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# Finite Element Analysis of One-Way Hollow Core Slab Capacity with Bamboo Apus and Bamboo Petung

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**Abstract**

*Design capacity was one of the main parameters in the concrete slab behavior analysis. In general, flexure tests for concrete slab had been conducted experimentally in the laboratory. However, it required a lot of energy, cost, and a long time. Hence the simulation approach with numerical methods were based on the finite element analysis by utilizing ABAQUS was appropriated. The prototype had been defined in the hollow one-way slab with the bamboo Apus and Petung as structural reinforcement. The prototype had been modelled in a 3D solid model with a concentrated load. Furthermore, the material properties had been determine) based on the experimental tests results. The numerical analysis results showed the similar failure behavior with the experimental test results. The difference in deflection between numerical testing and experimental testing of concrete slab specimens with bamboo apus was 1.47% and concrete slab with bamboo petung were 1.43%.-Experimental testing and numerical methods both have the same crack pattern in flexural shear cracking.. The maximum stress hollow concrete slab bamboo apus +17.71 Mpa and bamboo petung +23.2 Mpa.*

***Keywords:*** *capacity, hollow core slab, bamboo, finite element*

**Abstrak**

*Kapasitas desain merupakan salah satu parameter utama dalam analisis perilaku pelat beton. Secara umum, pengujian tekuk pelat beton akan diuji secara eksperimental di laboratorium. Namun hal tersebut membutuhkan banyak tenaga, biaya, dan waktu yang lama. Untuk itu diperlukan suatu pendekatan simulasi dengan metode numerik yaitu metode elemen hingga dengan menggunakan program ABAQUS. Benda uji berupa struktur komposit berupa pelat berlubang satu arah dengan tulangan struktur bambu Apus dan Petung, benda uji dimodelkan dalam model solid 3D dengan beban terkonsentrasi. Selanjutnya material akan diinput propertinya berdasarkan hasil pengujian eksperimen. Analisis numerik menggunakan ABAQUS menunjukkan perilaku keruntuhan yang serupa dengan analisis eksperimental. Hasil analisis numerik menunjukkan perilaku kegagalan yang serupa dengan hasil pengujian eksperimen. Perbedaan lendutan antara pengujian numerik dan pengujian eksperimental benda uji pelat beton dengan apus bambu sebesar 1,47% dan pelat beton dengan bambu petung sebesar 1,43%. Pengujian eksperimental dan metode numerik sama-sama memiliki pola retak yang sama pada retak geser lentur. Tegangan maksimum beton hollow slab bambu apus +17,71 Mpa dan bambu petung +23,2 Mpa.*

**Kata kunci**: *kapasitas, hollow core slab, bambu, elemen hingga*

# 1. Introduction

Slabs one of the most important structural elements, apart from beams and columns (Bhatt, MacGinley, and Choo 2010). The slab functions to accept the load that above it and then distribute them to other structures (Shojaee et al. 2012). Today, the utilizing of precast concrete often used in building structural elements such as beams, floors, retaining walls and irrigation channels. One of the precast concrete products for floor slabs is Hollow Core Slab (HCS) precast concrete (PCI 2015). Bamboo Hollow Core Slab (BHCS) is a cheap form of reinforcement in HCS because it uses reinforcement in the form of pipes or bamboo. Bamboo is known to have good properties as a substitute material for reinforcing steel (Pratima et al. 2013). Bamboo has a tensile strength which is almost equivalent to medium quality tensile steel. An understanding of the behavior of bamboo as a reinforcing material in one-way hollow slab concrete products can be obtained from experimental testing in the laboratory. One of the numerical methods used for structural modeling is the finite element method. Currently, the finite element method has been widely used as the basis for basic computation of computational programs to simulate linear and non-linear structural behavior. ABAQUS is a computation program based on the finite element method.

## 1.1 Slab Structures

Reinforced concrete slabs are thin structures made of reinforced concrete with a horizontal direction and loads acting perpendicular to the plane of the structure (Asroni 2010). Figure 1 below illustrate the stress and strain diagram of a conventional solid slab.

