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Flexural Behavior of Reinforced Concrete Beams with Utility Facilities in the Section Area

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Abstract—**Reinforced concrete beams that incorporate utility facilities are designed to enhance efficiency by reducing the overall volume of concrete required and providing a functional space for utility storage. The main objective of this study is to rigorously evaluate whether the load-bearing capacity of these specially designed beams is comparable to that of traditional solid-reinforced concrete beams. To achieve this, three beams were subjected to rigorous bending tests: one set of solid reinforced concrete beams and two sets that included utility facilities, utilizing 3-inch and 4-inch PVC pipes, respectively. The experimental results revealed that the bending capacity of each beam was primarily influenced by the allowable deflection, which was capped at 1.25 mm. The recorded bending capacities were as follows: 138.13 kN for the solid beams, 120.8 kN for the beams with 3-inch pipes, and 106.90 kN for those fitted with 4-inch pipes. These findings highlight a significant observation: the stiffness of the beams containing utility facilities—regardless of the pipe size—was notably lower than the solid reinforced concrete beams. However, these utility-equipped beams exhibited more excellent ductility, indicating they could undergo more deformation before failure. Additionally, the analysis of the relationship between load and deflection mirrored these trends, underscoring that the tensile strength of the reinforcement bars (rebar) plays a critical role in determining the bending capacity of the beams. This comprehensive evaluation provides valuable insights into the structural performance of reinforced concrete beams equipped with utility features, laying the groundwork for future construction practices prioritizing functionality and material efficiency.**

Keywords—**Hollow reinforced concrete beams; PVC pipes; bending capacity; load-deflection curve.**

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I. INTRODUCTION

Concrete is the most widely used construction material in the world for the construction of houses, buildings, port bridges, and tunnels [1], [2], [3], [4], [5]. The main reason is that some of the materials that make up concrete are readily available and cheap [6]. Concrete has been known for thousands of years, both during the Ancient Roman, Chinese, Egyptian, and Roman eras in 600 BC, and developed further after the discovery of cement by Joseph Aspdin in 1824 [7], [8]. In Indonesia, the development of reinforced concrete began during the Dutch colonial period and increased along with the development activities in the Dutch East Indies. The use of reinforced concrete between 1901 and 1942 can be seen in the buildings and infrastructure that still exist today [9], [10]. In addition, it is estimated that the construction of buildings and road infrastructure in the world will produce 4.4 billion tons of concrete annually, contributing about 8% of global CO2 emissions [11]. Lehne and Preston [12] asserts that concrete production is expected to increase to more than 5.5 billion tons by 2050. This condition is closely related to the massive urbanization that occurs in the third world, especially in poor countries [12], [13]. The Paris Agreement emphasizes that the increase in global temperature due to CO2 emissions, which is the result of cement production, is limited to 1.50C [14], [15]. The main components of concrete are made up of materials that can have environmental consequences, emphasizing the importance of adopting environmentally friendly practices to reduce their impact [16], [17], [18], [19].

The use of concrete for structural purposes needs to be reduced. It starts from the improvement of the mixed design and implementation system to an effective concrete structure obtained based on the criteria of performance, strength, and resistance to load [20], [21], [22]. The reason for the emergence of reinforced concrete beam structures with utility facilities in tensile cross-sections begins with the behavior of reinforced beam structures in withstanding bending loads [23]. Due to the bending moment, the top will withstand the compressive force, and the bottom will withstand the tensile force [24], [25], [26], [27], [28], [29], [30]. In a balanced condition, the tensile strength carried by the reinforcing steel is made equal to the compressive strength brought by the concrete part above the neutral line so that there is a concrete part below the neutral line that does not carry compressive force so this part can be eliminated or made with a hole [31].

