


An prediction of structural behavior in high beam based on finite element modeling (FEM)

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Article Info	ABSTRACT
Keywords: High beam, Load-deflection relationship, FEM, Ansys, Abaqus	An Until now, there are still many reinforced concrete constructions using high beams. High beam planning often uses analytical concepts. In this research, the structural behavior of high beams due to applied loads will be studied based on Finite Element Modeling (FEM) based simulations using Ansys and Abaqus. The structural behavior in question is the relationship between load and deflection. This research activity aims to ensure that FEM can be used optimally to predict the structural behavior of high beams without having to carry out experimental studies. Based on the results of the FEM analysis using Ansys, it shows that the prediction of the high beam load capacity has an error rate of between 1.5-3.77%. Meanwhile, based on the use of Abaqus software, it shows an error rate of 1-2%. Meanwhile, for the predicted value of high beam deflection capacity, the use of Ansys software gives an error value of 2.11-5.12%. Meanwhile, Abaqus software shows an error rate between 0.26-3.32%. The results of FEM analysis based on Ansys and Abaqus provide good accuracy.
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INTRODUCTION

Many reinforced concrete constructions still use high beams. When designing high beams, it is very important to take into account shear reinforcement (web reinforcement), in addition to flexural reinforcement. As the shear capacity of the high beam increases, the serviceability of the high beam can be increased.

The use of reinforced concrete high beams in structural elements has become a primary requirement for designing and planning various civil engineering buildings. High beams are generally used for transfer elements (transfer girders), either just one span or a continuous beam. In girder transfer, the load in the column area will be distributed horizontally toward other columns. High beams are also found in coupling structural walls, corbels, pile caps, brackets, and so on (Windah, 2011).

In the Strut and Tie Model (STM) method, the compression force (Compressive Force) acts in the compression zone (Compression Zone), which can also be called the strut zone, while the tensile force (Tie) can be said to be the longitudinal reinforcement, in this condition the concrete pressure force works with the diagonal plane of the strut is smoothed. Ritter (1899) introduced the STM method by explaining the performance of transverse

reinforcement (stirrups) in high beams. Then, Mörsch (1909) expanded the Ritter (1899) model by analyzing that diagonal compressive stresses do not have to be located in discrete zones but stresses can be located in continuous areas within the balance equation of stirrup forces at discrete points (Darma & Paryati, 2019).

The structural behavior in question is the relationship between load and working deflection. It is called a high beam if it has a clear span length (l_n) \leq four times the height ($4 \cdot h$) (Cagley & et al, 1999). In America there are standard provisions for high beams called ACI 318-99, this states that the calculation of high beam capacity refers to the compressive strength of the concrete (f_c') and the number of each reinforcement. Meanwhile, the distance of transverse reinforcement has a big influence on the capacity of high beams (Darma & Paryati, 2019). According to the Indonesian National Standardization Agency (National Standardization Agency, 2019), a high beam is a structure that is loaded on one side and supported on opposite faces so that compression components such as Strat can be formed between the load and the support. It says a high beam must have $\left(\frac{l_n}{h} \leq 4\right)$ dan $\left(\frac{a}{h} \leq 2\right)$.

There are several differences between designing high beams and ordinary beams. Firstly, high beams have two-dimensional behavior while beams can have one-dimensional behavior. The two high beams cannot be used with plane cuts representing planes, thus the strain distribution is no longer linear.

The finite element method (FEM) or finite element analysis (FEA) is based on the idea of building complex objects from simple blocks or dividing objects into smaller, manageable parts. It can be interpreted as a limited concept, namely to approach or represent smooth objects with a limited number of simple pieces and increase the number of pieces so that the accuracy of the representation increases (Chen & Liu, 2019).

So in this research, the structural behavior of high beams due to applied loads is based on Finite Element Modeling (FEM) based simulations. The structural behavior in question is the relationship between the load and the deflection caused by the working load. You will get accuracy results of $\pm 5\%$ based on experimental data from existing literature.

Research on nonlinear analysis of reinforced concrete high beams using modified compression field theory (Windah, 2011). This research simulates the collapse of a high beam using a finite element program. As validation, this research uses data from previous research. The concrete structure being analyzed is a highly reinforced concrete beam on a simple support which is loaded with a concentrated load in the middle of the member using modified compression field theory (MCFT).

