

Experimental Studies on the Performance of Prestressed Concrete Slabs with Parabolic Tendon Profile Shapes

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Abstract
Slab without beams cause bending cracks in the tensile region at a low loading level. One way to overcome these weaknesses is to provide a pre-concentric or eccentric initial bias style. In this study, we wanted to compare the performance of prestressed concrete slabs in terms of cross-sectional strength capacity and rigidity of concrete slab without prestressing through experiments. Objects that were tested without prestressing were made 1 piece, namely P1, and objects that were tested with prestressing were 3 piecesnamely P2 with 2 tendons, P3 with 3 tendons, and P4 with 4 tendons. The dimensions of each object tested are 100 × 40 × 8 cm and all of them are designed with concrete qualityf'c = 30 Mpa. The tendon usedis 8 mm plains teel that is pulled by tightening the nuts at both ends, with a parabolic profile shape and eccentricity value in the middle span of 1.5 cm. From the test results obtained a very significant increase in the crosssectional strength capacity of specimens P2, P3 and P4 against P1. The increase in peak load that can be borne by 192.18% is for P2, 286.54% is for P3, and 383.00% is for P4. It also happened to increase the peak bending moment which can be borne by 161.57% for P2, 241.05% for P3, and 322.68% for P4.
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I. Introduction

The rate of high-rise building construction in Indonesia in the modern era is currently very rapid. The demand from service users regarding cost and time efficiency in development must be a very important consideration for planning consultants. One of the most important in saving costs and construction time can be achieved by eliminating the use of structural beams on concrete slabs to reduce the height of each floor.

The removal of structural beams on a concrete slab contributes to all gravity loading (self weight, additional dead load and live load) fully retained by a concrete slab. As we know, concrete is a strong material in compressive conditions but weak in tensile conditions. The tensile strength of concrete varies between 8-14% of the compressive strength (Nawy, 2001). This can cause bending cracks in the tensile area of the concrete floor plate at a low loading level. One way to overcome these weaknesses is to provide a preliminary concentric or eccentric pre-stressing force on a concrete slab so it can provide an initial compressive stress distribution in the flexural tensile region that can reduce or eliminate tensile stress under all working conditions of gravity loading.

In this case the prestressed concrete slab study applies an eccentric prestressing force with a parabolic profile shape using reinforcing steel which is tightened with nuts at one end. We want to compare conventional concrete slabs with prestressed concrete slabs with the number of tendons varying from 2 to 4 pieces in one section. The use of variations in the number of tendons will certainly have a different effect on the performance of the structure. Some variables of the results are cross section capacity (ultimate workload, ultimate moment and shear force) and structural stiffness (in terms of deflection).

II. Literarture Review

Concrete is a construction material that is often used because its forming material is easily obtained and the process can be formed appropriate with the mold. Judging from its mechanical properties, concrete is a strong material in conditions of compressive stress but weak under tensile stress conditions. The tensile strength of concrete is only around 8-14% of the compressive strength (Lin, 1996).

Structural elements that are subjected to flexural loads, for example: beams and slabs often experience flexural cracks in the tensile section at low loading levels. This is due to the small tensile strength of the concrete so that the fiber tension in the tensile area due to the work load has exceeded the tensile strength limit (condition: Mu>Mcrack) (Lie, 1997). Therefore reinforced concrete is given reinforcing steel in the tensile part as a substitute for the weak tensile strength of the concrete and holding the tensile forces that work (Raju, 1988).

a. Basic Concepts of Awarding Prestress
The behavior of structural elements due to the application of P prestressing force and certain loading is determined based on the principle of mechanics and stress-strain relationship. In this case the prestressed beam is assumed to be homogeneous and elastic (Raju, 1988).

b. Basic Concept Method
The basic concept method is to calculate the fiber tension at the time of the initial pre-bias and at work load. If the initial prestressing force before the stress loss is Pi, and Pe is the prestressed force after the stress loss (Hibbeler, 2016).

c. Load Balancing Method
Another approach that is useful in the design and analysis of continuous prestressed structural elements is Lin's load balancing method. This method is based on the application of vertical prestressed force components to the draped or harped tendons to counter or offset the gravity load experienced by the beam (Hibbeler, 2016).

d. Concrete Compressive Strength
Concrete compressive strength (f'c) depends on the composition of the mixture, aggregate amount and time and quality of care. Concrete compressive strength is obtained from standard 6” × 12” cylinder specimens (ASTM C-39 standard) under standard laboratory conditions after 28 days. ACI stipulates the average use of f'c of 2 cylindrical specimens with the same test. The compressive strength of concrete in the actual structure may not be the same as the cylinder specimen due to differences in processing and compaction conditions (Collins, 1987).

