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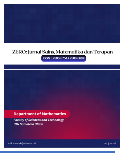

Numerical Modeling Based on The Finite Element Method by Fortran90 Software on Beam-Column Joint

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ABSTRACT

This research discusses the finite element modeling of flexural failure in beam-column joints subjected to monotonic loads. This research aims to model numerically based on the finite element method by Fortran90 software on beam-column joint. The analysis is conducted using two-dimensional finite element method with three sides (triangular). The method used is quantitative and experimental. Validation testing is carried out on beam-column joint specimens with beam dimensions of 15x20 cm and column dimensions of 20x20 cm (a length of 100 cm). The compressive strength of the beam-column joint is 21 MPa. The test was conducted with a loading pattern at the end of the beam at a height of 1 m from the column. The comparison between the calculations using laboratory testing and the finite element method shows very consistent results.

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1. INTRODUCTION

The joint between beams and columns is a support system that can withstand moments, vertical and horizontal forces. RC beam column joints are often found in buildings such as residential houses, places of worship, and others [1]. Analysis results sometimes do not align well with tests in the laboratory. The tests will show the non-linear behavior of the stress-strain relationship of the beam-column joint. In addition, it will also demonstrate the non-linear behavior of the shear load relationship of the column-beam joint. This research relates to the finite element analysis of beam-column joint behavior subjected to monotonic loading. The analysis is conducted using two-dimensional finite element method with three sides (triangular), approaching plane strain conditions and crack effects. Modeling of reinforced concrete beam-column joint material as a trilateral isoparametric element under two-dimensional plane strain conditions.

The deformation of a beam is defined as a state of deformation where deformation of shear (xz and yz) and normal deformation with respect to the x-y plane (z) is considered to be zero. Analysis of iterative procedures for cracking includes where the beam and column joints are initially assumed to be in a crack-free state. The principal tensile stress is compared with the defined tensile limit, and if it exceeds the stress limit, the layer is modified to account for the reduction in stiffness due to the occurring cracks. After that, testing is repeated until no crack detection occurs at the beam-column joint [2][3].

The basic design considerations for test objects follow the applicable guidelines [4][5][6][7]. Scientists and engineers use FEM for the analysis of concrete beams and slabs. FEM analysis procedure where slab elements are divided into several layers to accommodate cracks that develop throughout the slab's thickness [8]. A method to combine the effects of cracking as well as time-dependent influence of plate shrinkage [9] [10]. Research engineers consider that the cracks that occur only develop perpendicular and parallel to the reinforcement, and the researchers utilize elements that can crack progressively in the form of layered rectangular plates [11] [12] [13]. RC composites are materials that have behavior described through the layers of finite elements [14][15]. research on layered composite material modeling (LCMM) [16]. Consideration of slip-bond effects in FEM for the analysis of beam column [17] [18]. Research on numeric, analytical empirical relationships to analysis the shear capacity in RC beam-column joints [19][20][21][22]. For example, various studies on types of beam column joints produce experiments from semi-static cyclic tests and analyze the strain and stress of the related elements [23][24][25].

The novelty of this research is the creation of a specific program using the Finite Element Method with Fortran90 software, which allows for accurate analysis of beam-column connections. This FEM program will be compared with experimental methods in the laboratory of the Faculty of Engineering at Brawijaya University.

2. RESEARCH METHOD

2.1 Load Data Experimental

The analysis process is carried out step by step for the beam-column joint and applies a load at node point 74 from 100 kg until the beam column exterior joint collapses. In this study, the column beam joint is designed to receive a uniform load of 72 kg/m². Boundary conditions are used to define whether support and constraints are present. In this research, the boundary conditions of the beam column joint have a fixed relationship, while the columns are simply supported.

SNI 2847-2019 serves as the basis for specimen fabrication and ACI 318-14 as the basis for specimen testing on the chosen design criteria [20][1][2]. Static loads are applied to each test specimen with a load interval of 100 kg until failure occurs. An LVDT is installed at a distance of 100 cm on the beam for deflection measurement. The deflection testing model occurring on the RC beam column joint was seen in Figure 1.