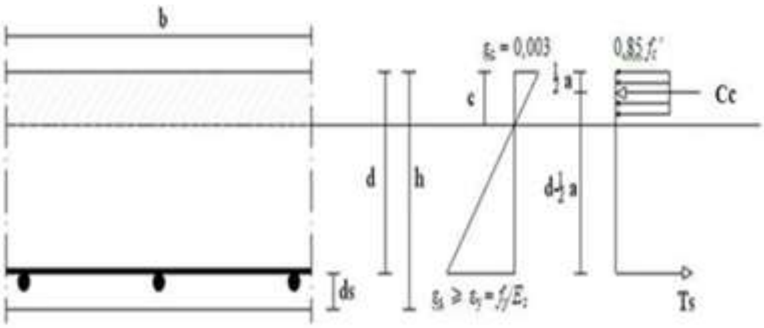


Figure1. Solid slab Stress-Strain Diagram

## 1.2 Bamboo

The strength of bamboo differs in each part, between the base, middle and ends. The following shows the results of several previous studies that can interpret the strength of bamboo as in table 1, and table 2 (Awalluddin et al. 2017), (Abdullah et al. 2017).

**Table 1**. Average Tensile Strength of Bamboo at Various Positions

| Various of Bamboo | Section | Tensile Strength (Mpa) |
|---|---|---|
| Petung | Top | 233 |
| | Middle | 201 |
| | Bottom | 232 |
| Apus | Top | 144 |
| | Middle | 137 |
| | Bottom | 174 |

**Table 2**. Average Compressive Strength of Bamboo at Various Positions

| Various of Bamboo | Section | Tensile Strength (Mpa) |
|---|---|---|
| Petung | Top | 277 |
| | Middle | 409 |
| | Bottom | 548 |
| Apus | Top | 215 |
| | Middle | 288 |
| | Bottom | 335 |

### 1.3 Hollow Core Slab (HCS)

The Hollow spherical concrete slabs (Bubble-Deck) have the same bending behavior as solid concrete slabs (Hollow-Core Slabs 2020). The presence of a hole in the center of the slab effectively reduce the self-loading of the slab without reducing its bending capacity (Shang, Zhang, and Lu 2016). So the HCS or BHCS system will be relatively lighter than the solid slab, even because of the use of prestress, the carrying capacity is greater. Theoretically, the HCS concrete under the compressed area will not reduce the slab's ability to withstand bending (Ezz El-Arab 2017).

### 1.4 Finite Element Analysis

ABAQUS an engineering simulation program package based on calculations using the finite element method (Li et al. 2012), which can solve problems ranging from relatively simple linear analysis to the most challenging nonlinear simulations (Simulia 2012). Concrete material is an isotropic material, which is a material that has properties that do not depend on direction. In addition, concrete has elastic properties in its compressive test which can be seen from the relationship between stress and strain (Simulia 2012). Bamboo an orthotropic material, which has three axes of symmetry, the properties of the material are perpendicular to each other and has different material properties along each axis (Silva, Walters, and Paulino 2006). The finite element method a numerical procedure that can be used to solve continuum mechanics problems with an acceptable level of precision. The finite element method itself is based on the principle of dividing or discretizing from a continuum, where the continuum can be a mass structure system or other solid object to be analyzed (Kellermann, Furukawa, and Kelly 2008). Meshing aims to classify an object into smaller elements, so that a system has finite degrees of freedom. The smaller the division of the elements under review, the more accurate the analysis results (Ismail 2018).

## 2. Research Method

### 2.1 Tools and Materials

The prototype is a composite structure of one-way the hollow core slabs with bamboo Apus and Petung as bar reinforcement. The test was carried out with the ABAQUS 6.14 computation program on two test objects with specifications as slab dimensions = 100 x 60 x 16 cm, The thickness of concrete slab = 3cm, Bamboo spacing = 8 cm (from outside bamboo boundary), Bamboo diameter = 10 cm.

