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The Live Load Capacity of Rectangular Precast Reinforced Concrete Stick Plates

Agus Maryoto[1], Han Aylie[2], Nanang G. Wariyatno[1]

Abstract – *The process of making reinforced cast-in-place concrete plates is a long-term one and it is very expensive. Cast-in-place concrete requires the use of formwork, which raises the cost. An innovation in the field of precast concrete plates will significantly reduce cost and time. The purpose of this study is to investigate the flexural capacity of precast concrete plates as a function of slab thickness, with identical tensile reinforcement. The concrete's cylindrical compression strength used in this study has been 22.5 MPa. This research has been conducted both experimentally and numerically using a single stick plate specimen with dimensions of 6 cm × 10 cm × 100 cm (ESP-6 and SSP-6) and 8 cm × 10 cm × 100 cm (ESP-8 and SSP-8). ESP stands for the experimentally tested specimen. The flexural test using a-single-point loading system has been performed in order to determine the capacity and the load-displacement responses of the stick plate. On the next step, a finite element model (FEM) has been constructed, and the experimental data obtained from the ESP specimens have been used to validate the SSP model. The FEM model has been further utilized to simulate the behaviour of a range in stick plates (SSP). The numerical models SSP have had a range in thickness from 70, 90 and 100 mm. It has been found that the live load carrying capacity of specimens SSP-6, SSP-7, SSP-8, SSP-9, and SSP-10 has been 63, 91, 127, 138 and 165 kg/m^2, respectively. The initial stiffness of the specimens has been identical up till 30% of the ultimate load, while the moment carrying capacity increased as a function of plate thickness, followed a linear path.*

***Keywords**: Precast Concrete, Stick Plate, FEM, Live Load Capacity*

Nomenclature

cm	Centimeter
fbo	The equibiaxial compressive strength of concrete
fco	The uniaxial compressive strength of concrete
K	Stress intensity factor
kg	Kilogram
kN	KiloNewton
m	Meter
m^2	Square meter
m^3	Cubic meter
mm	Millimeter
MPa	Megapascal
SNI	Indonesian national standard

I. Introduction

A building is one of the physical forms of construction work that can be built. Simple buildings such as a residential house are constructed to fulfil specific needs or demands. The floors and the slabs take an essential part in the overall construction system [1]. It has a very significant influence on the user, since this structural element is the part that directly carries the load. Based on their functional categorization, buildings can be distinguished in: public buildings, commercial buildings, and industrial buildings. The floors of multi-story buildings are usually constructed from cast-in-place or precast reinforced concrete [2]. The prefabricated of reinforced concrete slab reduces the waste of concrete production [3]. The casting of concrete plates on site requires a greater cost compared to the use of precast concrete plates, since the cost of making a formwork on site is more expensive compared to the cost of making formwork for a precast-concrete-plates in a manufacturing plant. The conventional casting of concrete plates uses formwork and wooden supports. As a result, the work on the floor below, i.e. tile work, and the wall finishing cannot be continued because of the scaffolding that is needed to support plate formwork.

Another advantage of precast plates is that the quality is generally better due to constant control and monitoring in the plant [4]. The compressive strength of concrete is higher than its tensile strength [5]. In the structural element of cast in site or precast concrete, which sustains the tensile or flexure load [6]. The steel reinforcement or fiber reinforced polymer is utilized at the tensile layer [7]. Sometimes, carbon fiber reinforce polymen is also utilized to strengthen the slab [8]. Incorporating steel into the concrete results in a material known as reinforced concrete [9]. The design of the reinforced concrete element structure is based on different principles; the

