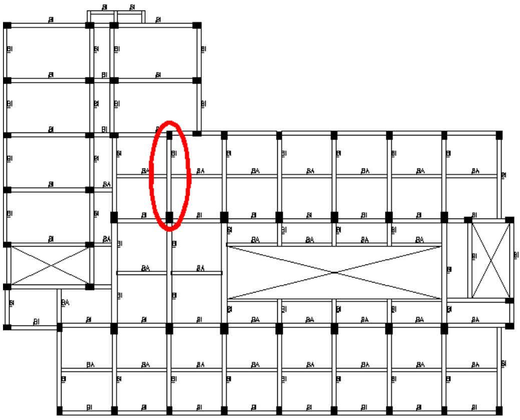
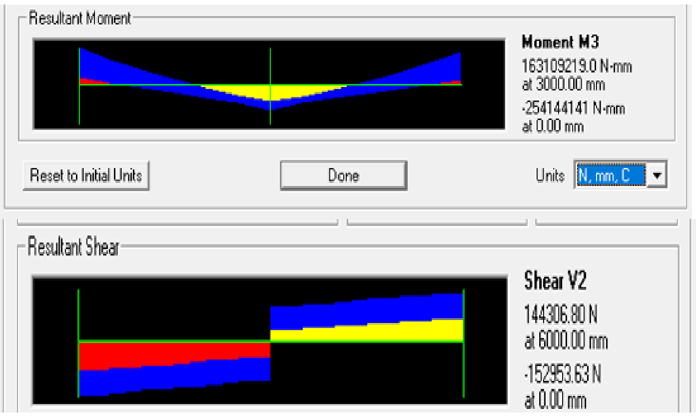


Figure 10. Layout Plan of the Reviewed U-Shell Beam

To obtain the internal forces occurring in the main beam with dimensions of 35/70 cm, the researcher used the computer program. The internal force output displayed in computer program can be seen in Figure 11.



Resultant Moment

Moment M3

163109219.0 N-mm
at 3000.00 mm

-254144141 N-mm
at 0.00 mm

Units N, mm, C

Resultant Shear

Shear V2

144306.80 N
at 6000.00 mm

-152953.63 N
at 0.00 mm

Figure 11. Ultimate Moment and Ultimate Shear Output from Computer Program

Based on the ultimate force analysis and reference to the planning regulations [19], the detailed recapitulation of U-Shell beam reinforcement data is presented in Table 5 and cross section of u-shell beam can be seen in Figure 12.

Table 5. Summary of U-Shell Beam Reinforcement After Composite

Forces	**Flexural Reinforcement**	
M_u	**Top**	**Bottom**
Field Area. : 163109219	5*D*16	3*D*16
N.mm	5*D*16	3*D*16

Support Area. :254144141 N.mm	
V_u	**Transversal Reinforcement**
152953.63 N	$\phi 10 - 150$

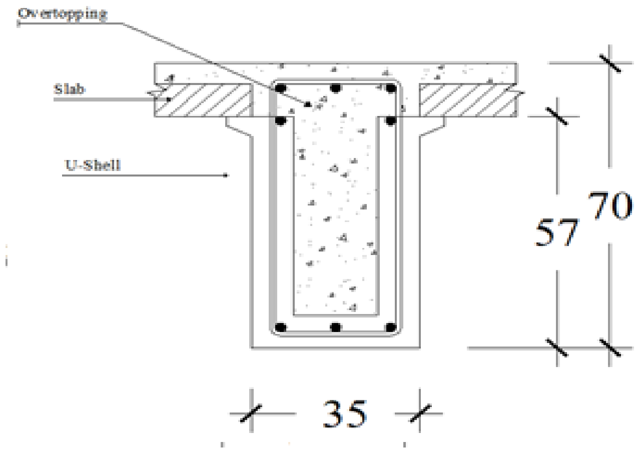


Figure 12. Cross Section of U-Shell Beam after Composite

3.4. *Deflection Control*

In the preliminary design, it was planned that the beam was designed to exceed the Hmin value, so the researcher can assume that deflection does not need to be calculated.

3.5. *Lifting of U-Shell Precast Beam Elements*

Analysis during lifting needs to be conducted to prevent damage during the lifting process. The illustration of moments during lifting can be seen in Figure 13.

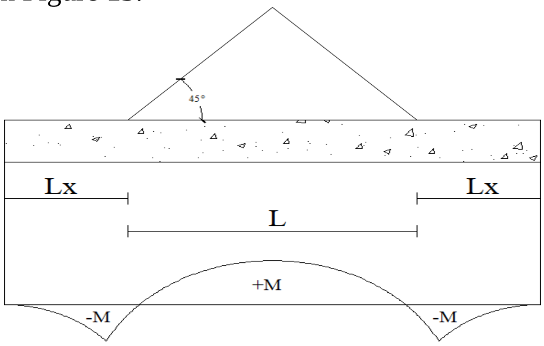


Figure 13. Moment During the Lifting of Precast U-Shell Beams

1. Design of Lifting Reinforcement Spacing

In determining the cable position, distance calculations are necessary. Figure 14 shows the results of the distance planning analysis during assembly.

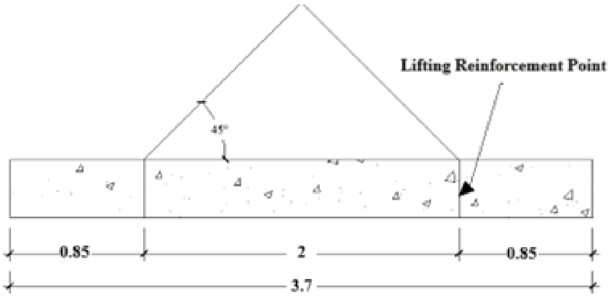


Figure 14. Lifting Reinforcement Spacing

2. Lifting Reinforcement

After obtaining the lifting reinforcement spacing, the next step is to determine the dimensions of the reinforcement to be used, hence the need for an analysis of the loads.

The weight of the U-Shell beam on the right and left sides = 0.09x0.49 x 5.4x2400= 571.54 x 2= 1143.1 Kg (11)
The weight of the U-Shell beam on the bottom side = 0.08x0.35 x5.4x 2400= 362.88 kg (12)
Total weight of the U-Shell beam = 1143.1 + 362.88 = 1505.1 kg (13)
After analysis, it was determined that the lifting reinforcement diameter is *f* 10 mm.

4. Conclusions

The researcher has drawn several conclusions from the analysis regarding the reinforcement plan for U-Shell beams in both conditions. In the condition before composite, the total number of main reinforcements installed is 6 pieces with a diameter of 13 mm. In the condition after composite, the total number of main reinforcements installed is 8 pieces with a diameter of 16 mm. The lifting reinforcement requires a diameter of 10 mm. Developing and analysing an innovative precast concrete U-Shell beam has complied with strength and serviceability.

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