Meanwhile, the research investigated the shear failure of high beams of reinforced concrete and fiber concrete using experimental methods, numerical methods, and strut and tie methods (Darma & Paryati, 2019). This research made conventional concrete high beam test objects and one fiber high beam each with dimensions of 170 mm x 420 mm x 850 mm. in making fiber test objects using full fiber from steel shavings waste without using coarse aggregate. Third, by using ATENA software as software for non-linear analysis/simulation of reinforced concrete.

Research on two-dimensional stress analysis in high beams using the finite element method and the 240-heft method (Purba, 2015). In this research, there is a high beam design with dimensions ($h=L$) 3 meters long, 3 meters wide, and 0.5 meters thick. The working load is an equivalent static vertical load of 400 kN acting on the beam (joint - roller). Has concrete quality (R_c)=350, concrete modulus of elasticity (E)= 25332084.4 kN/m², and Poisson's ratio (ν)= 0.3. The analysis will be carried out using the finite element method for two dimensions, while the comparison of stress values using the finite element method will be controlled using the Heft240 method.

Research on the application of the Strut-And-Tie model in high beam analysis based on SNI 2847-2019 and established Truss Models as well as computer-aided strut and tie (Tonny, 2020). Research is carried out analytically, and several activities such as design work, modeling, data analysis, and research completion reports. Calculating high beam analysis is carried out using two methods, namely by using STM and the CAST program.

Research on Numerical modeling behavior of reinforced concrete deep beam with strut-and-tie model (Taufik & Sugianto, 2021). In this research, 3D numerical modeling of high beams was carried out using finite element analysis. The analysis will produce nodal forces, forces, displacements, and element moments. Apart from that, crack patterns will also be generated to predict the beam's capability under ultimate concentrated load and the behavior of using the strut-and-tie model for high beam cracks.

METHOD

In this research, an analytical study was carried out. The stages or activity procedures from start to finish are summarized in a flowchart. The stages of research activities can be seen in Figure 1.