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most important one is the understanding of compression and tension layers. The design of the compression layer is based on the compressive strength of concrete, but the design of the tension layer is based on the tensile strength of steel bar [10]. The reinforcement in concrete can use both a steel bar, a steel wire and another material which has high tension strength [11]. There are two types of steel bar, namely deformed and plain steel reinforcement [12]. Reinforced concrete plates are widely used in civilian buildings, e.g., as building floors, roofing floors [13], bridge floors or floors of the dock [22]-[26]. There are two types of plate structure systems: one-way plate [14] and two-way plate system. The scheme of plate design consists of 3 steps, which are the calculation of the reinforcement, the dimensional enlargement, and the bending moment of the plate [15]. Loads acting on plates are generally considered as gravity loads. This load results in a bending moment. The flexural strength of a plate is caused by a mechanism of internal stresses occurring within the plates. It can be represented by internal forces, which form a moment coupling. The maximum value of this moment is defined as the capacity of the bending moment in the cross-section of the structural component. Flexural testing on plates and beams use the same methods; they include single point loading and the third point loading method. During the process of flexural testing, the specimen is loaded up to the failure condition. The process of failure is divided into three stages. The first stage is the arrival at the elastic limit. Once this limit is surpassed, the second stage is crack nucleation. This behaviour is followed simultaneously by plastic stages [16]. The flexural test has been conducted by several researchers [17], [18] in order to investigate the load capacity of a concrete beam strengthened by near-surface mounted bamboo reinforcement and slab panels with embedded cold-formed steel frames as reinforcement. The results showed that the flexural strength of the beam has increased due to the use of bamboo reinforcement.

The objective of this study is to analyse the live load capacity of stick plate concrete. The experimental work is complemented by numerical analyses in order to observe the behaviour of stick plate concrete. Finite element analysis (FEA) is conducted with ABAQUS software version 6.14 [19]. ABAQUS has some advantages over other similar programs; e.g. the complete menu is available on the path module [20], [27], [28]. The ABAQUS analysis consists of three levels: pre-processing, simulation, and post-processing. Numerical simulation can evaluate the results of completed simulations (completes) for strain, voltage, or other fundamental variables that have been computed [21]. The tested variables in this study are flexural strength, crack pattern, and deflection.

II. Methods

This experimental study has been conducted in the laboratory by preparing equipment and materials as needed. Raw materials for concrete were tested first to develop a concrete mix design. The concrete quality of 22.5 MPa has been obtained after the specimen has been aged for 28 days. The analysed specimens consisted of both experimental and numerical simulation specimens.

II.1. Experimental Procedures

II.1.1. Material and Equipment

The main materials utilized in this study are coarse aggregate, fine aggregate, cement, water, and steel reinforcement. The reinforcement used is a deformed steel bar with 10 mm diameter. The utilized equipment consists of the following: a specialized instrument for a preliminary test of concrete material, a concrete mixer, a compression testing machine (CTM), a universal testing machine (UTM), and a moulding for the single stick plate specimens.

II.1.2. Specimens

The test specimens used in this research are precast rectangular concrete plates. Two types of specimens have been examined. ESP-6 is a single stick plate measuring 6 cm × 10 cm × 100 cm; ESP-8 measures 8 cm × 10 cm × 100 cm. The thickness of stick plate of 6 cm and 8 cm has been adopted in the experimental tests in order to reduce the weight of the member and generate a lower ultimate load. The carrying capacity of stick plate with the thickness 10 cm and 12 cm would be predicted using trend line of the numerical simulation result. The number of a single stick plate test objects can be seen in Table I.

A deformed steel bar with a diameter of 10 mm has been inserted in the concrete, having a concrete cover with a thickness of 10mm from the bottom layer. The complete dimension can be observed in Figs. 1 and 2.

TABLE I
SPECIFICATIONS OF SPECIMEN

No.	Code of specimen	Amount
1	Single stick plate with thickness 6 cm (ESP-6)	3 pieces
2	Single stick plate with thickness 8 cm (ESP-8)	3 pieces

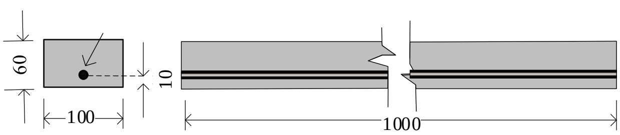


Fig. 1. Dimension of specimen ESP-6

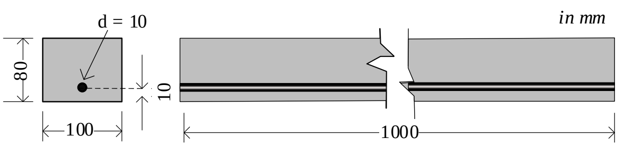


Fig. 2. Dimension of specimen ESP-8

II.1.3. Formulation of Concrete

Crushed stone and sand as material for concrete have been tested on their physical properties. The tests comprised of specific gravity, clay content, density, and the fineness modulus of the sand and the crushed stone.