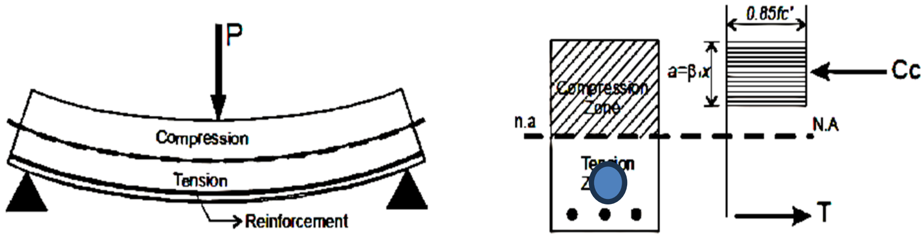

Fig. 1 Tension diagram of reinforced concrete structure with utility facilities

The purpose of providing pipe holes in reinforced concrete beams is to make the structure lighter and reduce cement production as the primary material for making concrete. The manufacture of cement, which causes carbon dioxide (CO2) gas emissions which can cause the greenhouse effect, can also be reduced [32]. In addition, PVC pipe holes can be used for utility lines (cables, drinking water pipes, and others).

Several studies have been conducted, among others, by Murugesan and Narayanan [33]who tested beams by placing PVC pipes of various diameters at a certain depth, obtaining the result that the capacity of the beam is determined by the tensile strength capacity of the reinforcement until a bending collapse mode occurs. This is based on the research of Sariman et al. [34] who used plastic bottles as cavity formers with various variations and obtained the result that the bending capacity of a whole reinforced concrete beam is the same as that of a hollow reinforced concrete beam.

Research by Al-Maliki et al. [35] on a 1000x120x180 mm reinforced concrete beam given longitudinal cavities measuring 40x80 mm and 80x80 mm. In this study, six numerical models of reinforced concrete beams with and without cavities were simulated using ANSYS software to evaluate the structural behavior of the beam model under a partially uniformly distributed load. The numerical results obtained were analyzed and verified and found to be very close to those obtained from experimental investigations in the literature.

The study by [36] aimed to test the behavior of high-strength hollow reinforced concrete beams (HSC) and very high strength (UHPC) with openings and compare them with hollow beams without openings. Hollow beams with openings are modeled using the finite element method and analyzed under torque, flexural, and cyclic loads with HSC and UHPC materials. The effect of the size of the opening section on the behavior of hollow beams was also evaluated. The openings formed in the hollow beam network cause a decrease in the capacity of the beam, even though hollow beams with small openings can withstand almost the same load as hollow beams without openings.

Alharthi et al. [37] investigated the behavior of SCC hollow beams reinforced by GFRP bars, with longitudinal openings between 6 and 15% of the total cross-sectional area in circles and squares. Conventional reinforced concrete beams with openings of 9% of the total cross-sectional area are used as control concrete. The results showed that the position of the hole had a significant effect on the behavior of the hollow GFRP-RC beam. Parametric studies show that the compressive strength of concrete is the most influential factor on the bending capacity of the beam, while the GFRP reinforcement ratio has little effect on the crack load.

The load-deflection relationship graph also shows that hollow reinforced concrete beams with a smaller cross-sectional area generally have a steeper curve slope than reinforced concrete beams with larger basins, as in the study of Alshimmeri and Al-Maliki [38] who used concave areas with an area of 7.4% and 14.8% of the cross-sectional area of reinforced concrete beams, then used stirrups at f10mm with distances of 100 mm and 50 mm and researchers Hassan et al. [39] which showed a load deflection graph of hollow reinforced concrete beams both in weak reinforcement (under-reinforced) and in strong reinforcement conditions (over-reinforced), which generally have the same pattern as hollow reinforced concrete beams.

The results of the above test are under the results of the study by [40] which uses plastic bottles as the cavity formed with a cavity height of 180 mm and a hollow length varying from 880 mm to 1760 mm and 2640 mm. The results tend to be the same as the above research, meaning that the stiffness of solid beams is greater than that of hollow reinforced concrete beams. On the contrary, the ductility of hollow reinforced concrete beams is better than that of solid reinforced concrete beams.

Based on the above background, this study aims to determine the bending capacity of reinforced concrete beams, both reinforced concrete beams and reinforced concrete beams with utility facilities. Also, this study defines the bending behavior of the control reinforced concrete beam compared with the reinforced concrete beam with utility facilities with different PVC pipe diameters, including the load-deflection diagram and the stiffness and ductility comparison of the specimen. Besides, this research determines the performance comparison of the test specimen of the control beam and the reinforced concrete beam with the utility facility.