e. Concrete Tensile Strength
The tensile strength of concrete (fct) is relatively small, which ranges from 0.1f'c - 0.2f'c. The tensile strength of concrete is more difficult to measure than the compressive strength of concrete because of the clamping problem on the tensile machines (Sadd, 2014). For flexural structural components, the modulus of raptur (fr) value used in the design is tensile strength. Testing fr based on ASTM C-78, carried out by testing a plain concrete block length of 18 "and 6" square. Plain concrete beams are tested with loads at one-third of the span to fail, whereas for normal concrete ACI sets the value $fr = 7.5\sqrt{f'c}$ (Collins, 1987).

f. Concrete Shear Strength
Concrete shear strength is more difficult to determine experimentally than other tests because of the difficulty of obtaining pure shear conditions. Concrete shear strength values from some literature can vary from 20% of the compressive strength of concrete to be able to reach 85% of the compressive strength of concrete under shear stress conditions occur together with compressive stress. Design control is rarely based on the shear strength of concrete because the shear stress must be limited to a small value to prevent diagonal pull (Collins, 1987).

III. Research Methodology

In this case we used 4 concrete test pieces measuring 100 × 40 × 8 cm. Each specimen was given numbering P1, P2, P3 and P4. Each specimen was given reinforcement of 6 mm diameter plain steel woven with a grid spacing of 15 × 15 cm. As for specimens P2, P3 and P4 use additional 8 mm diameter prestressed plain steel with a parabolic profile shape. In this case the eccentricity of a prestressed plain steel profile is made at the center of the span with only e = 1.5 cm (measured from the center of mass of the cross section of the concrete slab). Schematic drawing of prestressed plain steel profile shapes. The difference between P2, P3 and P4 specimens lies in the amount of use of prestressed plain steel. The differences are shown in Table 1.

Table 1: Modeling Test Objects P1, P2, P3 and P4

Type	Long (cm)	Wide (cm)	Thick (cm)	Amount	ReinforcementConfiguration
P1	100	40	8	1	Ø6-150×150 mm
P2	100	40	8	1	Ø6-150×150 mm + prestressedplainsteel Ø8 mm 2 pieces
P3	100	40	8	1	Ø6-150×150 mm + prestressedplainsteel Ø8 mm 3 pieces
P4	100	40	8	1	Ø6-150×150 mm + prestressedplainsteel Ø8 mm 4 pieces

In this study we used the post tension prestressing method and then ducting from a plastic hose for prestressed plain steel. At the end of the pre-stressed plain steel 4 × 4 × 0.4 cm steel slab is installed which functions as an anchor. Both ends of prestressed plain steel mounted fastening nuts rest on both anchors.

A. Procedure for Making Test Objects

1) Manufacture of Test Formwork

Formwork P1, P2, P3, P4 using 9 mm thick plywood reinforced with 5/5 cm rafters. The net size in formwork is made according to the size that has been set, 100 × 40 × 8 cm. Before casting the inner side of the formwork is coated with lubricant from oil so that it can be easily removed after being casted.

2) Non-Pre-woven Iron Plate / Non-reinforced Reinforcement

All test specimens were given non-prestressed reinforcement in the form of 6 mm plain iron weaving with a grid spacing of 150 × 150 mm. Elongated reinforcement is installed at the bottom of 3 lanes with 8 mm thick concrete decking. Transverse reinforcement is mounted above the longitudinal reinforcement. Details of non-prestressed reinforcement are shown below:

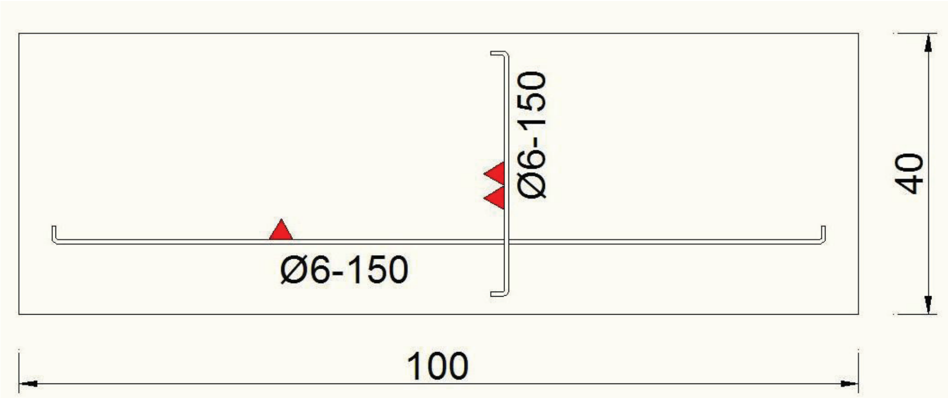


Figure1. Details of Non-Prestressed Reinforcement

1) Concrete Casting Test Objects

Concrete casting specimen using mix design with compressive strength plan f'c = 35 Mpa. The volume of fresh concrete requirements is 0.128 m3 for the four specimens. Stirring can use mini electric molen in LTS-UBL. Each specimen was made 1cylinder size of 15 × 30 cm (total volume of concrete requirements: 0.021 m3) to determine the compressive strength of concrete characteristics after 28 days of age.

