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Research Article

Deflection Behavior of Reinforced Concrete Beam Frame System with 3/4 Spacing Effective Height of The Beam

David D.M. Huwae[1], Pieter L. Frans[1], Lydia R. Parera[2]*

[1]Politeknik Negeri Ambon, Ambon, Indonesia
[2]Universitas Pattimura, Ambon, Indonesia

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**Corresponding author:*
E-mail:
lydiariekie@gmail.com

ABSTRACT

This study aimed to analyze the deflection behavior of reinforced concrete beams with a spacing of 3/4 of the effective beam height. This research is a laboratory experimental study with a design of 6 (six) test objects consisting of 3 (three) normal beams (BN) as control variable beams and 3 (three) reinforcing beams of the frame system with a spacing of 0.75d (BTR75) as the independent variable. Data were analyzed using the strength design method. The results showed that the deflection behavior of reinforced concrete beams with a spacing of 3/4 of the effective beam height (BTR75) had better serviceability and increased the flexural capacity of Mu beams up to 4.60% and reduced the amount of deflection of the beam BN.

Keywords: *Deflection behavior, Truss system, Reinforcement beams*

Introduction

The serviceability of a reinforced concrete beam structure is generally determined by short-term and long-term deflection. Deflection investigations had been carried out before the 1970s and the analysis gave concrete stress limits of approximately 45% of its compressive strength and steel stress of 50% of its yield strength in reinforced concrete beams (Araba & Ashour, 2018). In general, reinforced concrete beams use stirrup reinforcement installed perpendicular to the beam axis to withstand shear forces (Ahmad, Masri, & Abou Saleh, 2018). Meanwhile, to overcome deflections due to moments, longitudinal reinforcement is installed on the bottom and top sides of the beam cross-section (Figure 1) (Frans & Tahya, 2020). Along with developments in technology and knowledge, various ideas have been developed to increase the flexural capacity of reinforced concrete beams, one of which is the use of frame system reinforcement which changes the configuration of vertical reinforcement to inclined reinforcement (Frans, Parung, Djamaluddin, & Irmawaty, 2019). Changes in the geometric reinforcement of the frame system can increase the shear strength and flexural strength and reduce the amount of deflection in the beam (Figure 2) (Fan, Liu, Huang, & Sun, 2019). Many previous researchers recommended the use of frame system reinforcement in reinforced concrete beams showing higher

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flexural strength and shear strength than the use of vertical reinforcement system reinforcement (Yu, Luo, & Fang, 2020). Based on the author's observations, what is the deflection behavior of concrete beams reinforcing the frame system by changing the configuration of vertical stirrup reinforcement to inclined stirrup reinforcement with a spacing of 1/4 of the effective height of the beam (Hama, Mahmoud, & Yassen, 2019);(El-Helou & Graybeal, 2022). This research aims to analyze the deflection behavior of reinforced concrete beams in a frame system with a spacing of 3/4 of the effective height of the beam (Balaji & Thirugnanam, 2018). During the test, the applied load, strain in the concrete compression area, tensile steel at the mid-span, and deflection at the mid-span are measured up to failure (Albegmprli, Gülşan, & Cevik, 2019);(Obaidat, 2022). The response of the beam is examined and discussed in terms of deflection, strain, load capacity, crack patterns, and failure modes (Suparp & Joyklad, 2021).

Figure 1. Beam with vertical stirrup reinforcement

Figure 2. Concrete beam reinforcement frame structure

Methods

Normal beam type (BN) with 3 (three) vertical stirrups (see Figure 3). Type of concrete beam reinforcing frame system with a spacing of 3/4 of the effective height of the beam (BTR75) or a spacing of 0.75d (see Figure 4). Each test object has a cross-sectional size of 150 x 200 mm with a beam length of 3300 mm. Using 2Ø6 mm steel reinforcement as the top longitudinal reinforcement and 3D12 mm (Rahman, Dirar, Jemaa, Theofanous, & Elshafie, 2018) threaded reinforcement as the bottom longitudinal reinforcement and Ø8 mm steel reinforcement for the vertical and diagonal stirrup reinforcement (Chen, Zhou, Zheng, Wang, & Bao, 2020).

