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Opinion

Estimation of the Effects of Shear Rotation on Structural System Identifications Methods Based on Stiffness Matrix Methods

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Introduction and Areas covered

Structural modeling relies on the simulation of structural behavior. It is accomplishment stands on the processes in which with the use of a series of assumptions, physical problems are explained into mathematical ones. Many authors studied the structural behavior of beams [1,2]. Most of them are based on either Euler-Bernoulli's beam theory [3] or Timoshenko's beam theory [4]. According to many scholars [5] shear deformations are neglected in Euler-Bernoulli's beam theory approach since the plain section deformation assumption in this theory. This hypothesis states that plane sections remain plane and perpendicular to the neutral axis during and after bending deformation [6] and accordingly, shear strains are zero.

Opinion

In most of the loading cases, this theory fails, due to the fact that the only situation with zero shear force is a constant bending moment alongside the beam. Hence, Euler-Bernoulli's beam theory only applicable in this scenario. This theory generally uses in slender beams, where shear deformations are much smaller than the flexural ones, so their effects can be neglected. In these cases, the absence of shear strains and deformations should be considered a modeling error (such as any other feature assumed with a wrong value) [7]. Nevertheless, in structures lacking a unidimensional geometry (such as deep beams) shear deformation might play an important role and its effects should be introduced into the formulation [8]. Deep beams are characterized as beams in which the lengths of spans are three times less than the overall section depth based on Eurocode EN 1992-1-1 [9]. Also, ACI committee 318 [10] describes these beams as those whose spans are equal to or less than four times the depth of the beams. Shear effects may be remarkable on the other two dimensional structures as well, such as composite or sandwich structures. Timoshenko was the first one who was considering the effects of shear in structures. In his method which is generally known as Timoshenko's beam theory, he included the effects of both vertical deflections and rotations due to shear into beam theories. In this theory, besides bending rotation, shear rotation between the cross-section and the bending lines are allowed.

Finite Element Method (FEM) is a numerical problem-solving method. In this method, large equations are divided into smaller and simpler equations. FEM is one of the most powerful and common techniques for computer-based analysis in engineering [11], as it is normally employed for both simple and complex structures [12]. The Stiffness Matrix Method (SMM) is one of the major methods of FEM approach for analyzing the structural behavior of beam-like structures [13,14], especially suited for computer-analysis of complex structures.

System Identification (SI) which has been used in different engineering fields is a method for modeling an unknown system (Altunişik, A.C et al. 2017). SI began in the area of electronic engineering and, after a while, it has been extended to other fields of engineering (Gevers, M. 2006). The part of the SI which is dealing with the construction of mathematical models to identify the structural parameters is structural system identification (SSI) (such as flexural stiffnesses, axial stiffnesses or damping parameters) from the structural response [15]. Despite the importance of shear deformation in some structure cases, it is neglected by most of SSI methods. For most structures, shear deflections are smaller than the deflection due to the bending, hence this phenomenon can be overlooked. In these scenarios, shear effects are considered as modeling errors in the mathematical models (such as any property in the model assumed with a wrong value). Nevertheless, in some structures (such as deep beams, or thin-web bridges) shear effects might play an important role. SSI methods based on SMM normally use elementary beam theory, underestimating deflections and overestimating the natural frequencies since the shear deformation effect is disregarded [16]. When shear effects are significant, most of SSI methods based on SMM are not able to observe the correct values of parameters in structures (such as bending stiffness). To show the importance of shear rotation to identify material properties with actual measurement (sum up of bending rotation and shear rotation) an illustrative example is analyzed in the following [17-20].

Example: Simply supported beam

Consider the 5m long and 0.2m wide simply supported beam modeled with 3 nodes and 2 beam elements showed in figure 1a. This structure can be considered as a deep beam, where shear effects are not negligible. This beam has a constant cross-section and the value of its young modulus, shear area, cross-sectional area and inertia along the beam are 35 GPa, 0.800 m2, 1 m2 and 1.083 m4, respectively. Dimensions of the beam cross-section are presented in figure 1b and its mechanical properties are listed in table 1. The boundary conditions of the structure are horizontal and vertical displacements restricted in node 1 and vertical displacement restricted in node 3 (this is to say, $u_1=v_1=v_3= 0$). The beam is subjected to a concentrated vertical force in node 2 of 100kN ($V_2= 100$kN).

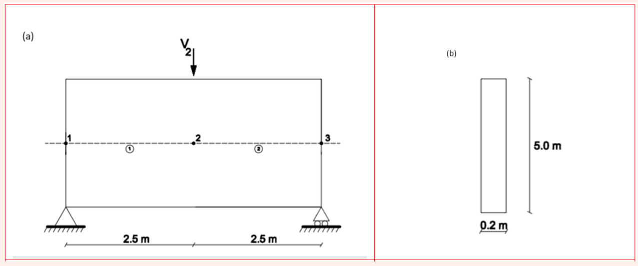

Figure 1: a) FEM for a simply supported beam.
b) Dimensions of beam cross-section.

Table 1: Properties of the FEM of the simply supported beam.

Properties (unit)	Values
Area [m2]	1.000
Shear Area [m2]	0.800
Inertia [m4]	1.083
Concrete Young's Modulus [GPa]	35.000
9Poisson's Ratio γ	0.250

In order to calculate the bending rotation, the Euler-Bernoulli beam theory is applied. Also, for the shear response of the structure in this simple example, formulations based on the Timoshenko beam theory can be used. The value of bending vertical deflections for the loading case presented in figure 1a, v_b and w_b the value of vertical deflection and rotation due to bending can be easily calculated. Shear rotation w_s at the node number 1 can be calculated from Timoshenko's assumptions as it is presented in Eq. (1).

$$w_s = \frac{Q_1}{A_{v*}G} \quad (1)$$

Where Av is the shear area, Q is shear force and G is the shear modulus. As it was expected, the effects of shear in this example is significant. The value of bending rotation in node number 1 is 4.12E-3 (m), while the value of shear rotation in the same node is 4.30E-3 (m). It is to say that in this academic example the value of shear rotation is even greater than bending rotation. Moreover, if the actual value of rotation (sum up of shear and bending rotation) is employed in inverse analysis the observed value for inertia will be obtained with more than 50 percent error in the result [21-24].

Expert Opinion

Stiffness matrix methods used normally to analyze structural behavior are based on Euler-Bernuly beam theory neglecting shear rotations. Also, all SSI methods reviewed in literature neglect rotation due to shear in their formulation as this phenomenon is usually less significant than the bending rotation. Despite the important role that this rotation might play especially in members with a low span-to-depth ratio, no detailed study addressing the particular effects of this rotation in structural behavior can be found to the best knowledge of the author. To fill this gap and show how important, the role of shear rotation might be, several different structures (from simply supported beam with a concentrated load and to bridge spans) with different length to height ratios should be studied. In fact, these examples will illustrate the difference between Timoshenko's theory and Euler-Bernoulli's theory in terms of rotation and their effects in inverse analysis. This issue is especially important due to the general use of Euler-Bernully based SMM in inverse analysis methods. SSI methods based on the SMM should be develop to calculate the shear rotation and take into account the effects of shear rotation in inverse analysis. Especially those methods which will be used in the structures with high ratio of shear rotation to the bending rotation.

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