After being casted, 24 hours later the formwork is removed and treated by specimen wrapping using burlap sacks that are always moistened with water. The curing process is carried out for a minimum of 7 days in order to achieve better concrete quality.

1) Painting the Test Blanket

Before carrying out load testing, the blanket of the test object must be painted in white and outlined in black into 4 × 4 cm grid shape pattern. It aims to make it easier to show and describe the crack pattern of the test specimen after a crack failure due to external loading that works.

2) Preparatory Plain Steel Preparation and Pre-Pricing Style

In this study P2, P3 and P4 concrete slabs are given a pre-stressed load before experiencing, receiving workloads or external loads using 8 mm plain steel which is tightened with bolt nuts at both ends. The two ends of prestressed plain steel are made to be grounded, threaded, and at both ends installed 4 × 4 × 0.4 cm steel slab which have been drilled with a whole diameter of 10 mm.

Nut tightening is done on one side of the end with a torque wrench with strength of 6 kg.m. The amount of force applied is measured based on the calculation of the nut shift calculation using the method based on Hooke's law. In this case it has been calculated in the preliminary design of the nut shift of 1.2 mm. The next step is testing the workload on the four test specimens in the laboratory.

A. Method of Testing Workload in the Laboratory

Workload testing in this study was conducted at the Civil Engineering Laboratory of Bandar Lampung University (LTS-UBL) by using a Universal Testing Machine. In this case the test object is tested by modeling it as a simple roller-joint beam. Workload applications are given from the bottom up at two points 1/3. Spans of the left and right supports are produced through load actuators in the form of line loads. Addition of workload is given in incremental load with a speed of 5000 N / minute and the amount of deflection is always recorded in the middle span of each change in workload. Deflection readings and total workload are recorded automatically by a computer with an output in the form of a graph or curve of the relationship between workload and deflection in the middle range. Loading continues until the test object stage experiences a tensile collapse in the upper fiber due to the bending moment. This course will show the structural behavior when testing is one-way bending behavior.

From the results of testing the workload on the test object can be obtained several data: workload in the middle span (P), deflection in the middle span (ΔC), bending moment in the middle span (MC), as well as ultimate workload (Pu), maximum deflection at middle span (ΔC.max) and ultimate bending moment (Mu) when there is a collapse of pull on the outer upper fiber of the test specimen. Based on the test data, a graph or curve of the relationship between the bending moment and deflection can be made. In addition, it can also be obtained the value of stiffness of each of the test objects. The stiffness of each test object can be calculated as follows:

$$\mathbf{k} = \frac{\mathbf{P_u}}{\mathbf{\Delta_{C.max}}}$$

With the data obtained from the results of these tests we can conclude and know the effect of the addition of prestressed plain steel on conventional concrete slabs.

B. Supporting Testing in Laboratory

In addition to testing the workload on the four test items, several other tests are also needed, namely:

1) Testing material properties for prestressed steel and non-prestressed steel (modulus of elasticity, melting strength and tensile strength of breaking) with the Universal Testing Machine.
2) Concrete compressive strength test that was achieved for all four specimens after 28 days with a compression testing machine.
3) Testing the specific gravity of cylindrical specimens.

IV. RESULT AND DISCUSSION

From the results of testing the workload on the four specimens the peak workload / peak (peak load: Pu) is obtained with maximum deflection in the middle span (Δc.max) that can be carried by each test object. A summary of the test results is given in Table 2 below.

Table 2. Summary of Loading Test Results of the Four Test Objects

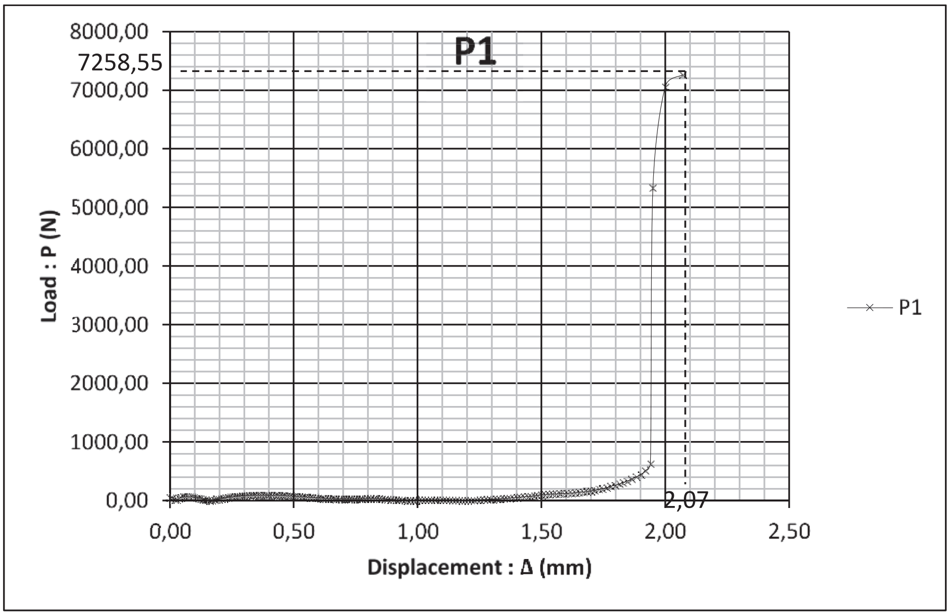
Test Objects	Pu N	$\Delta_{c.max}$ mm	L mm	L_n mm	q_d (↓) N/mm	q_b (↓) N/mm	M_u Nmm
P1	7258,55	2,07	1000	925	0,768		-1119026,46
P2	21208,30	16,30	1000	925	0,768	2,789	-3269612,92
P3	28056,91	36,46	1000	925	0,768	4,142	-4325440,29
P4	35058,47	49,27	1000	925	0,768	5,485	-5404847,46