II. Materials and Method

A. Beam Specimen Dimensions

The Beams' dimensions are planned according to the standard beam size of reinforced concrete bridges with a scale of 1: 3. The details are beams width: b=175mm; beams height: H=350mm; effective height: d = 314 mm. It includes 3D16mm tensile and compression reinforcement, which is 28mm. Sliding reinforcement, on support: 8–100 mm, medium in field 8–150 mm beams length L=3300mm (free span: 3000mm). PVC pipes are installed along beams with 3" and 4" diameters in the tensile section below the neutral line. The compressive strength of concrete fc = 25 MPa. Steel rebar tensile strength fy = 482 MPa.

B. Variables and Sample Notation

The test to be carried out is a bending test using reinforced concrete beams consisting of whole concrete beams (BLN) as control beams and reinforced concrete beams with utility facilities placed in the tensile area along the beams with 2 diameter variations, namely a 3" diemeter and a 4" diameter. The number of samples for each variation is 1 piece. The variables and sample notation tested in this study can be seen in the following Table 1.

TABLE I
SAMPLE VARIABLES AND NOTATIONS FOR THE FLEXURE TEST

No	Hollow Length (mm)	PVC Pipe Diameter (inch)	Beams Notation	Number of samples
1	0	0	Normal reinforced concrete beams	2
2	3300	3	Reinforced concrete beams with utility facilities 3-inch	2
3	3300	4	Reinforced concrete beams with utility facilities 4-inch	2

C. Theoretical Calculation of Bending Capacity of Beams

The test is by Nawy's theory [41] with a ratio of a/d = 4.68 for beams with a centralized load for bending failure. A sketch of the test can be seen in Figure 2.

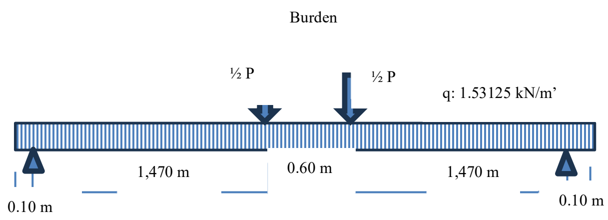

Fig. 2 Flexural test sketch

Figure 3 presents the results of calculating the specimen's beam mechanics and theoretical capacity. If a cut is taken in the middle of the span, then the tension diagram and strain diagram for reinforced concrete beams with double reinforcement are shown in the beam cross-section.

Style Balance: Cc + Cs = Ts, Cc = 0.85 f'c. a. b, Cs = A's. fy, and Ts = As. fy. Next, As = As_1 + As_2, As_2 = A's so that As_1 = As – A's. Moments that cross-sections can carry: Mu = Cc. (d-1/2a) + Cs (d- d'). If f'c = 25 MPa, fy = 482 MPa, b = 300 mm, h = 350 mm, d = 314 mm and d' = 32mm and tensile reinforcement 3 D16 (As = 602.97 mm^2) and rebar press 3f8 (A's = 100.53 mm2) then the theoretical moment capacity that the cross-section can bear can be calculated as shown in Table 2.