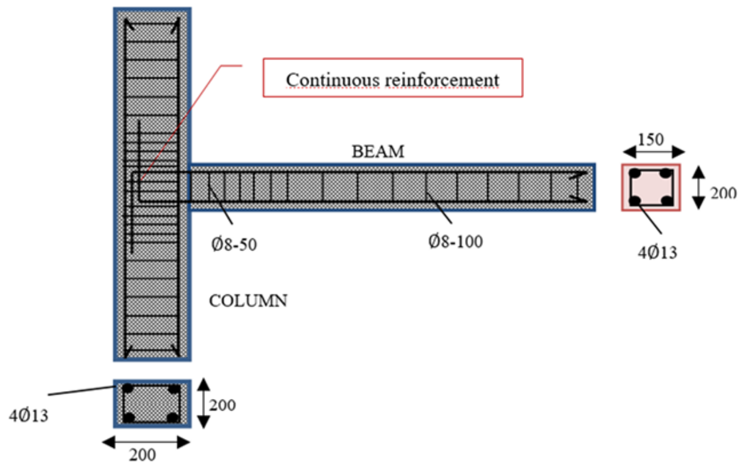

Figure 1. Specimen of beam colum joint

2.2 MODELING OF FINITE ELEMENT

The FEM principle is to divide the problem domain, whether it is the spatial domain or the time domain, into sub-domains or smaller elements. By calculating solutions at the elements and subsequently combining the overall elemental solutions, the total solution to the problem is obtained. In calculating solutions for each element, it is necessary for the elemental solutions to meet certain requirements, such as continuity at the nodal points and the interfaces of the elements.The steps used for problem solving in the finite element method for static structural problems with a systematic process are outlined in the following steps:

1. Domain discretization, at this stage, we determine the type of elements that we will use. For the 2-dimensional problem, the elements used are triangular 2-dimensional elements. These elements can be either linear or non-linear. One of the advantages of FEM is that elements of different sizes can be used. Smaller-sized elements can be used in areas with a large gradient of values.
2. Determination of the form of the approximation function, at this stage, the form of the interpolation function is determined. The function used is a polynomial function. The degree of this polynomial is determined by the nodes number in each element and the continuity requirements needed at the element boundaries. For triangular elements with three nodal points, the interpolation function is a linear function or polynomial of degree 1.

3. The calculation of the properties of the interpolation function elements determined in stage 2 is then substituted back into the differential equations and processed to obtain linear equations system or a matrix system representing the properties of the related elements.
4. Formation of the Matrix Linear Equation, the formed element matrices are then combined into a global matrix.
5. Solving the Linear Equation System, the global system formed in stage 4 can be in the form of a non-linear equation system or a linear equation system, and if the result system is a system of linear equations, we can use general techniques to solve the system.
6. Post Process Results After the solution is obtained from stage 5, the results can be displayed in the form of contour graphs or plots. If there are other parameters that depend on the results, then these parameters are calculated after the results are obtained.

In this research, it is limited by the calculations and efficiency of computational analysis, thus limiting the scope of the research to test specimens with a beam dimension of 15x20 cm and a column dimension of 20x20 cm (each with a length of 100 cm),was used, with the applied load increasing simultaneously under displacement control at the test point. Research on FEM is processed for the same data. In a two-dimensional element model with three sides (triangular) of FEM, the divided of beam column cross-section joint 2-D isoparametric elements. The mesh configuration for the 2-D isoparametric elements and the load in Figure 2.

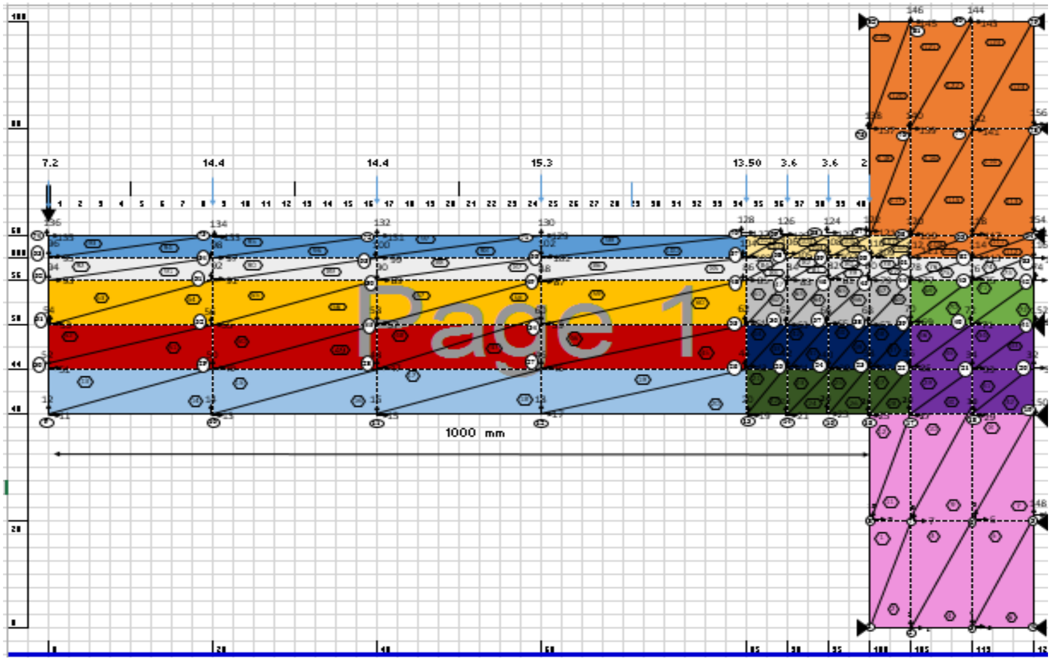

Figure 2. FEM idealization of beam column joint

The equations of beam column joint have been derived [19][24] as stated in Equation (1) and Equation (2).