Test Objects	M_d Nmm	M_b Nmm	$M_{u.total}$ Nmm	Increased Pu to P1		Increased $M_{u.total}$ to P1	
				(N)	(%)	(Nmm)	(%)
P1	-27380,00	0,00	-1146406,46	0,00	0,00%	0,00	0,00%
P2	-27380,00	298292,27	-2998700,65	13949,75	192,18%	1852294,19	161,57%
P3	-27380,00	442999,84	-3909820,45	20798,36	286,54%	2763413,99	241,05%
P4	-27380,00	586637,89	-4845589,57	27799,92	383,00%	3699183,11	322,68%

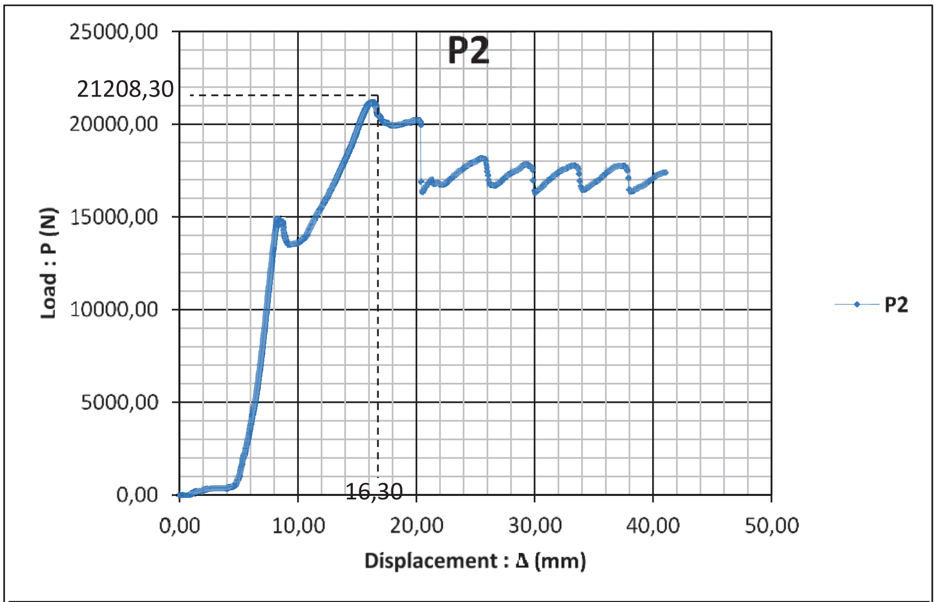
Information :
Mu: Peak bending moment due to peak load of UTM testing, Mu = -1 / 6PLn
Md: Bending Moment Due to Slab Self Weight, Md = -1 / 24qdLn2
Mb: Balancing Moment from Prestigious Style, Mb = 1/8qbLn2
Mu.total: Ultimate Total Moments, Mu.total = Mu + Md + Mb

From Table 2 it can be seen that the P4 specimen (Preferred Concrete Plates with 4 Tendons) has the greatest cross-sectional capacity in carrying the workload and bending moment, namely: Pu = 35058.47 N ≈ 3.5 tons and Mu.total = 4845589 , 57 Nmm. The specimen P1 (Conventional Concrete Plates / No Pre-Treatment) has the smallest cross-sectional capacity, namely: Pu = 7258.55 N ≈ 0.73 tons and Mu.total = 1146406.46 Nmm.