After obtaining values for the physical properties of sand and crushed stone through preliminary testing, the next step has been to design the mix proportion of concrete. Table II shows the results of the mix design of concrete with a cylindrical compressive strength 22.5 MPa.

TABLE II
MIX DESIGN OF CONCRETE 22.5 MPa

Materials	Weight (kg)
Cement	374
Fine aggregate	647
Coarse aggregate	1191
Water	184

II.1.4. Flexural Strength Test

A loading model with the single point loading at mid-point of the specimen was applied. This flexural test has been performed at a concrete age of 28 days. Fig. 3 shows the flexural testing schematic using the single point loading method.

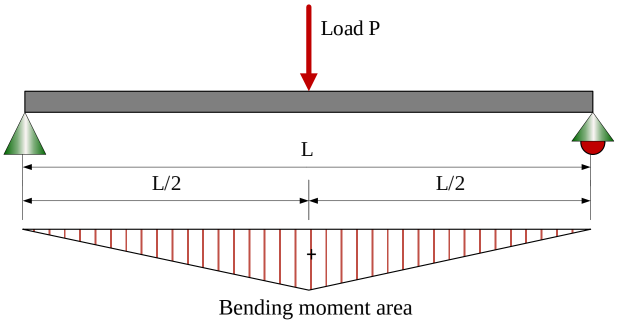


Fig. 3. Scheme of single point loading test

The flexural strength formula for a single loading system is:

$$M = \frac{1}{4} P L \quad (1)$$

where, M is the bending moment (kN·m), P is the load (kN) and L is the beamspan (m).

II.2. Numerical Analysis

II.2.1. Specimens

The modelled specimens in ABAQUS have been single stick plates (SSP). The SSP specimen have been distinguished by their specific thicknesses, namely SSP-6 (6 cm), SSP-7 (7 cm), SSP-8 (8 cm), SSP-9 (9 cm) and SSP-10 (10 cm). The number of each specimen code run through the model has been three. The properties of the concrete and steel bar used in the simulation are shown in Tables III and IV, and functioned as input to the model.

TABLE III
PROPERTIES OF CONCRETE

Property	Formula	Unit	Value
Compressive Strength, *fc'*	-	MPa	22.5
Young's Modulus	$4700\sqrt{f_c'}$	MPa	22294
Poisson Ratio, υ	-	-	0.18
Tensile Strength, *ft*	$0.15.f_c'$	MPa	3.375
Fixed crack(default)	-	-	0.7
Dilation angle	-	-	31
f_{bo}/f_{co}	-	-	1.16
K	-	-	0.667
Eccentricity, *e* (default value)	-	-	0.1
Density, γ	-	kg/m^3	2400

TABLE IV
PROPERTIES OF STEEL BAR

Property	Unit	Value
Tensile Strength, f_y	MPa	400
Young.s Modulus, E	MPa	200.000
Diameter of steel bar	mm	10
Poisson's Ratio, υ	-	0.3
Density, γ	kg/m^3	7.850

II.2.2. Meshing

In order to obtain the best meshing pattern and element finesse, a sensitivity analysis has been conducted, and the model leading in a convergence patter has been chosen. The element dimension has been 50 × 50 × 50 mm, the maximum deviation factor 0.1, with a minimum fraction global size of 0.1. Fig. 4 shows the meshing of the stick plate with the loadings and supports.