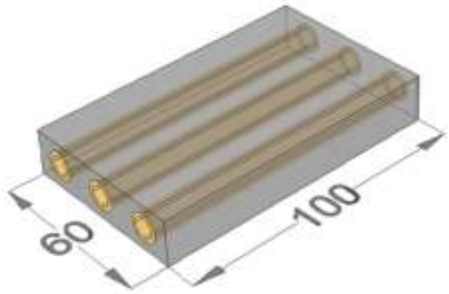


**Figure 2**. 3D Model of Hollow Concrete Slab

## 2.2 Research Procedures

This research was carried out through several stages, in order to get the expected results as Make a concrete design mix to make concrete mixtures with a quality of 30 MPa, Prepare apus and petung bamboos for testing of physical and mechanical properties (compressive strength, moisture content, and density of apus and petung bamboos), Test the compressive strength, moisture content, and density of apus and petung bamboo, Make a one-way slabanalysis to determine HCS dimensions, Make slab formwork, then make one-way and two-way slab specimens using lear and petung bamboo, Observe the behavior of the specimen during the  curing period until the concrete slab is tested at the age of 28 days, modeling HCS and analysis using ABAQUS, and Comparing the results of experimental testing and numerical analysis of HCS.

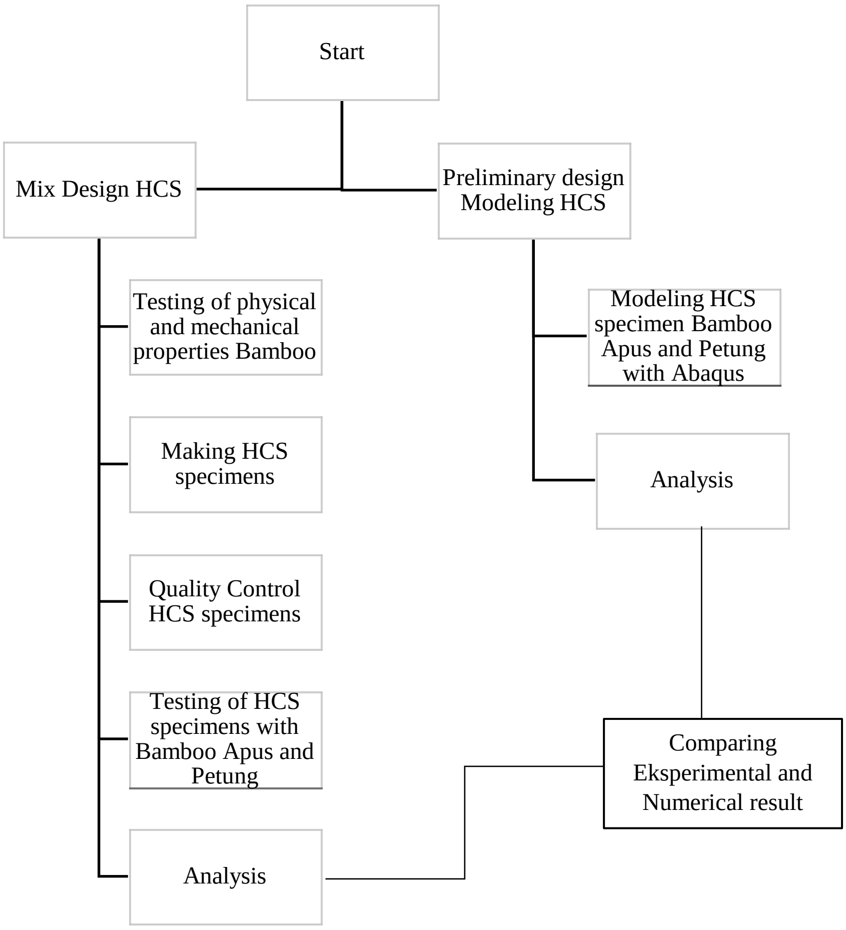


**Figure** 3. Flowchart research procedure

## 3. Results and Discussions

This test was carried out on two specimens of hollow concrete slab with bamboo apus and bamboo petung as reinforcing concrete with a size of 100 x 60 x 16 cm, designed to suffer structural damage using the ABAQUS 6.14 computation program. To shorten the name, in this test the test object for the hollow concrete slab with bamboo apus as reinforcement was named PBBA and the specimen for the hollow concrete slab with bamboo petungas reinforcement was named PBBP.