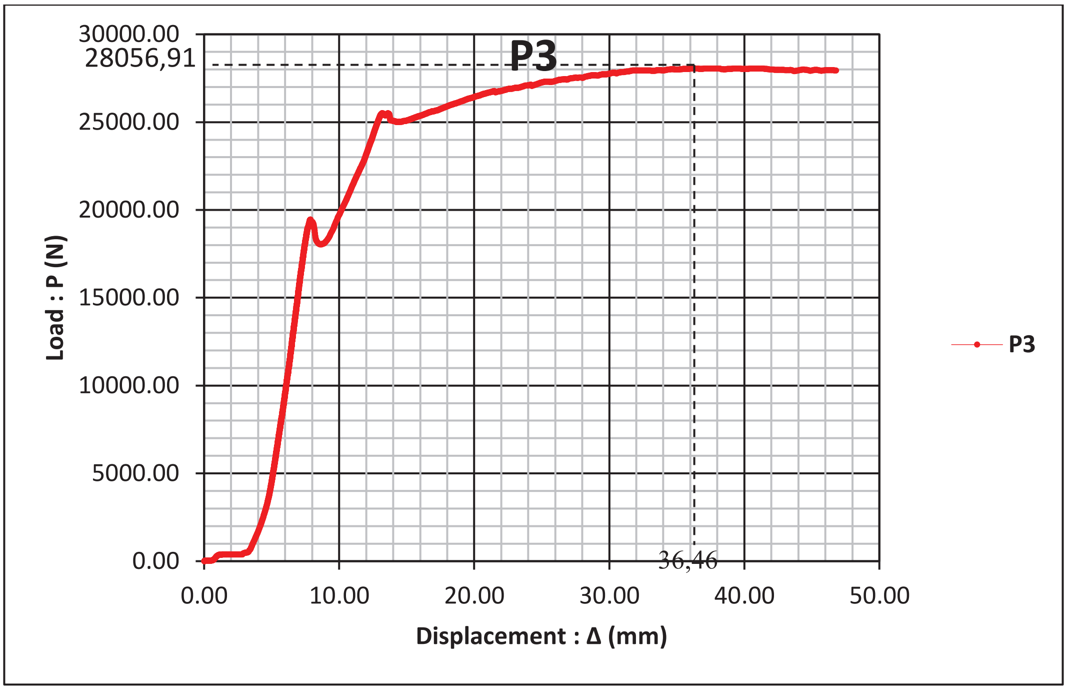
The relationship between the load and the deflection of each test object is shown in Figure 3.



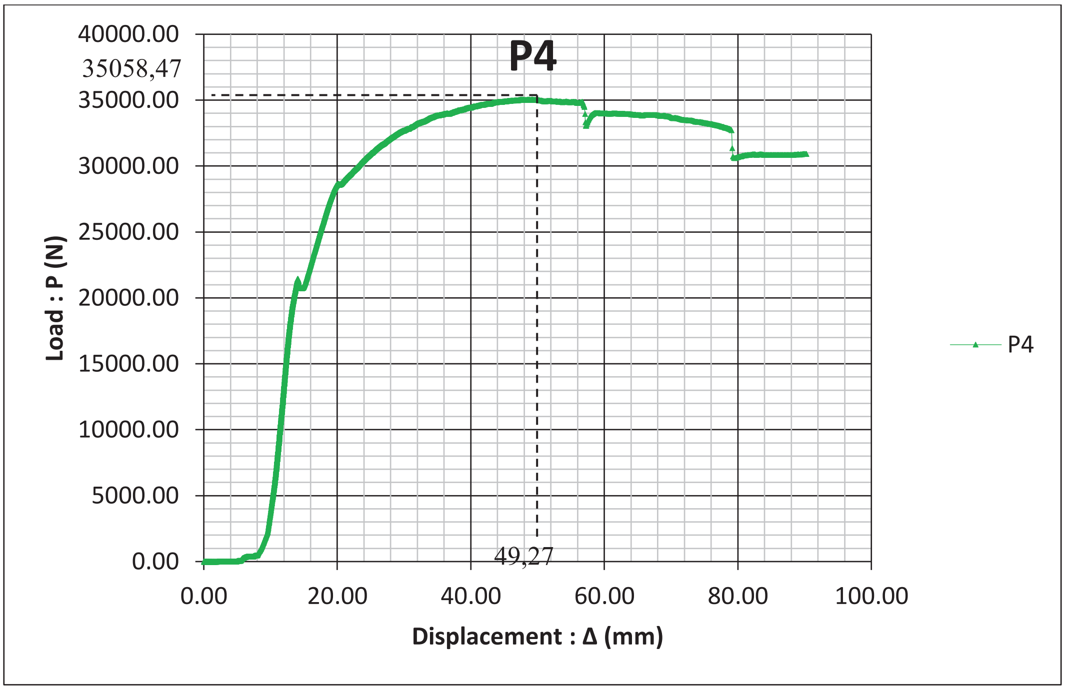
(a) Load vs Displacement Graph of Test Object P1



(b) Load vs Displacement Graph of Test Object P2



(c). Chart of Load Vs Displacementof Test Object P3



(d) Chart of Load Vs Displacement Test Objects P4

Figure 3: Load Vs Displacement Graph of Each Test Object

A comparison chart of the four test specimens for the relationship of load and deflection is shown in Figure 4.