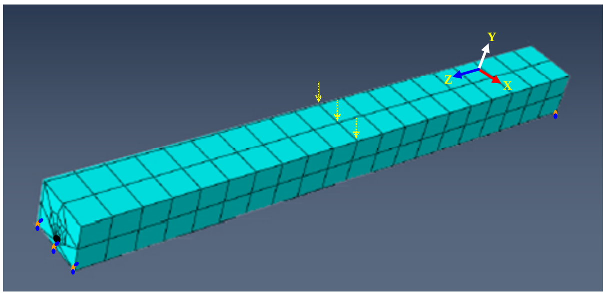


Fig. 4. Meshing, support and loading of single stick plate

II.2.3. Load

In the modelling of the stick plate using the Abaqus software, the external load has been increased incrementally from the smallest load until the maximum load that can be carried out by the stick plate. The boundary conditions of the supports of the specimen's ends have been modelled as a hinge and a roll. As was the case with the experimental model, the load has been placed at the centreline of the specimen.

III. Results and Discussion

III.1. Experimental Results

III.1.1. Compressive Strength

The fine aggregate used has been Serayu Riversand with a specific gravity of 2.49, a fine particle content of

1.83%, a fineness modulus of 2.49 grains, and a density of 1.44 kg/m^3. The coarse aggregate used has been crushed stone with a maximum diameter of 20 mm, a specific gravity 2.61, a clay content of 1.01%, a fineness modulus of 7.95, and a density of 1.54 kg/m^3. The cement used has been Type I cement, which is a pozzolan composite cement.

The aim of concrete compressive strength testing has been the one to know the strength of concrete created as a sample of the precast concrete stick plate. The size of the specimen has been a cube with length 15 cm, width 15 cm, and height 15 cm. The curing of concrete specimen has been conducted by immersing them in fresh water with a temperature around 27°C for 27 days.

Furthermore, the concrete has been placed in the ambient air for one day so that the test object has been completely dry. The preliminary compressive strength test has been performed 28 days after the mixing. The concrete compressive strength test results are presented in Table V. According to Table V, the average compressive strength for ESP-6 and ESP-8 was 254 and 260 kg/cm^2, respectively. This average concrete compressive strength has met the planning of the study.

Furthermore, it can be observed more deeply that the weight of the concrete unit does not affect the compressive strength.

TABLE V
COMPRESSIVE STRENGTH OF CONCRETE

Code	Weight (g)	Compressive Strength (kg/cm^2)	Average (kg/cm^2)
	8200	266.67	
SSP-6	8150	238.89	254
	8200	257.78	
	8050	266.67	
SSP-8	8150	257.78	260
	8150	255.56	

III.1.2. Flexural Strength

A flexural test has been performed on the stick plate specimens aged 28 days. The bending test results of ESP-6 has a weight of 15.05 kg, it could withstand 5200 N of centralized load, and its maximum moment of 425 N·m. SSP-8 has a weight of 18.55 kg, it can withstand a load of 8570 N, corresponding to a maximum moment of 575 N m. The bending moment capacity of ESP-8 is greater than the bending capacity of ESP-6 due to its greater thickness.

In the experimental work, the bending moment has been obtained when the steel reinforcement has reached the elastic limit before the concrete ruptures. The condition of reinforced concrete is commonly referred to reinforced condition.

The results of the flexural strength testing can be seen in Fig. 5.

III.1.3. Crack Patterns

Figs. 6 and 7 show schemes of the crack pattern of single stick plates with thicknesses of 6 mm and 8 mm.

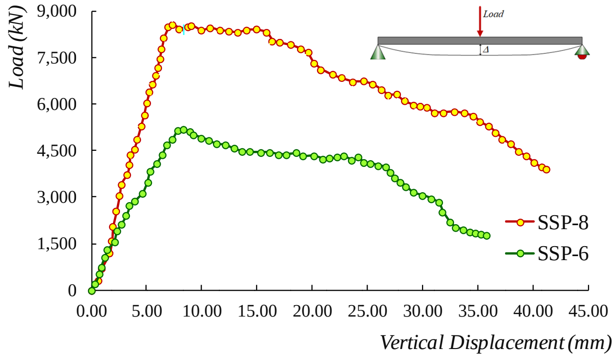
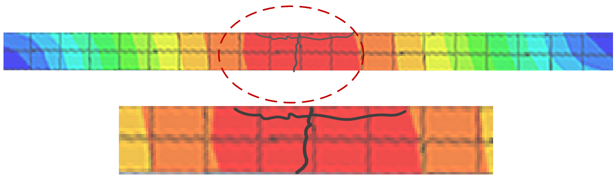