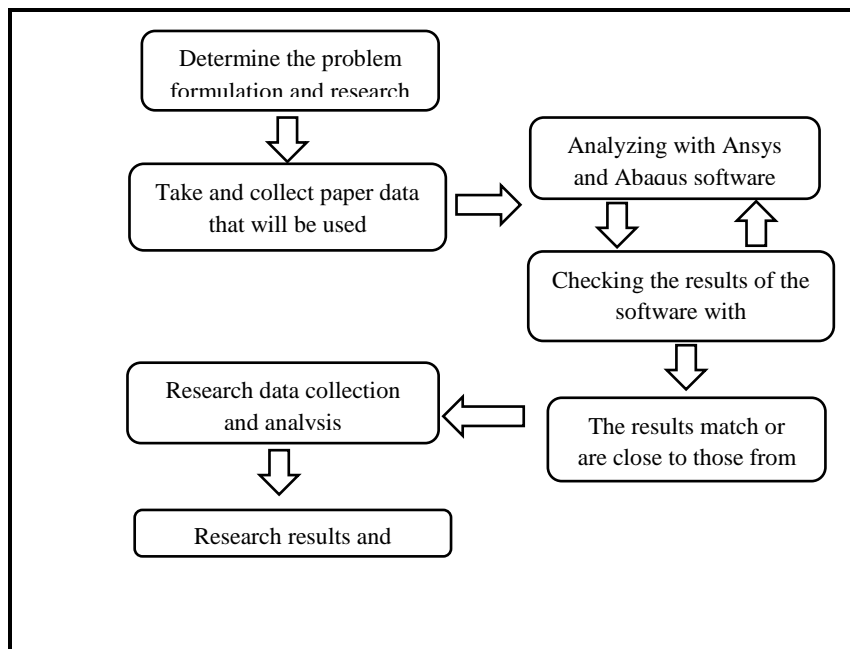


Figure 1. Flowchart

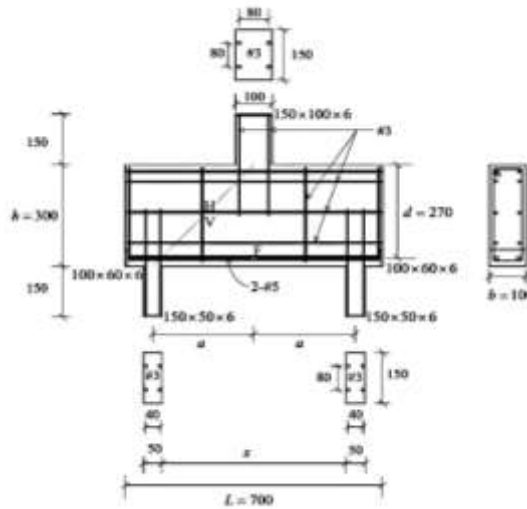


Figure 2. High Beam Details (Lu & dkk., 2014)

Based on experimental studies conducted by Lu & et al (2014), a graph of the relationship between load and deflection was obtained as shown in Figure 3. In this research, tall beam number 12 was used with the following data. $L = 700$ mm, $a_v = 200$ mm, $b = 100$ mm, $h = 300$ mm, $L_n = 400$ mm. In this case it has $L_n/h = 1.3333$ (qualifies) and $a_v/h = 0.6667$ (qualifies).

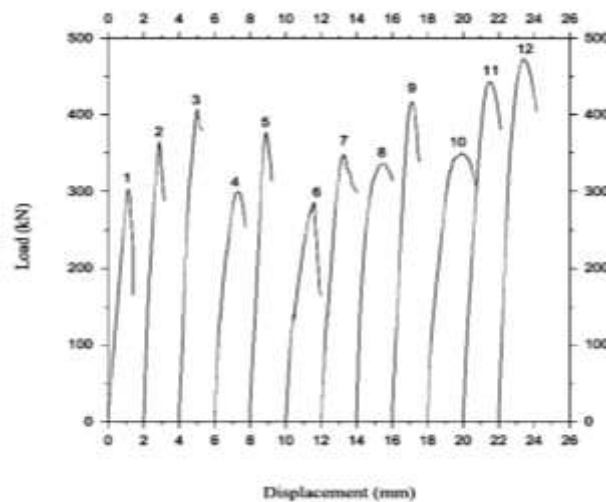


Figure 3. Graph of the relationship between load and deflection (Lu & et al., 2014)

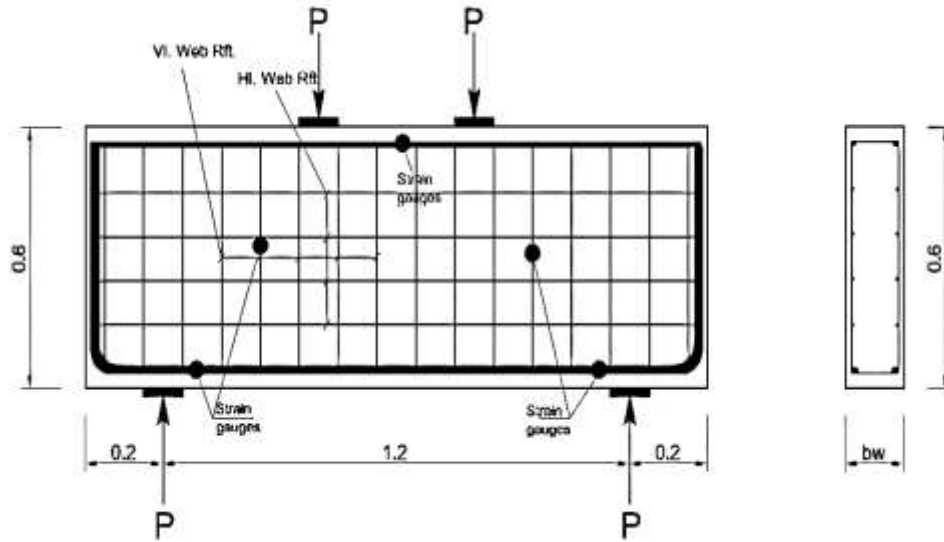


Figure 4. Detail of NSD high beam (Ibrahim & et al., 2018)