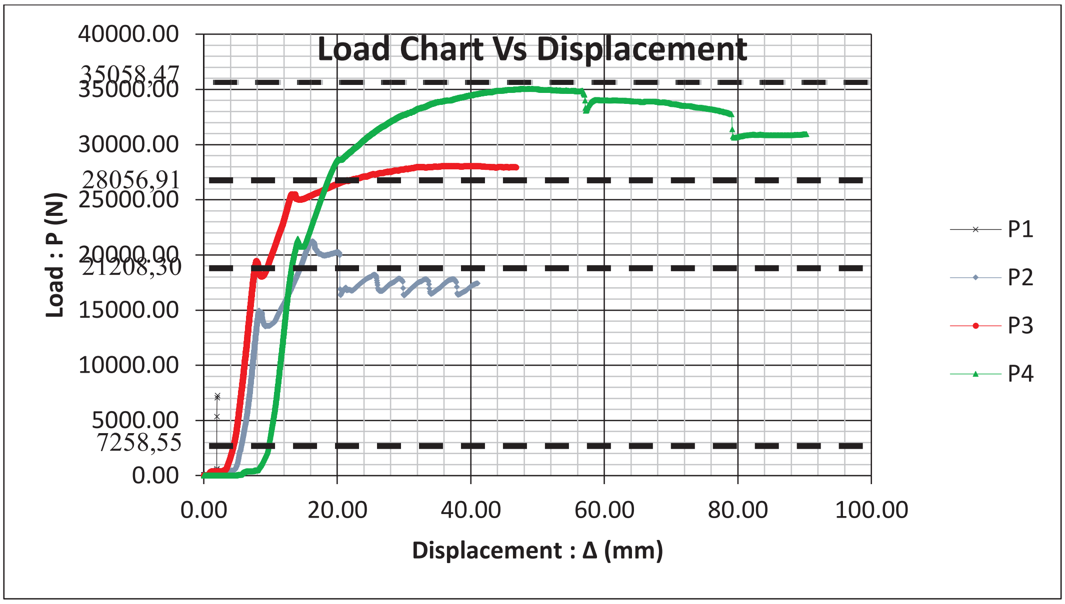


Figure 4: Comparison of the Four Test Objects for Load Vs Displacement

The relationship between the total bending moment and deflection is shown in Figure 5.

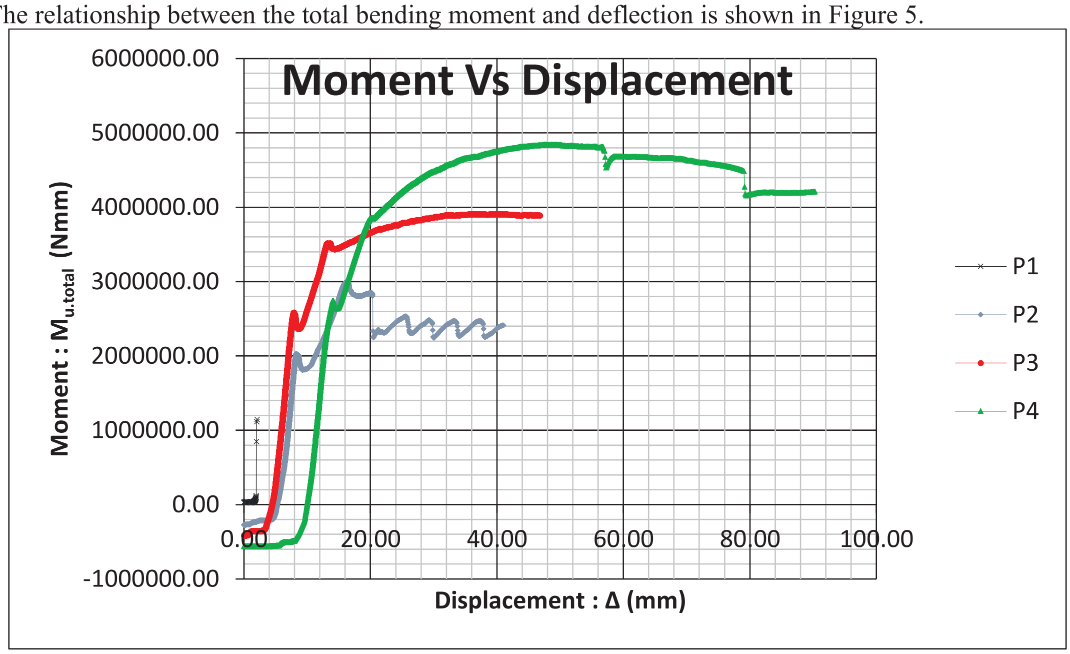


Figure 5. Comparison Chart of the Four Test Objects for Moment Vs Displacement

From Figure 5 above, it is clearly seen that at the initial loading stage, P2, P3 and P4 specimens (specimens using prestressed steel) still experience a positive bending moment (upward curvature). This actually shows the influence of the balancing load from the prestressed force which causes the vertical opposite load distribution downward, where at first the external workload from the UTM tool in the vertical direction upward has not been enough to compensate. Then at a greater loading level the test object will continue to experience a negative bending moment (curvature open downwards) until the boundary experiences a collapse / crack.