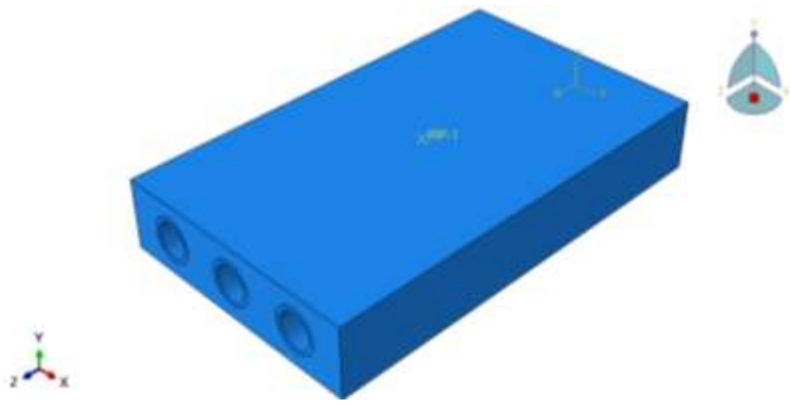

**Figure 4**. Modeling hollow core slab with ABAQUS

### 3.1 Hollow Core Slab with Bamboo Apus

In this test, the capacity of the concrete slab specimen to a centered load in the middle of the span is 93.395 kN. This can be seen from figure 6.

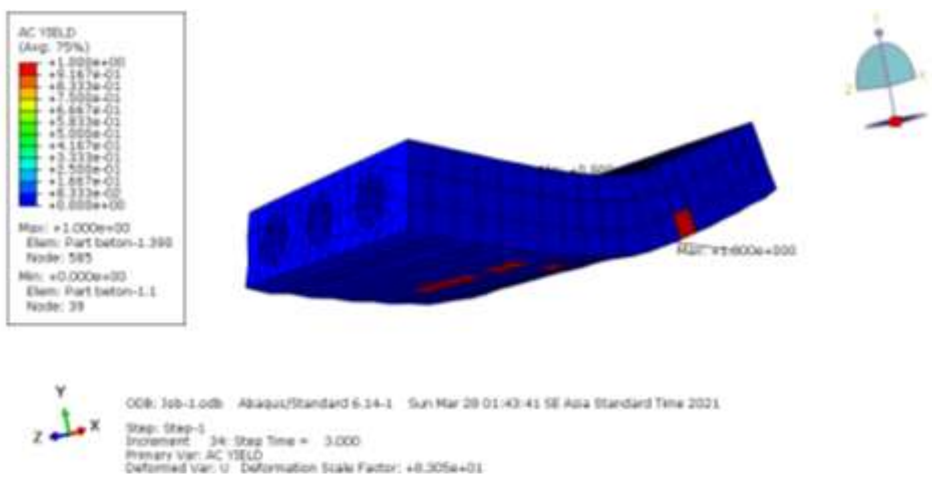

**Figure** 5. Response load distribution of PBBA

Response to load distribution the deflection valuedue to the ultimate load is 93.395 kN which is 12.04 mm. The results of numerical and experimental tests are shown in figure 6 and node deflection measured U1 shown in figure 7.