Based on experimental studies conducted by Ibrahim & et al (2018), a graph of the relationship between load and deflection was obtained as shown in Figure 5. In this research, NSD high beams were used with the following data. $L= 1600$ mm, $a_v= 400$ mm, $b= 120$ mm, $h= 600$ mm, and $L_n= 1200$ mm. In this case it has $L_n/h = 2$ (qualifies) and $a_v/h = 0.6667$ (qualifies)

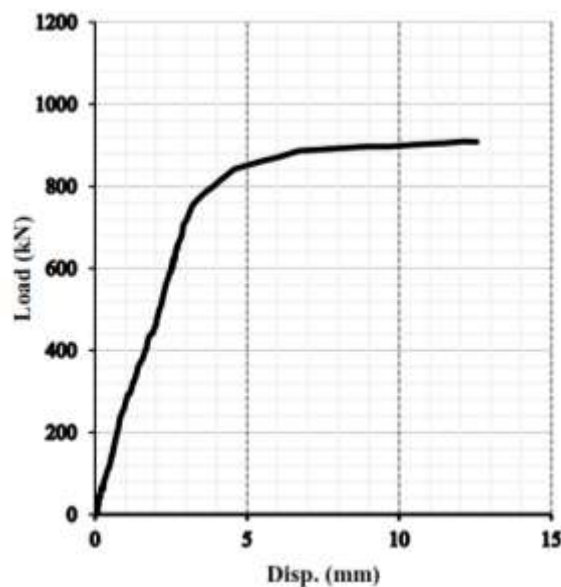


Figure 5. Graph of the relationship between load and NSD deflection (Ibrahim & et al., 2018)

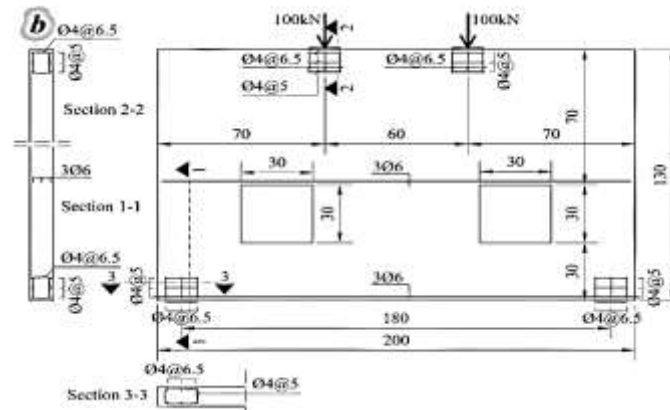


Figure 6. W2 High Beam Detail (Starčev-Curčin & et al, 2020)

Based on experimental studies conducted by Starčev-Curčin & et al (2020), a load and deflection relationship graph was obtained as shown in Figure 7. In this research, a W2 high beam was used with the following data. $L = 2000$ mm, $a_v = 600$ mm, $b = 100$ mm, $h = 1300$ mm, and $L_n = 1800$ mm. In this case, the ratio of the high beam is $L_n/h = 1.3846$ (qualifies) and $a_v/h = 0.4615$ (qualifies).

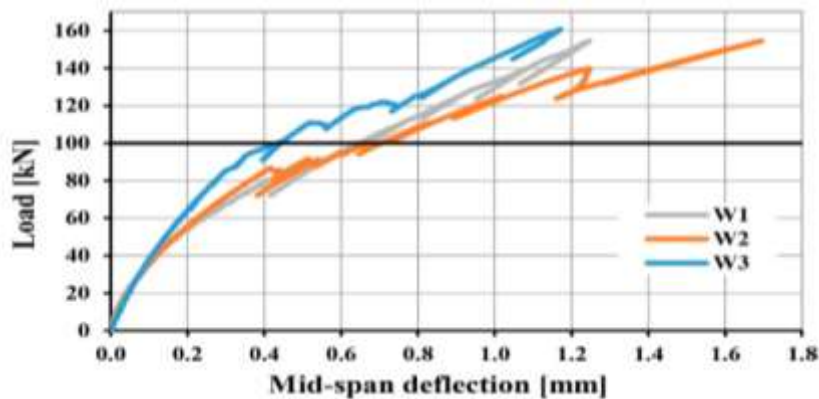


Figure 7. Graph of the relationship between load and deflection W2 (Starčev-Curčin & et al, 2020)

RESULT AND DISCUSSION

Graph of the Relationship between Load and Deflection on the First High Beam

The results of FEM analysis based on Ansys and Abaqus are related to the prediction of the load-deflection relationship of high beams based on experimental studies conducted by Lu & et al (2014), the graph of which can be seen in Figure 8.