$$\frac{d^2}{dx^2}\left(EI\frac{d^2w}{dx^2}\right) - \frac{d}{dx}\left(F\ \frac{dw}{dx}\right) = Pz \tag{1}$$

Equation (1) is the basic fourth-order bending differential equation of the beam-column where EI is the bending stiffness of the beam-column, F is the normal force, and Pz is the lateral force.

$$W = A\cos kx + B\sin Kx + Cx + D + f(x) \tag{2}$$

with w being the deflection of the beam-column, A, B, C, and D are constants determined based on the boundary conditions of the beam-column. The function f(x) is a particular solution for the lateral load q(x).

2.3 RESEARCH STAGES

The stages of the research are shown in Figure 3.

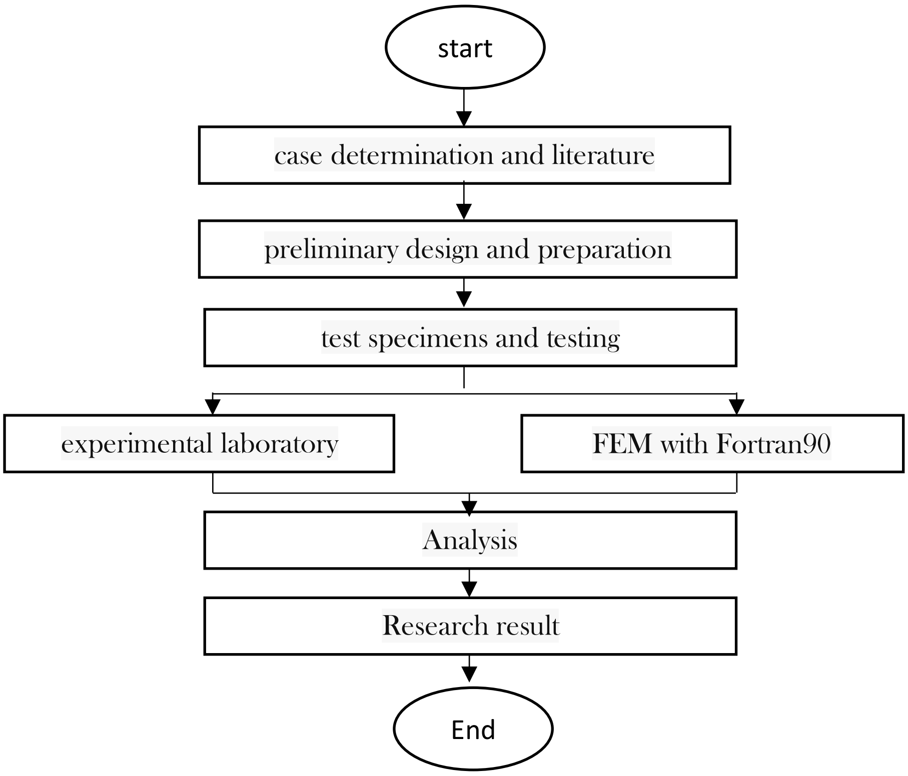

Figure 3. Research flowchart

3. RESULT AND ANALYSIS

3.1 Preliminary design

Basics of preliminary design

1. Beam basic assumptions
   a. The beam in the x direction only carries vertical loads in the y direction.
   b. The concreted beam is elastically fixed at the supports
   c. The load on the concreted beam is uniformly distributed
2. Column
   a. The dimensions of the column are determined
   b. The load is not applied

3.2 Data Modelling

Material Quality for Structural Components

The quality of materials used for reinforced concrete structures is as follows:

- Quality of concrete for beams, column beams : fc'= 21 MPa,
- Quality of reinforcing steel: fyD=4,000 kg/cm^2;

The following material constants are used for planning:

- Elastic modulus Ec = 2,100,000 kg/cm^2
- Linear expansion coefficient 1,0e-5 per degree Celsius
- Poisson's ratio υ=0.20,
- Specific weight of concrete wc = 2,400 kg/m^3.

3.3 The deflection results using the test results and programming.

The result of the FEM calculation using Fortran90 tools is presented in Table 1.