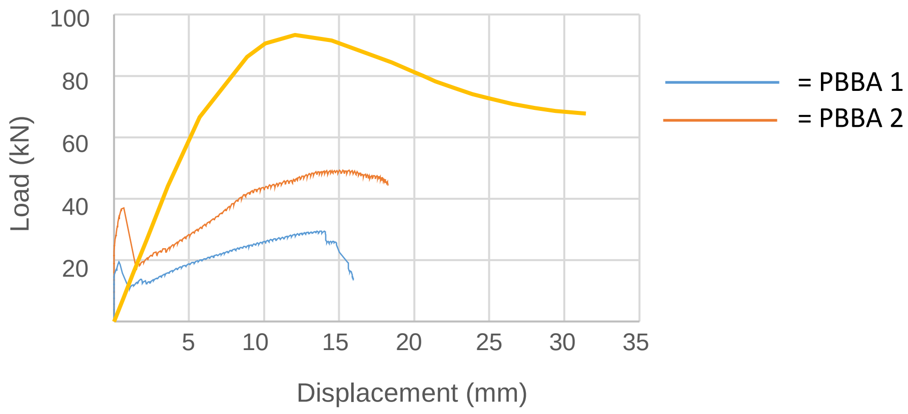


**Figure 6**. Load-deflection numerical test and experimental of PBBA

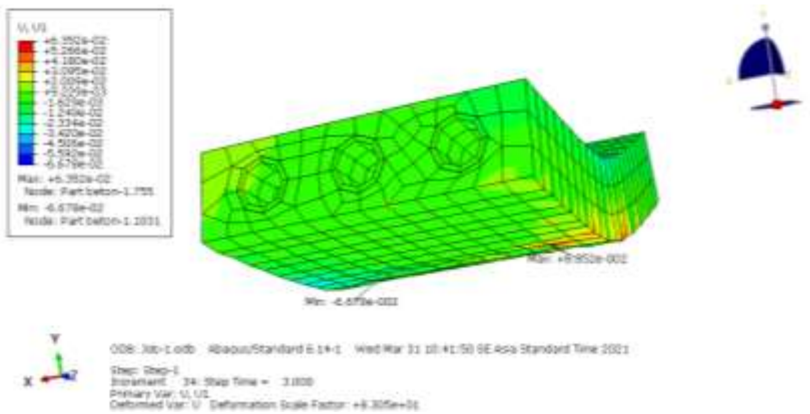

**Figure 7**. PBBA Node deflection measured U1

There was a similar failure pattern between the experimental test and the numerical test, namely the flexural shear crack. Shown in figure 8, and figure 9.

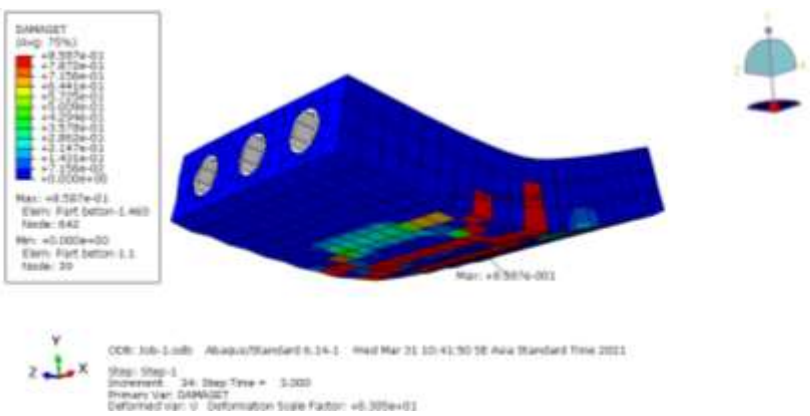

**Figure 8**. PBBA Failure Pattern Numerical

**Figure 9**. PBBA Failure Pattern Eksperimental

On the upper of the concrete slab, the stress value is –9.65 MPa, which means that the upper of the concrete slab compressed. Mean while, the lower of the concrete slab, the stress value is +9.55 MPa, which means that the lower of the concrete slab experience tension. The maximum stress value occurs in bamboo apus of +17.71 MPa. The stress distribution on the test object can be seen in figure 10.

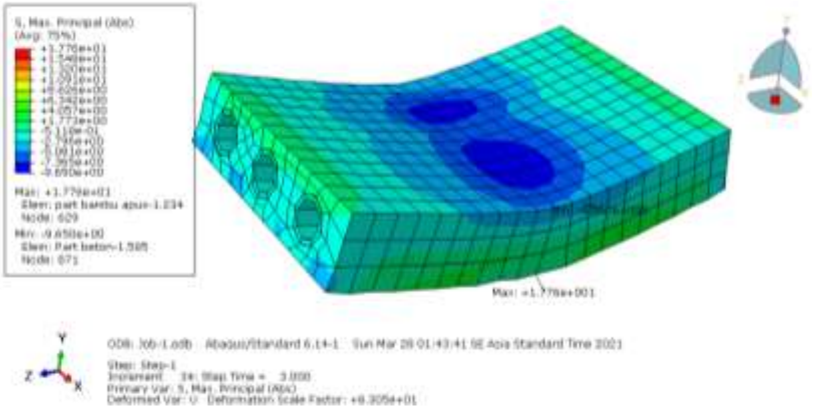

**Figure 10**. Stress Distribution on PBBA

The maximum strain value that occurs in a one-way hollow concrete slab with bamboo apus as reinforcement is 0.0005867, while the minimum strain value is 0.000001187. The strain distribution on the test object can be seen in figure 11.