Test specimen setup where the load is applied to a hydraulic jack on a mounted steel contrast frame. The jack is controlled by a hydraulic control unit at a rate of 0.2 mm/sec (see Figure 5) (Nematzadeh & Fallah-Valukolaee, 2021). A load cell with a capacity of 200 kN is placed between the jack and the distributor beam to precisely measure the applied force. During loading, it is recorded via a data logger. A linear variable differential transducer (LVDT) was used to monitor the vertica displacement of the concrete beam (Seara-Paz, González-Fonteboa, Martínez-Abella, & Eiras-López, 2018).

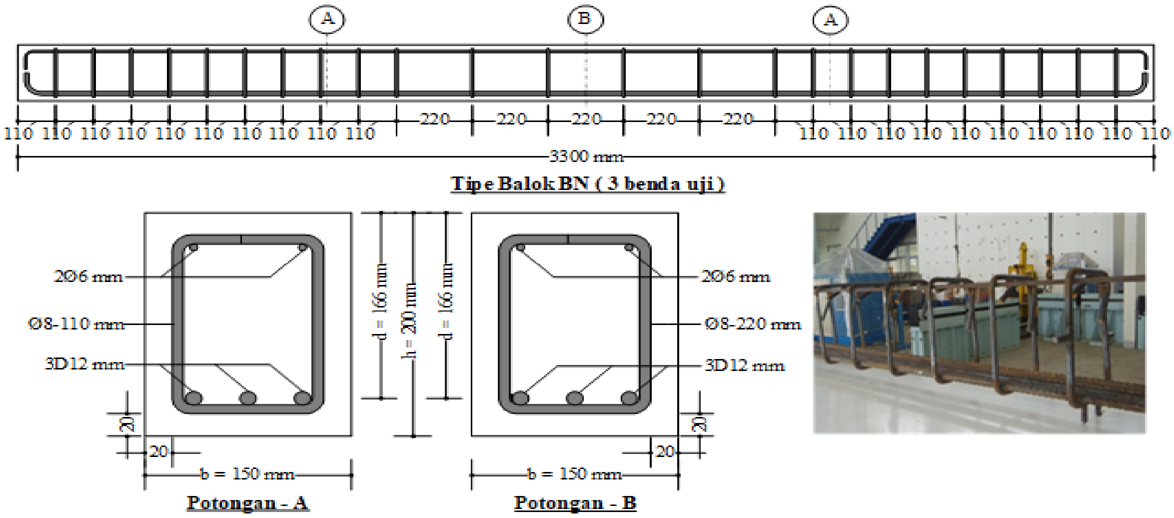

Figure 3. BN beam type

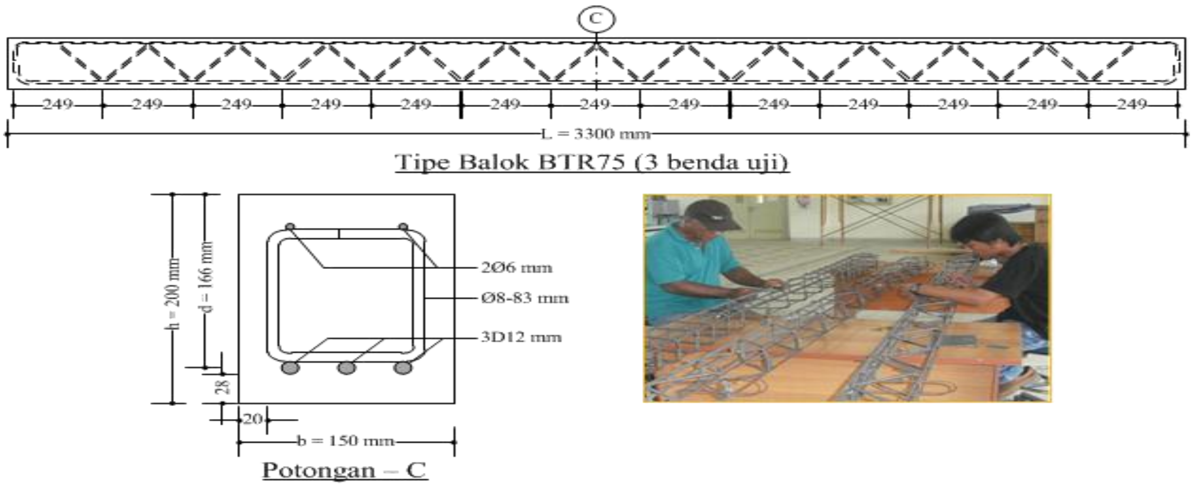

Figure 4. Beam type (BTR25) 0.25d

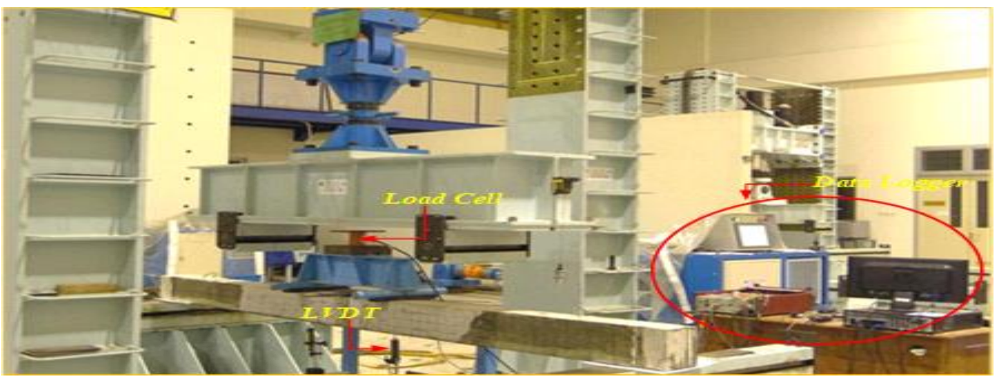

Figure 5. Test specimen setup

The concrete material is fresh, ready-to-use concrete which is mixed completely in a mixer (Mohammed, Al-Zuheriy, & Abdulkareem, 2023). The compressive strength of the concrete was obtained after 28 days with an average compressive strength f'_c = 18.50 Mpa (Shen, Jiao, Li, Liu, & Wang, 2021). The modulus of failure obtained was an average flexural strength of 2.59 MPa. The tensile strength of steel is obtained according to SNI 03-686.2-2002 for plain reinforcement Ø8 yield strength f'_y = 382.81 MPa and threaded reinforcement D12 with yield strength f'_y = 373.94 Mpa (Krall & Polak, 2019);(Lv, Yu, & Shan, 2021).

Result and Discussion

The theoretical assumption that the first crack occurs at the pre-crack level for BN and BTR25 beams is when the compressive load reaches P_{cr} = 2.96 kN or shows that the tensile stress at the bottom of the beam reaches the same as the modulus of failure f_r = 2.59 Mpa (Figure 6). The load-deflection test results on the BN beam obtained P_{cr} = 2.94 kN or it was assumed that the first crack occurred equal to a value of f_r = 2.59 Mpa. Meanwhile, the BTR75 beam experienced an increase in the compressive load P_{cr} of 10.61% compared to the BN beam. In the load-deflection diagram for area I of the BTR75 beam, it can be seen that the compressive load line P_{cr} tends to be perpendicular to the BN beam line. The increase in load was caused by the geometric change of the vertical stirrup reinforcement to diagonal stirrup reinforcement based on a spacing of 0.75d for the BTR75 beam. In another aspect, it provides additional stiffness to the concrete under compression thereby increasing the moment stress at the time of initial cracking. The analysis results show that the Mcr moment capacity of the BTR75 beam increases by 7.27% compared to the BN beam, as in Table 1.