Fig. 5. Flexural strength of ESP-6 and ESP-8

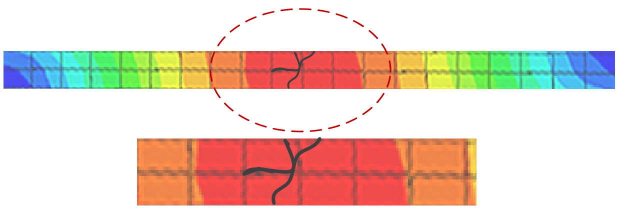
(a)



(b)

Figs. 6. Crack pattern of SSP-6: (a) Real picture, (b) Schematic picture

(a)



(b)

Figs. 7. Crack pattern of SSP-8: (a) Real picture, (b) Schematic picture

As the specimen has undergone the bending test, the first crack occurs in the bottom layer in the centre of the span. The crack then has propagated to the top layer of the single stick plate at location of the loading.

Additional cracks have been propagating around the first crack and around the loads. The overall crack pattern can be observed in Figs. 6 and 7.

III.2. Numerical Simulation Results

In addition to the physical tests, the plates have also been studied with computational models. Single stick plates with thicknesses of 6 cm (SSP-6) and 8 cm (SSP-8) have been simulated and calculated using ABAQUS software for finite element analysis. According to the results of the simulation, the load capacities of SSP-6 and SSP-8 have been 4090 N and 7500 N, respectively.

These numerical results are little lower than the experimental results due the non-homogeneous nature of the concrete. It is well known that concrete has a heterogeneous composition in which its material components may exhibit diverse physical and mechanical properties. This condition affects the interpretation of the simulations. However, advancements in concrete mixing closing to the practical generation of concrete as a homogeneous material in order to simplify its behaviour for further experimentation. Fig. 8 shows the contour deflection of SSP-8 when the external loads was applied in the numerical simulation. It can be seen that maximun deflection is concentrated at mid-span, and measures 7.2 mm. In retrospect to the experimental results, the deflection of ESP-8 was 6.5 mm, underlining the good representation of the FE model to the actual behavior.

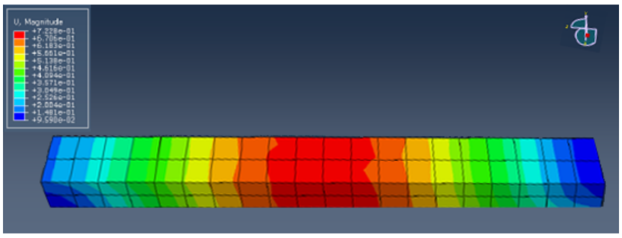


Fig. 8. Contour deflection in the SSP-8

These simulated SSP specimens have been then applied for SSP with the thickness 7, 9 and 10 cm. The results of those load and moment capacities are shown in Table VI. According to Table VI and Fig. 9, it can be confirmed that the live load capacity increases as the SSP thicken increased. In the fourth column of Table VI, the live load capacity is shown. The load carried by the plates can be distinguished into the dead load and live load. The dead load originates from the self-weight of the member, and the components such as tiles and plaster, on top of the plate. By subtracting the total load carrying capacity with the dead load, the live load that can be added to the plate are obtained. This live load is the physically benefit that can be used by the inhabitants.

The single stick plates with thicknesses of 6 and 7 cm cannot be applied for a simple residential house. Two factors contribute to this: the minimum thickness mandated by the code, and the minimum load.

But the SSP-8 can be utilized for simple residential house have a minimum live load capacity of 125 kg/m^2. SSP-9 and SSP-10 with live load capacities of 138 and 164 kg/m^2, respectively, can be also applied for the simple residential house. The trend line can theoretically be used to predict the capacity of plates with a thickness dimension larger than 10.