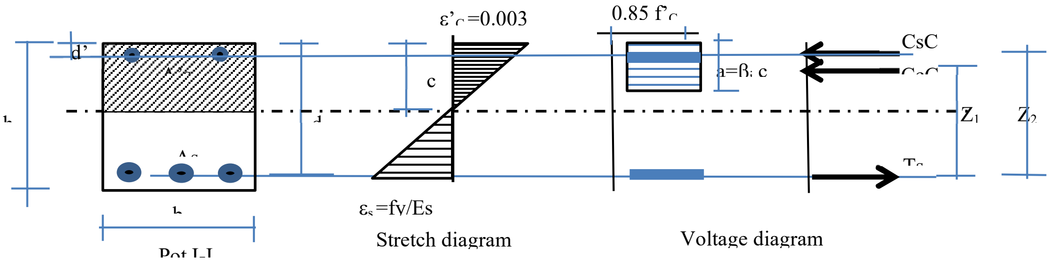

Fig. 3 Reinforced concrete beam tension diagram sketch

TABLE II
CALCULATION OF THE THEORETICAL CAPACITY OF REINFORCED CONCRETE BEAMS

Description	Notation	Unit	Types of Beams		
			Normal reinforced concrete beams	**Reinforced concrete beams with utility facilities 3-inch**	**Reinforced concrete beams with utility facilities 4-inch**
Pipe Diameter	Dp	Mm	0	76.2	101.6
Beam Weight	Q	Kg	503.1	454.2	420.2
Beam unit weight	q	kN / m	1.5245	1.3764	1.2733
Moments in the middle of the stretch	Mu	kN m	0,6P + 1,6980	0,6P + 1,5329	0,6P + 1,4182
Height of the press beam (a)	a = A's.fy / 0.85 f'c. b	Mm	64.88	64.88	64.88
Distance the neutral line from the press side, β_1 = 0.85	c = a / β1	Mm	76.33	76.33	76.33
Distance from the center point of the tension beam to the center of the reinforcement	Z_1 = d – 1/2 a	Mm	281.56	281.56	281.56
Compressive strength contributed by concrete	C = 0,85 f'c. a. b	**N**	241278.26	241278.26	241278.26
Distance of tensile reinforcement with pressed reinforcement	Z_2 = d – d'	Mm	282.00	282.00	282.00

Description	Notation	Unit	Types of Beams		
			Normal reinforced concrete beams	Reinforced concrete beams with utility facilities 3-inch	Reinforced concrete beams with utility facilities 4-inch
Compressive strength contributed by reinforcing steel	T	**N**	48275.97	48275.97	48275.97
Momen Ultimate	Mu	N mm	81547943.79	81547943.79	81547943.79
	Mu	kN m	81.55	81.55	81.55
Burden	P	kN	133.08	133.36	133.56

D. Flow Chart

To further simplify the course of the research, starting from literature review, preparation of research tools and materials, making steel formwork, iron tensile test, and concrete mix design, then continued with the implementation of bending tests, collection, and analysis of test results data as well as discussion of test results and conclusions made a research flow chart as shown in Figure 4.

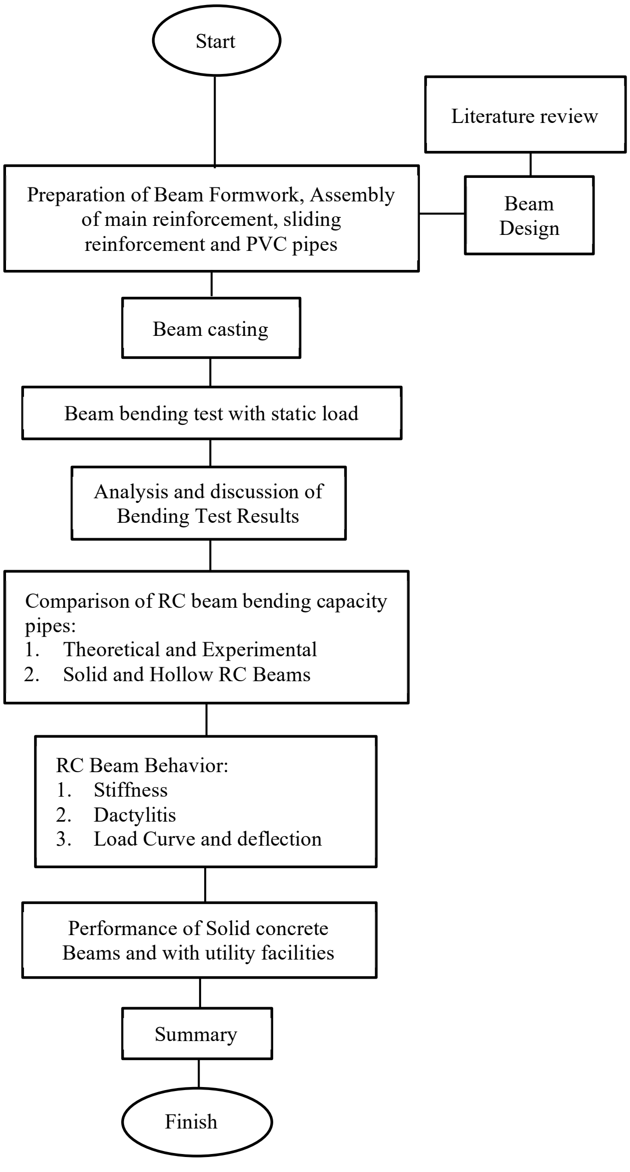

Fig. 4 Elasticity Flow Chart

E. Fabrication and Lifting of Test Specimens

After the reinforcing iron is installed and the formwork is ready, the casting starts from the base of the test beam and stops at 80 mm. After that, the PVC pipe is by the diameter that has been set, laid on the concrete surface, according to the length that has been set. Casting is then continued until the formwork is complete. All test beams are maintained for 28 days and then lifted to the test site for flexural testing.