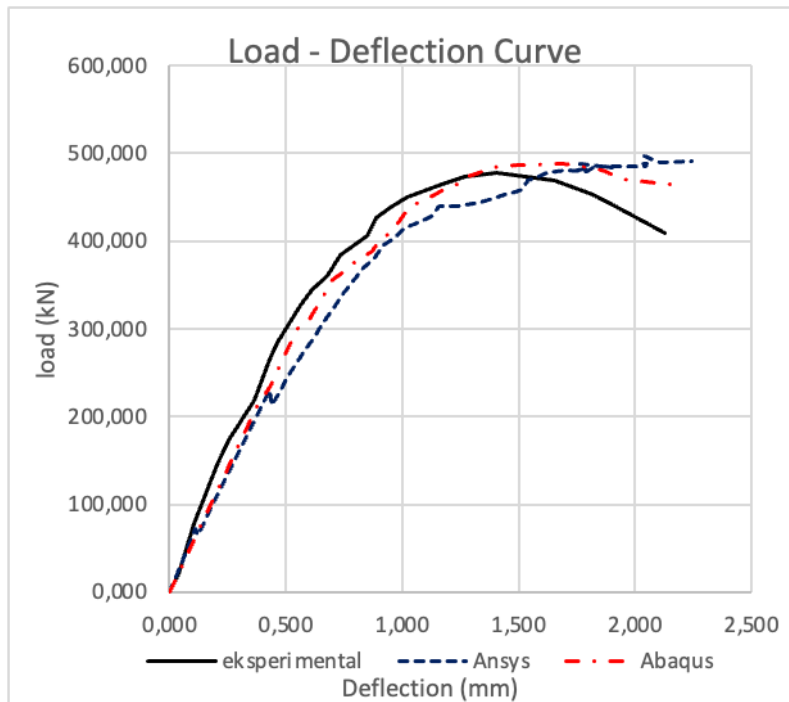


Figure 8. Comparison of FEM analysis results with experimental studies for the first High Beam

The difference in analysis results for load versus experimental is 3.7652% for Ansys and 1.9929% for Abaqus. Meanwhile, the deflection gives a difference of 5.1229% based on Ansys and 3.3159% based on Abaqus. The results of this analysis can be seen in Figure 8 and Table 1.

Table 1. Comparison of analytical and experimental results on the first high beam

Data	Load (kN)	Deflection (mm)	Comparison to experimental results	
			Load (%)	Deflection (%)
Balok Tinggi nomor 12 (Lu & dkk., 2014)	478,104	2,127		
Ansys	496,810	2,242	3,7652	5,1229
Abaqus	487,826	2,200	1,9929	3,3159

Graph of the Relationship between Load and Deflection on the Second High Beam

The results of FEM analysis based on Ansys and Abaqus are related to the prediction of the load-deflection relationship of high beams based on experimental studies conducted by Ibrahim & et al (2018), the graph of which can be seen in Figure 9.

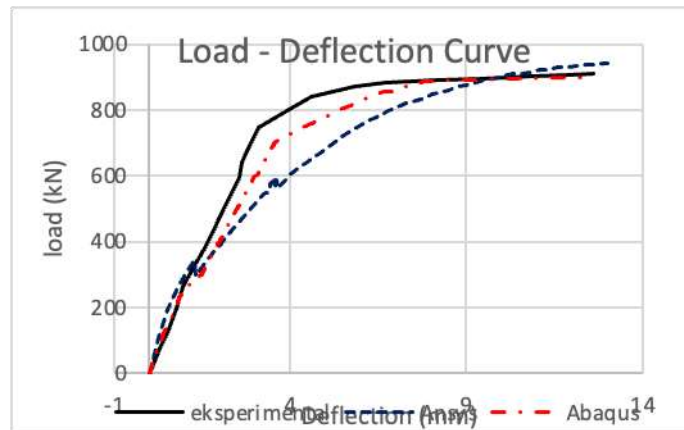


Figure 9. Comparison of FEM analysis results with experimental studies for the second High Beam

The difference in analysis results for load versus experimental is 3.3304% for Ansys and 1.0430% for Abaqus. Meanwhile, the deflection gives a difference of 2.979% based on Ansys and 0.2582% based on Abaqus. The results of this analysis can be seen in Figure 9 and Table 2.