Table 1. Percentage of Mcr cracking moment test results

Test Beam	Test Results		Percentage	
	P_{cr} (kN)	M_{cr} (kNm)	P_{cr} (%)	M_{cr} (%)
BN	2,94	2,57	-	-
BTR75	3,25	2,76	10,61	7,27

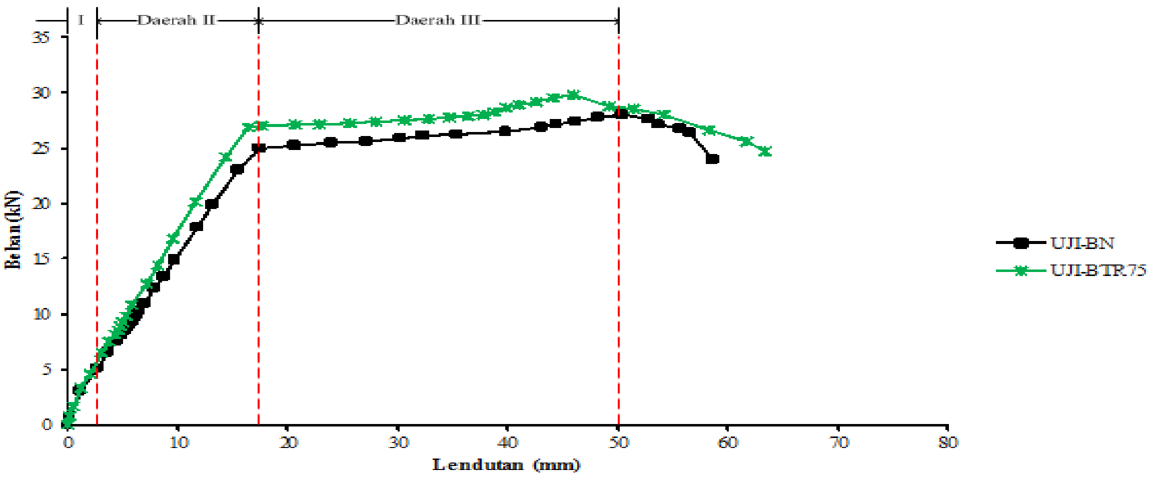

Figure 6. Relationship between load and deflection

Table 2. Percentage of melting moment My test results

Balok Uji	Hasil Uji		Persentase	
	P_y (kN)	M_y (kNm)	P_y (%)	M_y (%)
BN	25,18	15,92	-	-
BTR75	26,92	16,96	6,88	6,53

Table 3. Percentage of MP_f holding moment

Test Beam	Test Results		Percentage	
	P_u (kN)	Mu (kNm)	P_u (%)	Mu (%)
BN	28,11	17,67	-	-
BTR75	29,46	18,49	4,82	4,60

When the load is increased, the beam will experience deflection according to the level of cracking. If a flexural crack has occurred, the tensile contribution of the concrete can be said to no longer exist, so the tensile reinforcement holds it. Tensile reinforcement is assumed to replace an equivalent area of concrete (nA_s) or transformation area. The transformation cross-section is calculated by the elastic homogeneous beam method (Oktaviani et al., 2020). In the post-crack level area or when the reinforcement yields, it can be seen that the compressive load line P_y of the BTR75 beam rises perpendicular to the BN beam line and at the deflection line Δ decreases from the BN beamline (Figure 6). This is due to the strengthening of the moment of inertia of the crack section I_{cr} in the BTR75 beam which increases by 0.15%. The increase in load P_y was 6.88% and the increase at the moment when the reinforcement yielded M_y was 6.53% compared to BN beam (Table 2). Furthermore, changes in the geometric reinforcement of the frame system in inclined stirrups contribute to the tensile strength of the concrete and reduce deflection in the beam when the reinforcement yields (Tunc, Dakhil, & Mertol, 2021).