(a)

(b)

Fig. 5 (a) Factory; (b) Beam lifting

In the casting of the test beam, it is necessary to pay attention to the quality of the concrete, so that it is in accordance with the Mix Design, therefore every 3 x mixtures are slump tested so that the viscosity of the concrete is still within the specified tolerance limit. Maintenance is carried out for 28 days by keeping the concrete in a humid state, therefore the concrete must be periodically watered and kept moist by covering it with wet sacks. After a minimum of 28 days of age, the beam is lifted to the test site using a pulley.

F. Test Setup

Before starting the test, all equipment must be set so that during the test there are no things that can hinder the implementation of the test. Once the test beam is in place, all tools are set and set. The load cell and actuator are checked for condition, the three deflection gauge dials are placed in the middle of the span and below the two load points. The test beam must have grid lines made so that it is easy to draw when cracks occur. The setting of the test tool can be seen in Figure 6.

Fig. 6 Test Equipment Setup

Fig. 6 shows the loading settings of the test piece. All beams are tested with two loading points using actuators with the most considerable load of 1500 kN. Load cells with a capacity of 200 kN are used to measure the magnitude of the load.

G. *Test Execution*

The load is applied 2-5 kN per step until the load reaches 50 kN. Then, a load of 10 kN per step is given until the maximum load is reached. Each loading step is recorded simultaneously with the deflection recording installed at 3 points. Similarly, cracks occur, drawn directly on the beam along with the load, resulting in cracking. The load is carried 2-5 kN per step to the maximum load. Three Dial gauges measure the beam's deflection. Each load reading is measured for deflection, and the cracking pattern is described.

Fig. 7 Test execution

This beam test is implemented for each beam type with the same procedures and record-keeping. The results of the bending test on hollow beams carried out by several researchers show that the capacity of hollow reinforced concrete beams is not significantly different from that of whole reinforced concrete beams.

III. Results and Discussion

A. *Results Test*

The results of the average deflection load test are presented in the following Table 3. The average deflection value is obtained from the deflection test results in Table 3. In Table 3, it can be seen that at loads up to 50 kN, the load-deflection curve tends to be the same, but after the load exceeds 50 kN, the graph tends to be different due to the difference in deflection values at the same load, this is due to the difference in beam stiffness. At a load of about 140-147 kN, the bending capacity of the three reinforced concrete beams is the same until the tensile strength of the reinforcement is reached.

TABLE III
DEFLECTION LOAD TEST RESULTS

Description	Normal reinforced concrete beams		Reinforced concrete beams with utility facilities 3-inch		Reinforced concrete beams with utility facilities 3-inch	
Weight	503.10 kg		468 kg		438.6 kg	
No.	Load (kN)	Deflection (0.01mm)	Load (kN)	Deflection (0.01mm)	Load (kN)	Deflection (0.01mm)
1	0	0	0	0	0	0
2	2	20	2	23	2	25
3	4	27	4	34	4	38
4	5	40	5	47	5	45
5	8	46	8	50	8	53
6	12	80	12	90	12	103
7	17	120	17	132	17	140
8	20	159	20	180	20	168
9	25	197	25	234	25	195
10	30	241	30	258	30	230
11	35	273	35	294	35	309
12	40	330	40	359	40	388
13	45	393	45	451	45	504
14	50	434	50	540	50	685
15	60	519	60	637	60	785
16	70	566	70	724	70	879
17	80	694	80	810	80	954
18	90	782	90	898	90	1076
19	100	881	100	1010	100	1150
20	110	953	110	1146	110	1295
21	120	1029	120	1238	120	1398
22	130	1150	130	1379	130	1529
23	140	1273	140	1464	140	1565
24	145	1413	145	1609	145	1665
25	146	1491	146	1734	146	1774
26	147	1624	147	1804	147	1829
27	147	1807	147	1825	147	1865
28	140	2015	140	1850	140	1965
29	130	2140	130	1980	130	2074
30	120	2250	120	2125	120	2235
31	90	2300	90	2340	90	2450