1) Comparison of Theoretical and Experimental Results

In this case we compare the results of theoretical calculations of nominal moment capacity (Mn) with peak bending moment that can be borne from the UTM (Mu.total) test results for each test object. Table 3 shows the difference between theoretical and experimental calculations.

Table3: Comparison of theoretical and experimental calculation results

Test Objects	Mn (Theoretically) Nmm	$M_{u.total}$ (Experimental) Nmm	Difference in Calculation Nmm	(%)
P1	975005,33	1146406,46	171401,13	17,58%
P2	2895439,95	2998700,65	103260,70	3,57%
P3	3752950,09	3909820,45	156870,36	4,18%
P4	4547878,60	4845589,57	297710,97	6,55%

2) Calculation of the value of the elastic limit stiffness of a test object (k)

The elastic limit stiffness of each test object can be calculated from the gradient of linear curve load vs. displacement before a fine crack occurs in the outer concrete fiber during UTM testing. To simplify the load vs. displacement graph is modified by removing the offset at the initial loading where the curve still looks flat and eliminating curves that have crossed the elastic limit. With the help of Microsoft Excel, the gradient of the linear function that represents the coordinates of the load vs. deflection is obtained. Figure 6 shows the elastic loading curve vs. deflection of each specimen.

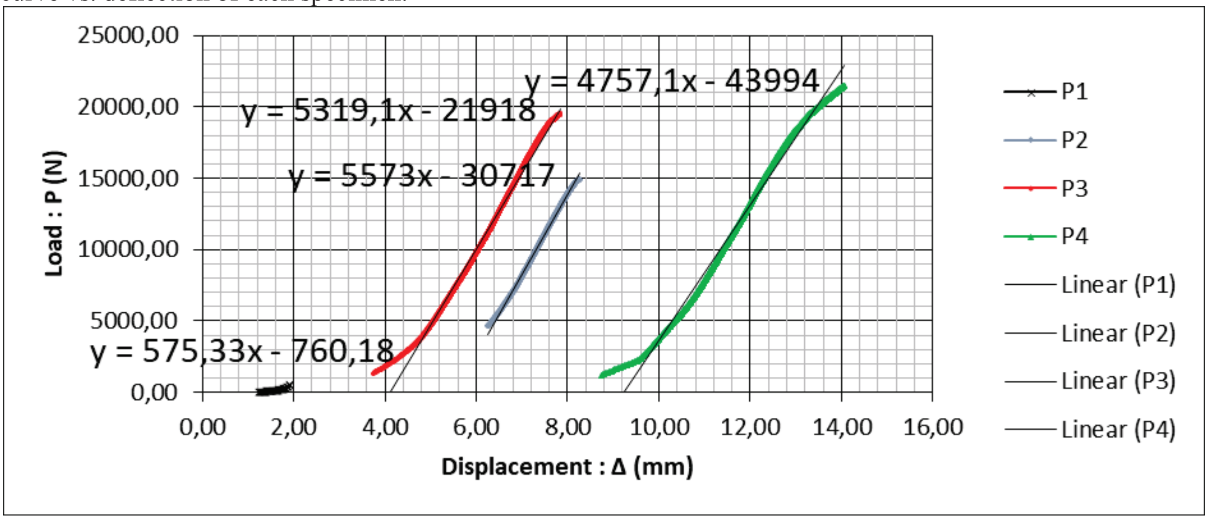


Figure 6. Elastic Loading Boundary Curves vs. Deflection

From Figure 6 the elastic stiffness of each test object is obtained as shown in Table 4 below.

Table 4.Value of Elastic Stiffness of Test Objects

Test Objects	Elastic stiffness k (N/mm)	Increase in P1 (N/mm)	Increase in P1 (%)
P1	575,33		
P2	5573	4997,67	868,66%
P3	5319	4743,67	824,51%
P4	4757	4181,67	726,83%

3) Calculation of the Collapse Time of Each Test Object

From testing the workload with UTM the collapse time when it reaches the peak load is also obtained. The collapse time of each test object is shown in Figure 7 below. The P1 test object has the shortest collapse time of 0.28 minutes. By giving a tendon, it gives a large increase in collapse time, ie the value of P2 specimen collapse time is 4.41 minutes, P3 specimen is 6.93 minutes and P4 specimen is 8.17 minutes.