When the additional service load is applied to the ultimate limit, the beam will experience instantaneous deflection. Figure 6, the results of the load-deflection test at the post-serviceability level show that the compressive load line P_u of the BTR75 beam increases in curvature above the BN beam line and the deflection line Δ decreases from the BN beam line. This is because the effective inertial stiffness I_e of the BTR75 beam increases by 0.12% from the BN beam. Table 3 shows an increase in the ultimate P_u of 4.82% and an increase in the ultimate moment M_u of 4.60% of the BN beam. Thus it is concluded that concrete beams reinforced with frame systems with a spacing of three-quarters of the effective height of the beam (BTR75) have better serviceability than BN beams and increase the flexural capacity when the load reaches the ultimate.

Simulation of beam deflection that occurs in the middle of the beam span using the Finite Element Method (FEM) analysis method. In modeling test objects in FEM there are several mathematical models that can be used, namely isotopic, orthotropic, and anisotropic, as 2D line elements (Sijavandi, Sharbatdar, & Kheyroddin, 2021): a). Modeling Geometry, Describes the geometric attributes of concrete with a concrete cross-section height of 200 mm and a concrete cover height of 20 mm. With 3D12 tensile reinforcement, 2ø6 compression reinforcement, and ø8 stirrup reinforcement for vertical and diagonal according to beam variations. b). Defining Support or Pedestal. In the selection of supports in this modeling, the type of joint and roller placement is used based on experimental testing in the laboratory. c). Defines material properties, The elastic modulus of concrete is 20,222.37 MPa with a concrete stress of 18.50 MPa. The elastic modulus of steel is 200,000 MPa for stirrups 382.81 MPa and for tensile reinforcement 373.94 MPa. Poisson's ratio for concrete is 0.20 and for steel is 0.30. In defining the material chosen is the isotropic model. For concrete, concrete (model 94) and potential von misses stress steel were chosen, as shown in Figures 7 and 8. The simulation results show the similarity of the maximum deflection at mid-span for BN beams and BTR75 beams when the ultimate P_u load is applied (Zhang, Elsayed, Zhang, & Nehdi, 2021).