B. *Flexural Capacity*

1) Comparison of beam capacity between theoretical calculations and experimental test results: The experimental bending capacity is determined through the relationship between load and deflection. According to SNI 2847-2019 beam regulations, the maximum deflection is L/240. Thus, the maximum deflection = 3000/240 = 12.5 mm. Meanwhile, the theoretical bending power is obtained from calculations according to Table 3. A comparison of theoretical bending capacity and experimental test results can be seen in Table 4 below.

TABLE IV
COMPARISON OF THEORETICAL AND EXPERIMENTAL TEST CAPACITY OF TEST BEAMS

Pu	Theoretical calculation	Experimental Test
	Kn	Kn
Normal reinforced concrete beams	130.98	138.13
Reinforced concrete beams with utility facilities 3-inch	131.25	120.85
Reinforced concrete beams with utility facilities 4-inch	131.45	106.90

The theoretical bending capacity of normal concrete beams is 5.05% less than the experimental test results. This proves that the safety factor has been included in the theoretical calculations. Meanwhile, in beams with utility facilities, the theoretical bending capacity of beams using utility pipes with a diameter of 3-inch was 7.92%, and with a diameter of 4-inch beams were larger (11.07%) than the experimental test results. This shows that in theoretical calculations, the stiffness of the beam is not considered, but only the tensile capacity of the reinforcement is considered. This must be regarded when implementing reinforced concrete beams with utility facilities in tensile cross-sections or hollow concrete beams in general.

2) Comparison of the capacity of standard reinforced concrete beams and concrete beams with utility facilities: From the load-deflection relationship of each beam, a comparison of the cliff power of standard reinforced concrete beams with reinforced concrete beams with utility facilities 3-inch and 4-inch can also be obtained.

TABLE V
COMPARISON OF BENDING CAPACITY OF NORMAL REINFORCED CONCRETE BEAMS AND BEAMS WITH UTILITY FACILITIES (3 AND 4-INCH PIPE)

Pu	Experimental	%
	Kn	Differences
Normal reinforced concrete beams	138.13	
Reinforced concrete beams with utility facilities 3-inch	120.85	87.49 %
Reinforced concrete beams with utility facilities 4-inch	106.90	77.39 %

The shading capacity of normal reinforced concrete beams is greater than the bending capacity of the beam with 3" diameter pipe utility facilities, which is only 87.49%, and the bending capacity of reinforced concrete beams with utility facilities 4-inch is only 77.39% of the bending capacity of normal reinforced concrete beams.

C. Flexural Behavior

1) Specimen Stiffness: The stiffness of the beam is calculated by the following formula:

$$K = Pcr/\Delta cr \quad (1)$$

where K is stiffness with KN/mm, and Pcr is the load at the initial crack (elastic limit) KN. Δcr is deflection at the initial crack (elastic limit) mm. The results of the calculation of beam stiffness are shown in Table 6.

The stiffness of the Beam with utility pipe is smaller than the stiffness of the normal beam. The larger the diameter of the utility pipe, the smaller the stiffness value. For beams with 3" diameter and 4" diameter utility pipes, the stiffness is 91.07% and 83.84% of the normal beam stiffness, respectively.

TABLE VI
CALCULATION OF BEAM STIFFNESS

No	Specimen	Pcr	Dcr	K	K
		N	Mm	kN/mm	%
1	Normal reinforced concrete beams	15500	0.108	143518.5	100%
2	Reinforced concrete beams with utility facilities 3-inch	14900	0.114	130701.8	91.07%
3	Reinforced concrete beams with utility facilities 4-inch	14800	0.123	120325.2	83.84%

2) Specimen Ductility

The following formula obtains tenacity:

$$\mu m = \Delta y / \Delta u \quad (2)$$

where μm is ductility ratio, Δy is deflection at the time of yield strengthening and Δu is deflection at the final load.