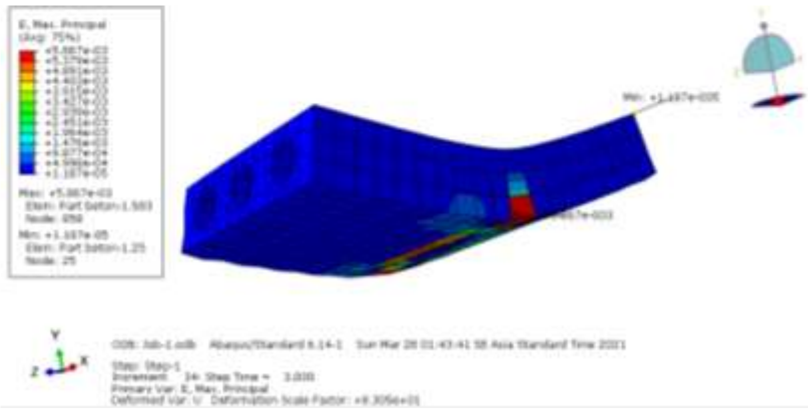

**Figure 11**. Strain Distribution PBBA

### 3.2 Hollow Core Slab with Bamboo Petung

In this test, the capacity of the concrete slab specimen to a centered load in the middle of the span is 98,114 kN. This can be seen from figure 12.

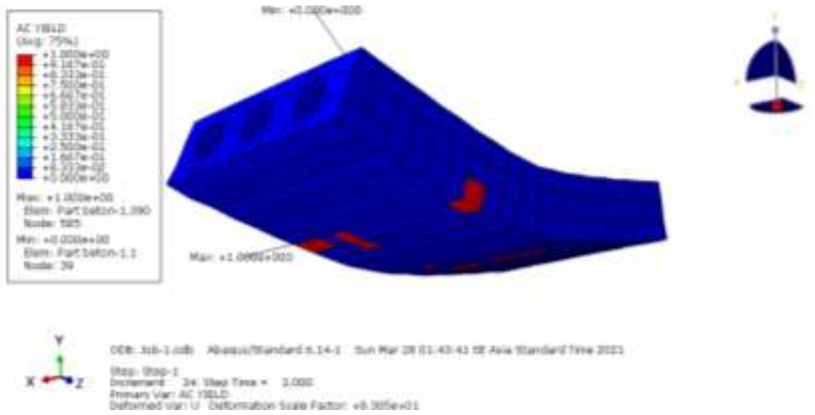

**Figure 12**. Response load distribution of PBBP

The deflection value due to the ultimate load is 98,114 kN which is 11.11 mm. The results of numerical and experimental tests are shown in figure 13 and node deflection measured U1 shown in figure 14.