Table 1. FEM and testing result of beam column joint

FEM result		Testing	
Load Kg	Deflection L=100 cm	load Kg	Deflection L=100 cm
0	0.00	0	0.00
100	0.068	100	0.03
200	0.118	200	0.06
300	0.158	300	0.100
400	0.198	400	0.160
500	0.231	500	0.280
1,000	0.870	1,000	1.580
1,200	1.281	1,200	2.180
1,400	1.980	1,400	3.380
1,600	2.870	1,600	5.080
1,700	3.540	1,686	6.080
1,800	5.120	1,584	9.260
1,600	9.438	1,324	11.910
1,400	11.810	1,122	14.060
1,200	13.810	1,200	13.810

Based on the test results and compared with programming using Fortran90 obtained the corelation between the applied load and the deflection that occurs in the beam-column joint test results is shown in Figure 4.

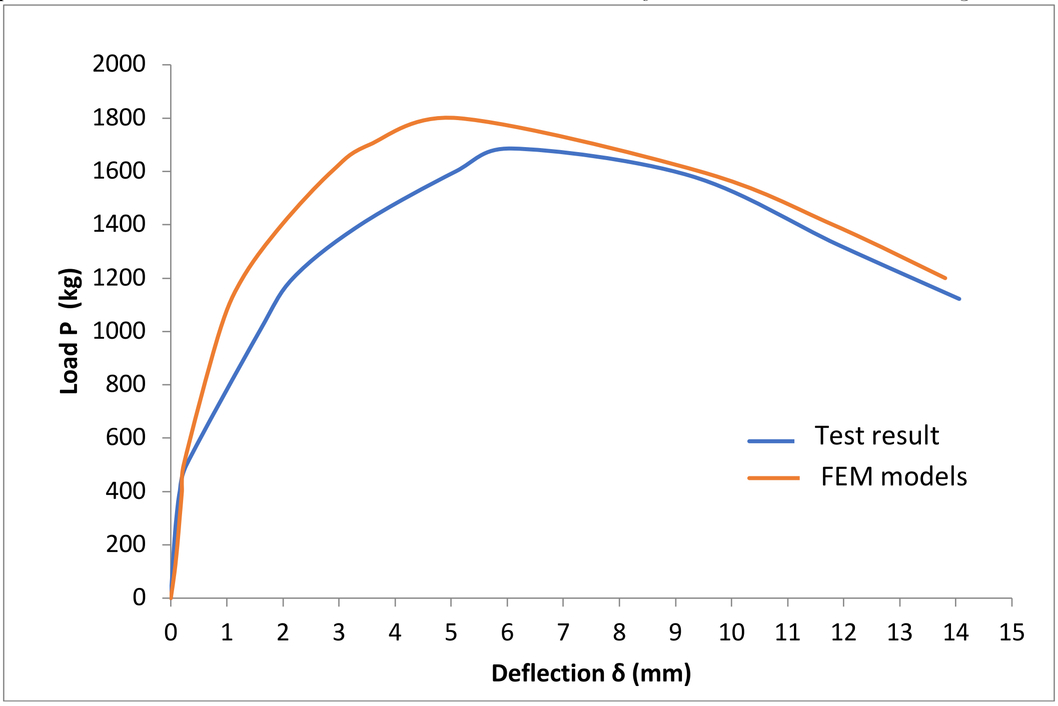

Figure 4. Load and deflection correlations

The results of the calculations from the FEM show that the initial response produced is somewhat stiffer compared to the results of laboratory experiment testing. This is indicated by the influence of several assumptions on the variables used, including the use of tensile and compressive properties of concrete, or uncertainties in testing such as indications of inherent differences between responses obtained from monotonic loading. As shown in Figure 3, the behavior determined in the lateral load-displacement diagram generated from FEM for the exterior joint specimen reasonably matches the experimental results.

4. CONCLUSION

This research uses FEM to analyze the modeling of beam-column connections with a two-dimensional finite element method with three sides (triangular). The connection between beam and column is considered as a linear isotropic elastic material under stress or strain conditions. Research on the relationship of beam-column joints concludes that there is an indication of the influence of stiffness stress based on numerical and experimental results, which is very important in the analysis. The calculation results in the modeling with the isoparametric 2-D finite element method show that modeling using the affected elastic constants can be developed to analyze the correlation that occurs between the transfer load of the RC connection of the column beam subjected to monotonic loading. The adequacy and availability of the nonlinear program will be verified and confirmed using experimental data in the laboratory. The results show the process of deterioration, modes of failure that occur, and predictions of strength for beam-column joints governed by accurately defined modes of failure under monotonic loading. The behavior of column joints controlled by flexural damage is well captured in terms of capacity, damage, and the modes of failure that occur.

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