Table 2. Comparison of analytical and experimental results on the second high beam

Data	Load (kN)	Deflection (mm)	Comparison to experimental results	
			Load (%)	Deflection (%)
Balok Tinggi NSD (Ibrahim & dkk, 2018)	910,086	12,619		
Ansys	941,440	13,006	3,3304	2,979
Abaqus	900,594	12,586	1,0430	0,2582

Graph of the Relationship between Load and Deflection on the Third High Beam

The results of the Ansys-based FEM analysis related to the prediction of the high beam load-deflection relationship based on the experimental study conducted by Starčev-Curčin & et al (2020), the graph can be seen in Figure 10.

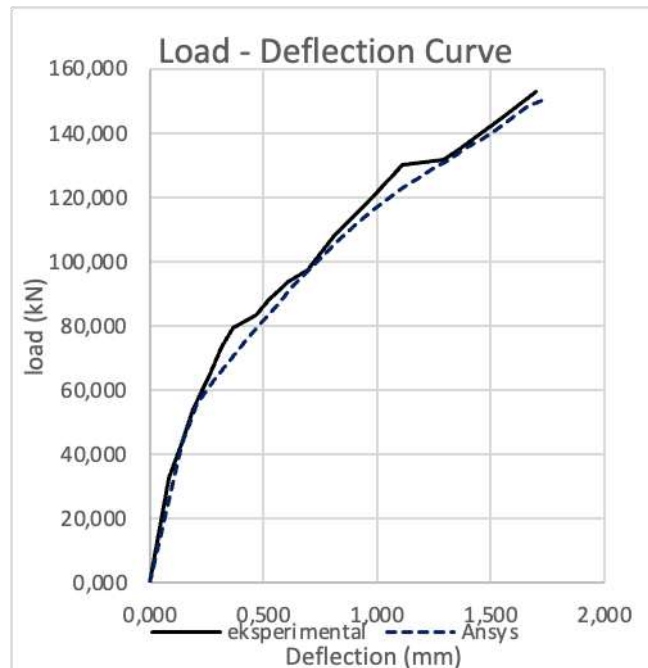


Figure 10. Comparison of FEM analysis results with experimental studies for the third High Beam

The difference in analysis results for load versus experimental is 1.5407% for Ansys. Meanwhile, the deflection gives a difference of 2.1082% based on Ansys. The results of this analysis can be seen in Figure 10 and Table 3.

Table 3. Comparison of analytical and experimental results on the third high beam

Data	Load (kN)	Deflection (mm)	Comparison to experimental results	
			Load (%)	Deflection (%)
Balok Tinggi W2 (Starčev-Curčin & dkk, 2020)	152,845	1,700		
Ansys	150,490	1,736	1,5407	2,1082

CONCLUSION

Based on the analysis results that have been displayed and described in detail, several conclusions can be drawn, namely: The results of testing the paper Tests of reinforced concrete deep beams (Lu & et al, 2015) have a high beam size of $L_n/h = 1.3333$ (requirement $L_n/h \leq 4$) and $a_v/h = 0.6667$ (requirement $A_v/h \leq 2$). From the results it can be concluded that the difference in error between the load is Ansys 3.7652% and Abaqus 1.9929%, while the error rate in deflection is Ansys 5.1229% and Abaqus 3.3159%. This amount is compared to the results of the paper. Results from testing the paper Experimental Study of New Reinforcement Details for Reinforced Concrete Deep Beams With Shear Opening (Ibrahim & et al, 2018) has a high beam size of $L_n/h = 2$ (requirement $L_n/h \leq 4$) and $a_v/h = 0.6667$ (a_v/h condition ≤ 2). From the results it can be concluded that the difference in error between the load is Ansys 3.3304% and Abaqus 1.0430%, while the error rate in

<https://doi.org/10.3390/APP10186217>

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