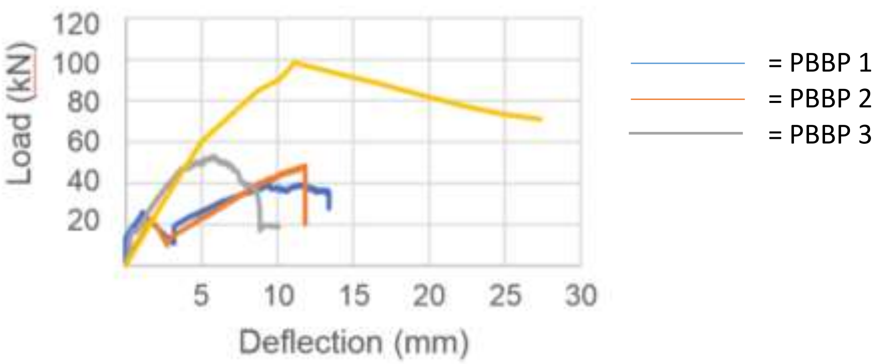


**Figure 13**. Load-deflection numerical test and experimental of PBBP

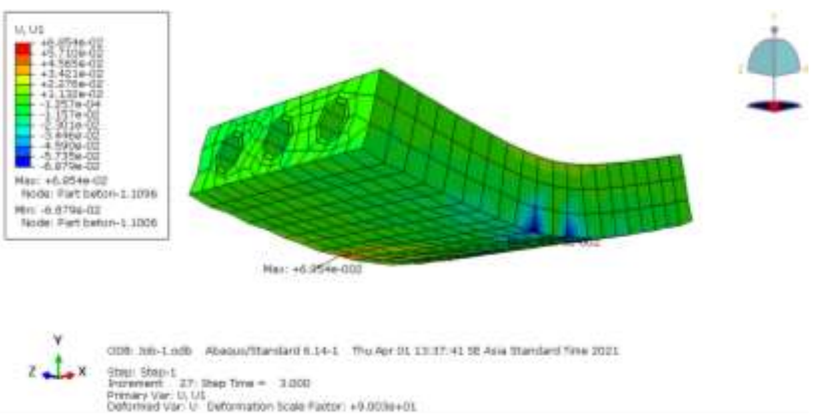

**Figure 14**. PBBP Node deflection measured U1

There was a similar failure pattern between the experimental test and the numerical test, namely the flexural shear crack. Shown in the figure 15, and figure 16.

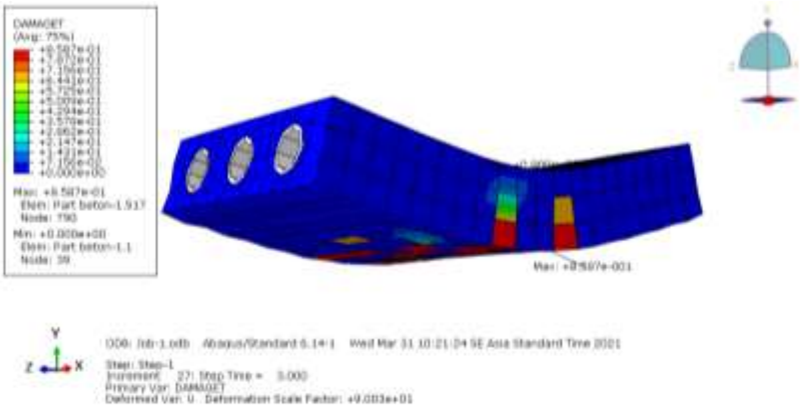

**Figure 15**. PBBP Failure Pattern Numerical

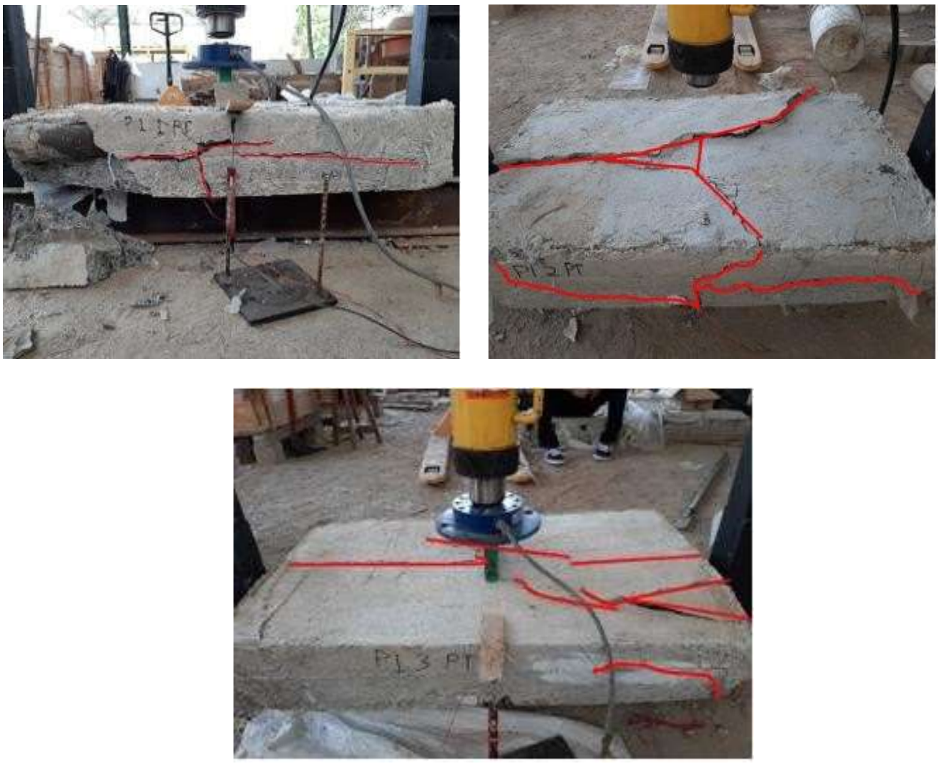

**Figure 16**. PBBP Failure Pattern Eksperimental

In the upper of the concrete slab, the stress value is –9.15 MPa, which means that the upper of the concrete slab is compressed. Meanwhile, the lower of the concrete slab, the stress value is +8.13 MPa, which means that the lower of the concrete slab experiences tension. The maximum stress value occurs in bamboo petung of +23.2 MPa. The stress distribution on the test object can be seen in figure 17.