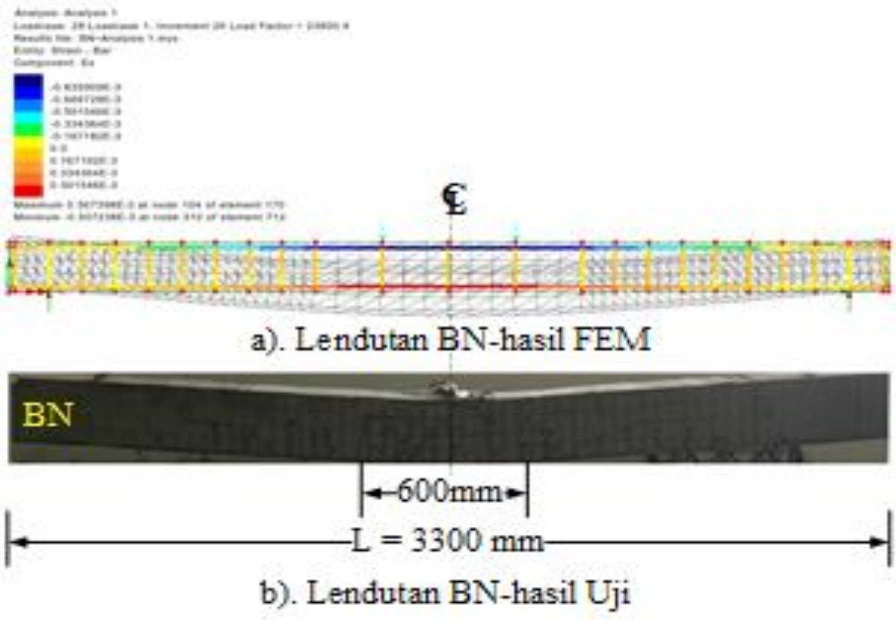

Figure 7. Simulation of BN beam deflection

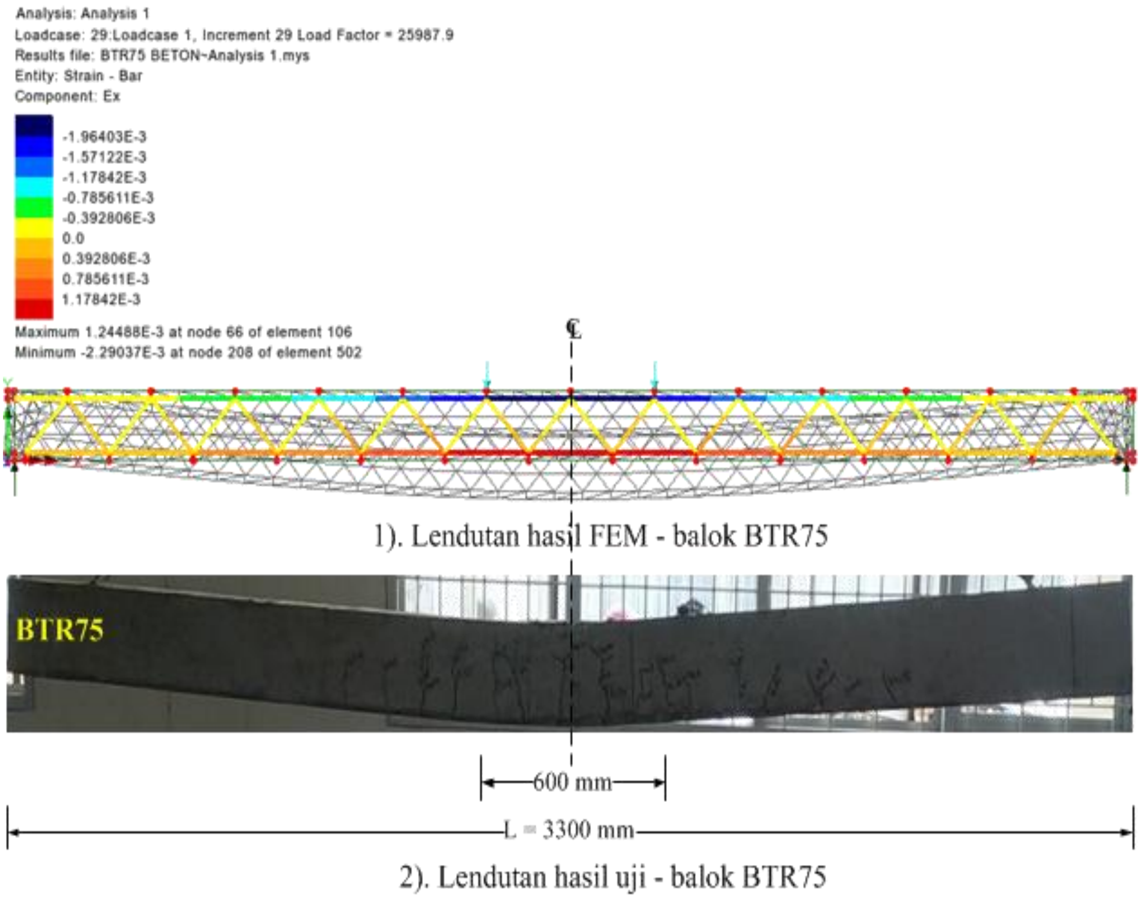

Figure 8. Simulation of BN beam deflection

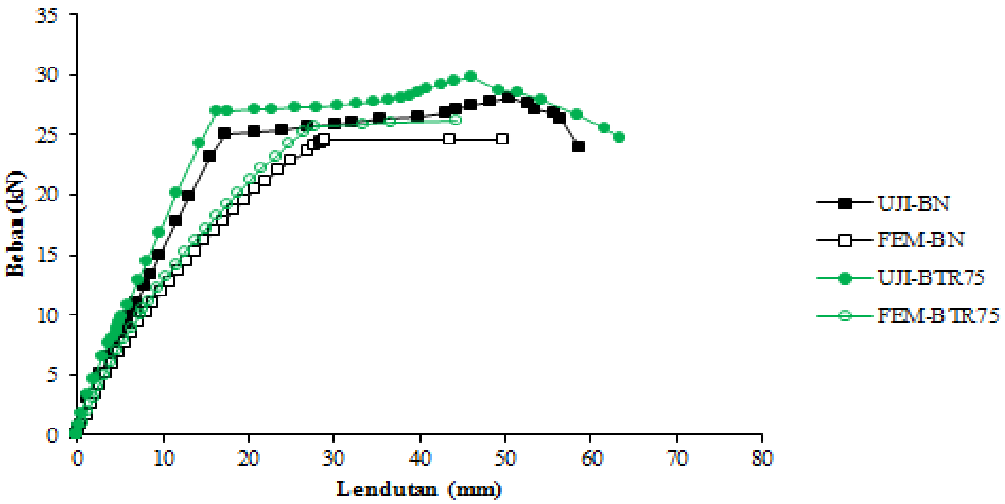

Figure 9. Load deflection from test results and FEM

Table 4. Load-deflection ratio from test results and FEM

Beam	Test Results		FEM Results		Ratio	
	P_u (kN)	Δ_u (mm)	P_u (kN)	Δ_u (mm)	P_u (%)	Δ_u (%)
BN	28,11	38,01	28,93	32,23	1,02	0,85
BTR75	29,46	37,81	29,43	32,09	0,99	0,85

Table 5. Mu ratio of test results with FEM

Test Beam	FEM results	Test results	Ratio
	M_u(kNm)	M_u(kNm)	M_u (%)
BN Beam	18,17	17,67	1,02
Beam BTR75	18,47	18,49	0,99

The load-deflection relationship diagram resulting from FEM analysis and the results of experimental testing in the laboratory were idealized into a trilinear form which produces similar load-deflection relationships in both methods (Figure 9) (Meutia, Lumowa, & Sakakibara, 2022). In the FEM analysis, it can be seen that the compressive load line P_{cr} in the pre-crack level area and the compressive load P_u in the post-crack level area or when the reinforcement yields for the BTR75 beam rises perpendicularly from the BN beam line (Annadurai & Ravichandran, 2018). Meanwhile, at the post-serviceability level, it shows that the compressive load line Pu of the BTR75 beam increases in curvature above the BN beam line and the deflection line Δ decreases compared to the BN beam line. The maximum