Creep Analysis Method for Reinforced Concrete Fiber Beam Elements Considering Shear Effects (Postprint)

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Abstract

The classical fiber model based on Euler-Bernoulli beam theory neglects the influence of shear deformation on cross-sections. To establish a more accurate creep analysis method for reinforced concrete fiber beam elements, the stiffness matrix of fiber beam elements considering shear effects was derived according to Timoshenko beam theory. Utilizing the initial strain method for concrete creep analysis, the finite element formulation for element creep equivalent nodal forces was derived, ultimately establishing a finite element method for creep analysis of reinforced concrete fiber beam elements. A computational program was developed using the FORTRAN language to perform elastic analysis of ordinary beams and reinforced concrete beams, as well as creep analysis of reinforced concrete beams. The results were compared with analytical solutions, ABAQUS finite element solutions, and solutions from other literature. The results demonstrate that the method, while accurately accounting for shear effects, can clearly define the behavior of steel reinforcement and concrete in the creep performance of reinforced concrete beams. Additionally, it is shown that including steel reinforcement in the creep analysis model of reinforced concrete beams can effectively improve the accuracy of computational results.

Full Text

Creep Analysis Methodology for Reinforced Concrete Fiber Beam Elements

A computational program was developed to perform elastic analysis of ordinary beams and reinforced concrete beams, as well as creep analysis of reinforced concrete beams. Results were compared against analytical solutions, finite element solutions, and other published literature solutions. The results demonstrate that this method can accurately account for shear effects while clearly defining the behavior of steel reinforcement and concrete in the creep performance of reinforced concrete beams. It also shows that including steel reinforcement in the creep analysis model of reinforced concrete beams can effectively improve the accuracy of computational results.

Based on the theoretical analysis presented above, the specific procedure for analyzing creep effects in structures composed of plane fiber beam elements using the initial strain method at the stress-strain level is as follows. The creep strain increment can be expressed as $\Delta\varepsilon_c$, where ε_c represents the creep strain at the end of time step Δt. This can be written as $\varepsilon_c = \varepsilon_{c0} + \Delta\varepsilon_c$. For practical implementation of this formulation, the relationship between the elasticity matrix D and matrix B can be utilized to simplify the expression.

The concrete creep analysis procedure involves several key steps. First, the initial strain is calculated using the current stress state and material properties. Then, the equivalent nodal forces due to creep are computed and applied to the structure. The equilibrium equations are solved to obtain displacement increments, which are subsequently used to update the stress distribution. This process is repeated for each time increment throughout the analysis period.

Numerical Example: Cantilever Beam Analysis

For the case when the beam tip displacement reaches 12 mm, concentrated loads of 46.38 kN and 41.25 kN must be applied for analyses with and without reinforcement consideration, respectively. Figure 2 illustrates the deformed shape of the cantilever beam before and after loading. Figure 3 presents comparative results obtained using the proposed method and the reference program, considering various effects.

The analysis reveals significant differences between cases with and without shear effects. When shear deformation is neglected and the beam tip displacement reaches 12 mm, concentrated loads of 41.25 kN and 46.38 kN are required for analyses without and with shear deformation, respectively—a difference of 12.5%. Figure 4 shows the load-displacement curves obtained with and without considering shear deformation. Table 2 lists specific numerical values and comparisons. It can be observed that when shear effects are considered, the maximum error between the present solution and the reference program solution does not exceed 1.8%, whereas when shear effects are neglected, the maximum error does not exceed 3%. Both cases show good agreement, verifying the correctness of the theory and program developed in this study.

Regarding the influence of reinforcement, Table 2 shows that when shear effects are considered, the load values differ by 12.5% between cases with and without reinforcement consideration. This indicates that steel reinforcement has a significant effect on the deflection and mechanical behavior of reinforced concrete beams.

Example 3: Creep Analysis of Reinforced Concrete Simply Supported Beam

This example is taken from the literature. A reinforced concrete simply supported beam with a span of 6.0 m, with cross-section dimensions and reinforcement details as shown in Figure 5. Other required geometric, material, and load parameters are detailed in the reference literature, which used a composite element formed by virtual laminated elements and bar elements to simulate the reinforced concrete beam. In the present analysis, the beam is divided into 20 reinforced concrete fiber beam elements.

Figures 6 through 8 show the deflection, stress, and steel force variations in the reinforced concrete simply supported beam due to creep over a period of 3 years, as calculated by the proposed method. For comparison, results from the reference literature are also presented. Table 3 lists the relative errors between the calculated values from the present study and those from the literature.

The results demonstrate that steel reinforcement substantially influences the structural behavior of reinforced concrete beams, particularly for members with a tension-compression reinforcement ratio of 0.185% (as in this example). After 3 years of creep, the midspan deflections of the simply supported beam under self-weight and sustained load, considering and neglecting reinforcement effects, are 2.47 mm and 2.68 mm, respectively—a difference of 7.8%. Therefore, to improve the accuracy of creep analysis for reinforced concrete beams, especially those with relatively high tension-compression reinforcement ratios, it is recommended to include steel reinforcement in the computational model.

Table 2: Comparison of Cantilever End Loads

Analysis Case	Load (kN)	Difference (%)
With shear, with reinforcement	46.38	12.5%
With shear, without reinforcement	41.25	-
Without shear, with reinforcement	41.25	12.5%
Without shear, without reinforcement	36.56	-

Table 3: Relative Errors Between Present Study and Literature Values

Parameter	Error (%)
Midspan deflection (3 years)	2.3%
Concrete stress at midspan	1.8%
Steel tensile force	3.1%

Conclusions

The creep analysis method for reinforced concrete fiber beam elements proposed in this study can account for shear effects that may exist in actual structures. The calculated results are expressed in terms of axial force, shear force, and bending moment at the element level, similar to beam theory, which facilitates practical application in cross-section design and reinforcement verification. Unlike analytical methods that require different assumptions for simply supported versus continuous reinforced concrete beams—leading to lack of generality—the present finite element-based approach is universally applicable across various types of reinforced concrete structures without such limitations.

The numerical examples demonstrate that steel reinforcement significantly affects the mechanical behavior of reinforced concrete beams. For members with tension-compression reinforcement ratios of 0.185%, the difference in midspan deflection after 3 years of creep between models with and without reinforcement consideration reaches 7.8%. Therefore, to improve analytical accuracy, particularly for reinforced concrete beams with relatively high reinforcement ratios, it is recommended to include steel reinforcement in the computational model.

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Note: Figure translations are in progress. See original paper for figures.