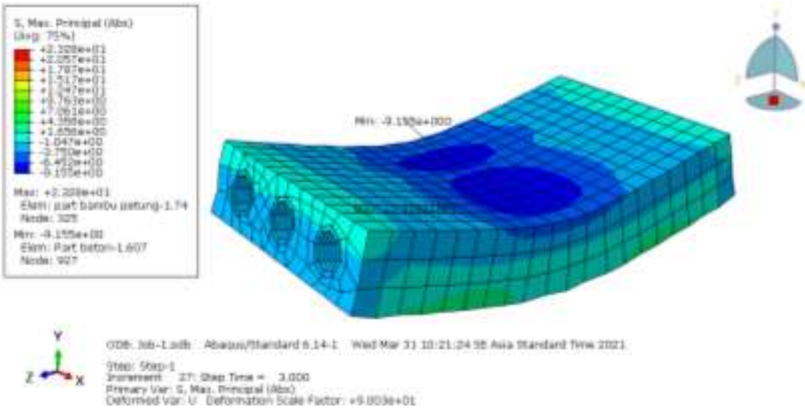

**Figure 17**. Stress Distribution on PBBP

The maximum strain value that occurs in a one-way hollow concrete slab with bamboo petung as reinforcement is 0.000403, while the minimum strain value is 0.000001135. The strain distribution on the test object can be seen in figure 18.

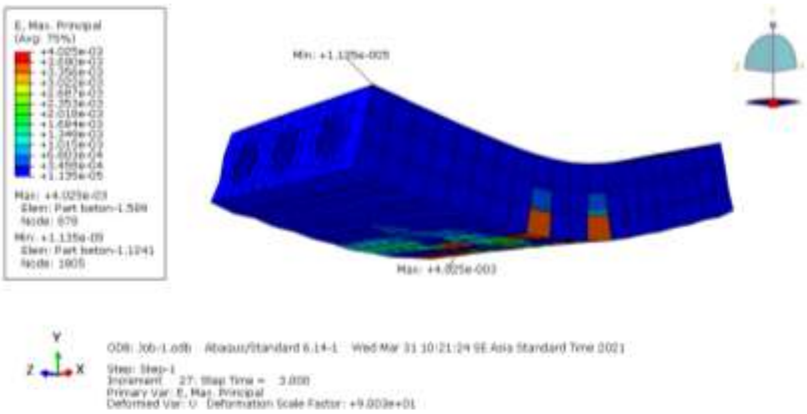

**Figure 18**. Strain Distribution on PBBP

# 4. Conclusions

Based on the results of the research, the data analysis and discussion, the following conclusions were obtained. The difference in load capacity between numerical testing and experimental testing of concrete slab specimens with bamboo apus is a 142.21% and specimens for concrete slabs with bamboo petung are 109.96%. The difference in deflection between numerical testing and experimental testing of concrete slab specimens with bamboo apus was 1.47% and concrete slab with bamboo petung were 1.43%. Tests with numerical and experimental methods, both concrete slab specimens with bamboo apus and petung produce a similar crack pattern, namely flexural shear crack. The stress value on the concrete slab on the upper of concrete bamboo apus –9.516 Mpa, and on the lower +9.557 Mpa, the maximum stress concrete slab bamboo apus +17.71 Mpa. The stress value on the concrete slab on the upper of concrete bamboo petung –9.15 Mpa, and on the lower +8.13 MPa, the maximum stress concrete slab bamboo petung +23.2 Mpa. The maximum and minimum strain values on a concrete slab with bamboo apus are 0.0005867 and 0.000001187 while on a concrete slab with petung bamboo, the maximum and minimum strain values are 0.000403 and 0.000001135.

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