load-deflection in an instant by FEM is compared with the analysis of laboratory test results for the load capacity P_u with the amount of deflection Δ_u, a ratio between 0.85 to 1.02 is obtained, where according to the general formula for a ratio scale of 0.90 - 1.0, it is categorized as very good (Table 4) (Khan, Al-Osta, Ahmad, & Rahman, 2018). The results of the M_u ultimate moment analysis using FEM were compared with analysis based on laboratory tests for the beam's bending capacity, obtaining a ratio of 0.99 to 1.02 (Table 5). According to the general formula, this ratio with a ratio scale of 0.90 – 1.0 is categorized as very good (Rosanka et al., 2021). Based on the simulation results of FEM analysis compared with the analysis of experimental test results in the laboratory, it can be concluded that concrete beams reinforced with frame systems with a spacing of 3/4 of the effective height of the beam or 0.75d (BTR75) have better serviceability than BN beams. When the load reaches the ultimate P_u, the beam capacity increases with a bending moment M_u of 4.60% (Ebead & El-Sherif, 2019).

Conclusion

The deflection behavior of concrete beams reinforced with a frame system with a spacing of 3/4 of the effective height of the beam (BTR75) has better serviceability increases the flexural capacity of the Mu beam by up to 4.60% and can reduce the amount of deflection of the BN beam.

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