TABLE VI
THE LIVE LOAD CAPACITY OF STICK PLATE

Specimen	Moment capacity (Nm)	Dead load (kg/m^2)	Live load capacity (kg/m^2)
SSP-6	1022	18	63
SSP-7	1400	21	91
SSP-8	1875	23	127
SSP-9	2050	25	138
SSP-10	2410	28	164

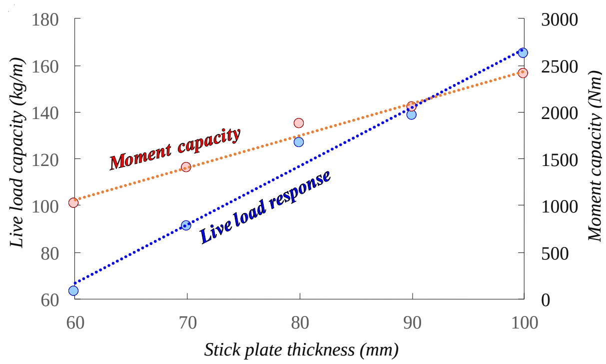


Fig. 9. The Live Load Capacity of Various SSP

The stick plate can be mass produced before the starting building construction.

It will significantly reduce both the cost and the completion time of a project.

The plate thickness must be chosen to meet the intended function of the building.

IV. Conclusion

Based on the results and above discussion, the following were concluded:

1. The load versus vertical displacement of laboratory tested specimens ESP-6 and ESP-8 showed that the initial flexural stiffness of the members was identical. The increase in member depth of 20 mm has not influenced this initial stiffness. The enhancement in thickness however, significantly effects the load carrying capacity, and the ESP-8 member had a 65% higher load carrying capacity when compared to ESP-6. The initial cracking occurs at 30% of the ultimate load. Subsequently to this point, the stiffness of ESP-6 has significantly deviated from its initial stiffness, whiles for ESP-8 this depreciation has been insignificant.
2. The stiffness of members has demonstrated a linear behaviour, up till the maximum load, and both the specimens had a post descending branch generated by the yielding of reinforcing steel. The depreciation angle for these post peak curves was similar, and an

excellent ductile behaviour was demonstrated by both the specimens ESP-6 and ESP-7. Failure has been marked by crack initiation in the tensile zone, and finally crushing of concrete in the compression zone.

3. The finite element model generated to represent the stick plate has been proven to be valid, based on the comparison of the predicted ultimate load as well as the visual observation on the stress distribution pattern and crack propagation. The model conservatively deviated 21% to the laboratory tested specimen due to the fact that in the FEM perfectly simply supported boundary conditions have been assumed. In reality both the end-supports of the ESP-6 and ESP-8 have been responding as pinned. The model was further utilized as a tool to analyse the behaviour of a variation in plate thicknesses.
4. The numerical simulation of stick plates has been used to analyse the live load capacity of a range of plate thickness. The increase in live load carrying capacity followed a linear path with an ascending angle of 76^o. This angle implicates that the influence of increase in plate thickness is very pronounced. A thickness increase of 40 mm resulted in a live load capacity enhancement of 1.6 times, compared to a volume increase of only 67%. The moment multiplication ratio in this case has been 1.4 times, affected by the additional concrete self-weight of the additional 40 mm thickness.
5. The study has proved that the stick plate has an excellent load carrying capacity. The function of live load rise that can be supported by the plate followed a direct, linear relationship to the thickness of the section. The members all failed in a ductile manner. The yielding of reinforcement steel in the tension area resulted in crack propagation. The plate finally collapsed due to crushing of the concrete in the compression zone.
6. An almost identical initial member stiffness ensured a good serviceability at design loading conditions
7. A study on the relationship of concrete strength and steel ratio is currently conducted, so that these plates can be industrially mass produces. The fabrication of plates will not only conserve the cost of scaffoldings and formwork, but will be also beneficial in terms of financial revenue, due to the speed of the building process and fast use.
8. Even though, the carrying capacity of precast stick plate can be identified well for various slab needs, unfortunately the connection between precast stick plate and beam has not been developed yet in this study. The next interesting study should be about the investigation of a method to connect between the precast stick plate and the beam, also the connection between precast stick plates.

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