TABLE VII
SPECIMEN DUCTILITY CALCULATION

No	Specimen	Dy	Du	Mm	K
		Mm	Mm	Dy/ Dmax	%
1	Normal reinforced concrete beams	1.109	12.5	0.886	100%
2	Reinforced concrete beams with utility facilities 3-inch	1.290	14	0.924	104.24%
3	Reinforced concrete beams with utility facilities 4-inch	1.448	15.4	0.942	106.27%

The ductility of beams with utility pipes is greater than that of Solid beams. The larger the diameter of the utility pipe, the greater the ductility value. beams with 3" diameter and 4" diameter utility pipes, their ductility is 104.24% and 106.27% respectively compared to the tenacity of normal reinforced concrete beams.

3) Deflection relationship load: The deflection load for all specimens can be seen in Fig. 8.

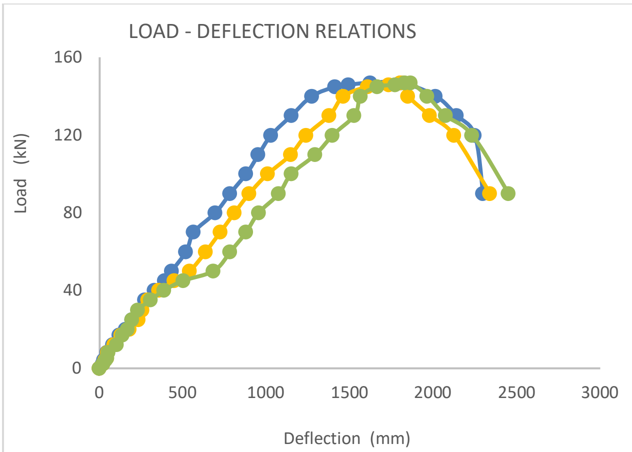

Fig. 8 Load beam Specimen Deflection

Figure 8 shows that at loads up to 50 kN, the load-deflection curve tends to be the same, but after the load exceeds 50 kN, the graph tends to be different due to the difference in deflection values at the same load. This is due to the difference in beam stiffness. At a load of about 140-147 kN, the bending capacity of the three reinforced concrete beams is the same until the tensile strength of the reinforcement is reached.

4) Performance of solid concrete beams and concrete beams with utilization facilities: The performance of the specimen can be seen from the comparison of the moment-bearing capacity with the weight of the beam (Mu/W). The comparison of the maximum moment ratio and the weight of the test specimen is presented in Table 8 as follows:

TABLE VIII
COUNT MU/W

No	Specimen	Momen Ultimate Mu)	Specimen Weight (W)	Mu/W
		kN m	Kg	
1.	Normal reinforced concrete beams	138.13	510	0.271
2.	Reinforced concrete beams with utility facilities 3-inch	120.85	468	0.258
3.	Reinforced concrete beams with utility facilities 4-inch	106.90	438	0.244

IV. CONCLUSION

The bending capacity of solid reinforced concrete beams theoretical = 133 kN is smaller than the experimental test result = 138 kN, this proves that the safety factor has been included in the theoretical calculation. While the theoretical bending capacity of reinforced concrete beams with utility facilities is greater than the results of the experimental test, this is due to the fact that in the experimental test, the bending capacity is limited by the allowable deflection, in which case L/240 = 12.50 cm whereas the theoretical calculation does not take into account the deflection factor.

The bending capacity of reinforced concrete beams with utility facilities is smaller than the bending capacity of normal concrete beams, namely reinforced concrete beams with utility facilities 3-inch = 87.49 % and reinforced concrete beams with utility facilities 4-inch = 77.39 % compared to the bending capacity of normal reinforced concrete beams. This is also evidenced by the level of stiffness reinforced concrete beams with utility facilities 3-inch = 91.07 % and reinforced concrete beams with utility facilities 4-inch = 83.84 % compared to normal reinforced concrete beams. On the other hand, the tenacity of reinforced concrete beams with utility facilities 3-inch = 104.24% and reinforced concrete beams with utility facilities 4-inch = 106.27% is more remarkable in theoretical capacity normal reinforced concrete beams = 132 kN. In contrast, the traction capacity of normal reinforced concrete beams is smaller.

The performance of reinforced concrete beams is obtained by comparing their capacity with their weight. The Mu/W ratio in solid and normal reinforced concrete beams showed the highest value compared to the Mu/W of reinforced concrete beams with utility facilities 3-inch and 4-inch beams.

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