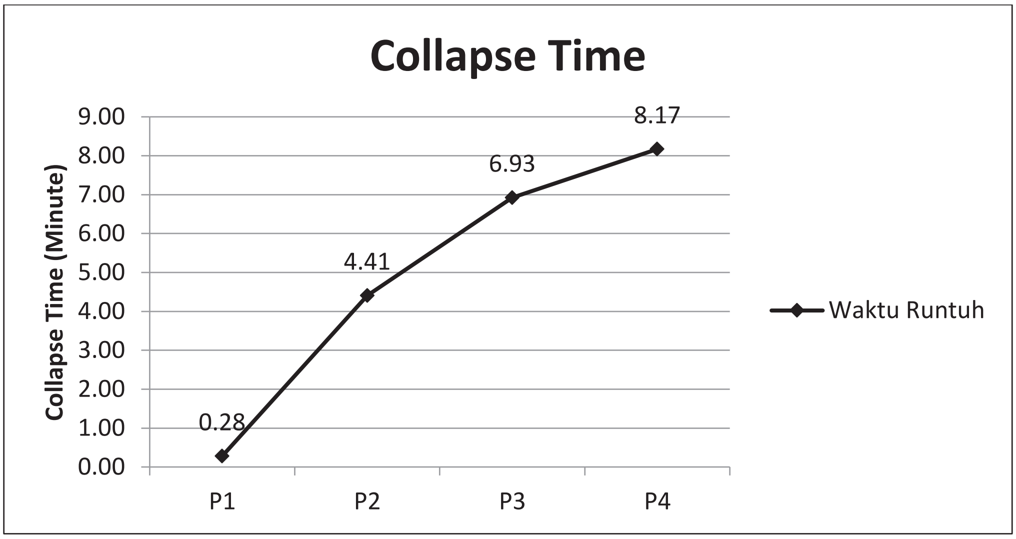


Figure 7. Collapsing Time of Each Test Object

V. CONCLUSION

1) The presence of prestressed steel in the form of a parabolic profile on a concrete plate has a very significant effect. This can be seen from the P2 specimen (with 2 prestressed steels) capable of carrying peak loads and peak bending moments that are much greater than P1 specimens (conventional concrete plates). Increased peak load capacity is 13949.75 N or around 192.18% and peak bending moment capacity is 1852294.19 Nmm or around 161.57%.

$$\mathbf{P_{u.P2}\ (21208{,}30\ N) >> P_{u.P1}\ (7258{,}55\ N)}$$
$$\mathbf{M_{u.total.P2}\ (2998700{,}65\ Nmm) >> M_{u.total.P1}\ (1146406{,}46\ Nmm)}$$

2) From the three specimens using prestressed steel (P2, P3 and P4), it can be seen that the addition of prestressed steel can increase the capacity of its supporting forces to withstand peak loads and peak bending moments that occur. This happens where the specimen P4 (with 4 prestressed steels) has the maximum strength.

$$\mathbf{P_{u.P2}\ (21208{,}30\ N) < P_{u.P3}\ (28056{,}91\ N) < P_{u.P4}\ (35058{,}47\ N)}$$
$$\mathbf{M_{u.total.P2}\ (2998700{,}65\ Nmm) < M_{u.total.P3}\ (3909820{,}45\ Nmm) < M_{u.total.P4}\ (4845589{,}57\ Nmm)}$$

3) The calculation of the bending moment capacity is theoretically smaller than the bending moment capacity that can be assumed when testing. The difference in calculation of the P1 specimen is 17.58% and the specimens P2, P3, P4 are still below 7%, as shown in Table 4.2. This is clear because theoretically the ultimate method ignores areas that experience tensile strength in concrete cross sections due to the mechanical properties of small concrete tensile strength, which in fact the tensile area of concrete still contributes capacity in bearing the moment that occurs.
4) Based on the ratio between the burden borne by the deflection that occurs at the elastic limit, the specimen P1 has the minimum stiffness value, which is equal to k1 = 575.3 N / mm. Meanwhile, the application of prestressed tendons to concrete slabs can increase the value of stiffness to be very large. This can be seen in the maximum value of P2 (with 2 tendons), which is equal to k2 = 5573 N / mm. The amount of increase was 4997.7 N / mm or 868.71%.
5) With a UTM load speed of 5000 N / min, an increase in peak load gives an increase in the collapse time. Test object P4 has a maximum collapse time of 8.17 minutes. It can be concluded that the collapse time is directly proportional to the peak load.
6) In this study it can be concluded that for the case of slabs with a size of 100 × 40 × 8 cm, the use of 2 parabolic tendons has been very effective in the performance of prestressed concrete slab structures. This can be seen at the maximum P2 stiffness value of 5573 N / mm and has been able to provide an increase in peak load that can be borne very large than conventional concrete slabs by 192.18%.
7) From the descriptions above it can be concluded that concrete slabs using additional prestressed steel can replace conventional concrete slabs with beams for the sake of achieving efficiency in the construction of buildings.

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