Modelling of Multi-Storey Frame Interacting with Rigid Core of the Building

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Abstract. Impact of bar incompressibility assumption on frames has been analysed in this paper. It has been shown, that in some cases of high buildings, where rigid core is surrounded by set of bars, assumption of columns incompressibility is justified. With compressible bars, significant bending moments occurs on beams connected to core of the building.

1. Introduction

3D design of buildings becomes common practice. Using software, intended for 3D modelling, enables creation of complex computational models. Modern engineering software encourages to the approach, where 3D geometrical model of structures, can easily be transferred to computational model, consisting of bars, planes and often solid elements. Then, calculations which in most cases can be efficiently performed with one of commonly used computational software, usually with finite elements method. The most difficult part of this procedure is verification and validation of the results, [1-2].

In this paper, computational model of 15-storey building, shown on figure 1a, will be analysed. The structure of this kind of building is usually modelled as rigid core surrounded by set of columns. In 3D modelling, complex computational model will be taken, shown on figure 1b. During design process, engineers encounters several difficulties, such as eccentricities between columns (this problem is omitted in this paper) and incompressibility of bars, especially – columns.

In first part of the paper, auxiliary example will be described, evaluating influence of incompressibility of columns in simple frame.

In second part, larger frame model connected with rigid core of the building will be discussed. There, as it will be showed, assumption of incompressibility, in some cases can be desired.

2. Structure rising and bar incompressibility

A few decades ago, structural engineers commonly used assumption about bar incompressibility. It simplified calculations, by decreasing number of unknowns in the task. Complexity of the task and large numbers of freedom degrees stopped being significant problem with computer analysis, what caused incompressibility assumption nearly forgotten, [3-5]. Most of engineering software does not let the user to make such assumption directly, which implies using artificial solutions.
Building shown on figure 1 is an example, where columns incompressibility is worth considering. It comes from technology of process of structure rising. The process goes storey after storey, and column strains rises together with the object.

3. Bar incompressibility modelling methods
Two ways of incompressibility modelling, while using finite elements method, should have been mentioned.

First of them is physical parameters modelling. It can be achieved by multiplication of bar sectional area, for example by 10, 100 or 1000 times. Bigger values should not be used, because they can lead to numerical errors.

Second method is geometrical modelling. In this approach, displacement bonds between nodes needs to be placed. Axial displacement equality:

\[ u_i = u_j \]  \hspace{1cm} (1)

is assumed, as shown on figure 2.
Figure 2. For incompressible beam we have $u_i=u_j$.

4. Three-storey planar frame

Auxiliary case of simple structure: planar frame, shown on figure 3, will be analysed in this section. The impact of columns incompressibility will be discussed.

Calculations have been made for a structure shown on figure 3. Parameters assume: $E = 33$ GPa, sections: 30x30cm for columns and 30x50cm for beams. Finite elements method was used in two variants: I - compressible bars, II – incompressible columns and compressible beams. Incompressible assumption has been achieved in two ways: a) physical modelling, b) geometrical modelling.

Figure 3. 2D frame: a) dimensions, b) nodes and bars numbering, c) loads definition
On figure 4, bending moments have been showed. FEM analysis have been performed in variants I and IIa by Autodesk Robot Structural Analysis Professional 2019 (ARSAP) and Finite Element Analysis System (FEAS). Furthermore, IIb variant have been performed by FEAS system. As predicted, differences in bending moments values between all variants were relatively small and can be omitted for engineering purposes. Similar for transversal forces.

For axial forces, physical modelling of columns incompressibility leads to same results as without this assumption. On the other hand, geometrical modelling implies no axial forces in incompressible columns.

Differences can also be noticed in vertical nodal displacements, as shown in table 1.

| Vertical nodal displacements [cm] |
|-----------------------------------|
| FEM | FEM\(^b\) incompressible columns |
|-----|----------------------------------|
| 1   | 0.0 | 0.0 |
| 2   | -0.027 | 0.0 |
| 3   | -0.520 | -0.489 |
| 4   | -0.046 | 0.0 |
| 5   | -0.448 | -0.398 |
| 6   | -0.056 | 0.0 |
| 7   | -0.644 | -0.583 |
| 8   | -0.065 | 0.0 |
| 9   | -0.055 | 0.0 |
| 10  | -0.034 | 0.0 |
| 11  | 0.0 | 0.0 |

\(^b\) Results presented for geometrical modelling of bar incompressibility

Using assumption of bar incompressibility does not affect frame internal forces. The only exceptions are axial forces, with geometrical modelling. In this case, axial forces should have been derived from nodal forces equilibrium.
5. **Computational model – planar frame with rigid core of the building**

For the building shown on figure 1, computational model of planar frame connected to rigid core will be taken, as shown on figure 5.

![Computational model of planar frame with rigid core a), and statical scheme with boundary conditions b)](image)

Two types of connections between beams and core have been analysed: I - rigid link and II - joints. For both approaches, two ways of calculations have been performed: with a) compressible and b) incompressible columns.

With joints between frames and core, results between a) and b) were close. Both models can be assumed as correct for engineering purpose.

With rigid links between frame and core, results are quite different. Bending moments and axial forces have been shown of figure 6 and 7.
Figure 6. Bending moments in frame with: a) compressible columns, b) incompressible columns
Figure 7. Axial forces with: a) compressible columns, b) incompressible columns

Differences can be seen in bending moments. Model with compressible columns should be treated as partially incorrect. During process of rising, structural elements are subjected to loads gradually. Technology of building implies assuming partially incompressible columns, as displacements
are partially compensated during the process. The effect shown on figure 6a can be handled by inserting joints between frames and core.

6. Conclusions
Simple case, often occurring in engineering practice, have been analysed. As has been shown, assumption of bars incompressibility, willingly used by structural engineers in past, can find its use in modern analysis. The effects shown in analysed case would have been even more significant for similar structures with more storeys.

Avoiding verification and validation of calculations by engineers, can lead to major mistakes in structural designing.

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