Computer modelling of R.C. shear walls - comparative analyses at different values of the reduction coefficient. Internal forces values.

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Abstract. The report shows a continuation of analyses of reinforced concrete shear walls solved by horizontal forces [14]. In certain places in the walls the stiffnesses are reduced, thus comparing the obtained results between the groups of models. Solutions for wall and mixed structural systems are shown. The decisions were made with specialized Tower software based on work by the Finite Element Method. Interesting conclusions can be seen for the level between the rigid basement and the first floor. Decreases in bending moments and increases in shear forces are observed. Motivation – quick analysis of walls subjected to the action of horizontal forces (hand analysis, without program system); the goals - proving the idea of the influence of the supports from the basement levels; the methodology - solutions with specialized software - only for a certain speed in the decisions. The solutions have characteristic geometry and loads and can be easily parameterized with correction factors.

1. Introduction

Reinforced concrete walls (shear walls) are a key element of the load-bearing structure of buildings with wall and mixed structural systems. Of particular importance is the way of computer modelling (simulations) of the walls, as well as obtaining (interpretation) of the internal forces in them, necessary for their analysis. [14] The structural elements are designed for stress states: eccentric compression and shear. These structures are suitable for the modern level of design of earthquake-resistant structures. The dimensions of the walls section are designed according to the Eurocodes and has a boundary zone with enough thickness. Thicker walls absorb larger shear forces. This is beneficial on the first floors of the walls and especially in the basements. The effect of the slenderness ratio (height to thickness) affects the failure of the compression of the boundary zones of the wall, because with greater slenderness (thinner walls) smaller areas of the load-bearing reinforcement are obtained, compared to the walls with small slenderness. This is because the physico-mechanical reinforcement coefficient is lower. This is a circumstance for not ensuring the local ductility of the wall. The instability outside the plane in the shear walls is expressed precisely by the plastic mechanism of destruction - loss of stability due to its small thickness (from compression) [13]. It is possible that the bearing capacity of shear is not realised for the thin walls. Therefore, engineers must carefully choose the reduction factor $\alpha_f$ [2] by which the effective bending stiffness is determined. This factor reduces the stiffness of reinforced concrete elements to account for the presence of cracks in them (for critical zone). The coefficient does not take into account the real mechanisms of dissipation of seismic energy in various structural elements and systems - does not depend on the type of structural element. In this article, by reducing the stiffness by 50%, the critical zone is realized, and the Poisson's ratio is additionally zeroed. The various directions in which work is done in the worldwide - are shown in the developments [1], [4], [10] - there are been studied problems, describing various theoretical and experimental formulations. Basic information for the development of the models shown in the report was used by [5], [13], where which was illustrated with examples and theoretical postulates. Some of the studies, for example [7] - show a comparison of the deformed and stressed states of shear wall with
holes, obtained in different modelling approaches, by comparing two types of computational models, based on finite elements, respectively - beam and plate. Questions about analyses that take into account geometric nonlinearities, i.e. the influence of normal forces on the rigidity of the structure are considered in [8], from where a certain analogy can be made with the frame’s computational models. Analysis with ANSYS by modelling the reinforcement for slabs, is shown in [11]. Information on the mechanism of transfer of shear forces in reinforced concrete elements subjected to both shear and compression - with name aggregate interlock, is given in [12]. Reporting the susceptibility of the soil base is a characteristic indicator in the analyses, information can be seen in [6]. The requirements for sustainable development have been the criteria laid down in a number of documents, information can be read in [9].

The idea for the presented analyses was for a "quick" check at the beginning of the design, through a different type of analysis, of the existing scientific base. The report presents a study of vertical load-bearing elements - walls.

2. Information about the loads and groups of computational models

Five groups of computational models have been compiled. Tower 6 software product [15] was used. Comparisons of the values from the obtained results were made (internal forces in characteristic horizontal sections in the height of the R.C. shear walls). For the numerical experiments is accepted concrete class (grade) C25/30 according to BDS EN 206: 2013+A1: 2016 / NA: 2017 [3]. The walls for all models was with lengths 6 m and 25 cm thickness (solid walls) rectangular cross sections in plan, with a storey’s height of 3 m. It is customary for the walls to be rigidly clamped (fixed base) in their foundations. Linear supports are modelled between the basement and the floor. The analysis is linear (static), with increasing horizontal forces from E₁ = 50 kN (for the first level) to E₆ = 300 kN (for the last, sixth level) - Figure 1. The dimensions of the finite elements are 10/10 cm. The software product offers an option for automatic "Generation" for discretization.

Figure 1. Geometry and applied loads for solid walls (the schemes apply to all considered solutions)
Model groups:
Group I. Models without reduced stiffness - Figure 2.
Group II. Models with 1 critical zone (above the ground – rigid basement) - Figure 3.
Group III. Models with critical zones – the rigid basements and the level above it - Figure 4.
Group IV. Models with critical zones above the ground – the rigid basement - Figure 5.
Group V. Models with critical zones – rigid basements and levels above it - Figure 6.

In the models with (purely) elastic stiffness, without critical zones in height:

\[ E = 3.1 \times 10^7 \text{ kN/m}^2 \text{ and } \nu = 0.2 \] are used.

Models: 1, 2 and 3. Models with adjusted stiffness only for rigid basements and/or levels above it (for wall system).

Model 4 and Model 5. Models with corrected stiffness (for walls from mixed system).
The stiffness correction is expressed in a 50% reduction of the E - modulus of the material and zeroing of the Poisson's ratio.

Shown are the critical zones by hatching (in red) in Figures 3-6.
Figure 3. Schemes of Group II

Figure 4. Schemes of Group III
3. Results of numerical experiments
The results for: bending moments $M$ and shear forces $V$ are presented in figures 7 – 16 (directly from the software product). For Models 1 of Figures 2, 3 and 5, the results of [14] are shown.

**Note:** Capacitive correction shear force adjustment was required if they were used to analyse the load-bearing reinforcements for the elements! [14]
Figure 7. Values of Bending moments in Group I of models in the considered sections.

Figure 8. Values of Shear forces in Group I of models in the considered sections.

Figure 9. Values of Bending moments in Group II of models in the considered sections.
Figure 10. Values of Shear forces in Group II of models in the considered sections.

Figure 11. Values of Bending moments in Group III of models in the considered sections.

Figure 12. Values of Shear forces in Group III of models in the considered sections.
Figure 13. Values of Bending moments in Group IV of models in the considered sections.

Figure 14. Values of Shear forces in Group IV of models in the considered sections.

Figure 15. Values of Bending moments in Group V of models in the considered sections.
The diagrams show that:

From the presented internal forces (bending moments and shear forces) for a single section at level +3,10 m, it can be assumed that the considered models of reinforced concrete shear walls behave equally, due to the close values of the obtained results for all groups of models.

At a level +0,10 m there is a sharp limit in the values of the bending moments between the models, first, without including the level of the terrain and second considering the level of the terrain, as in places the values are several times higher.

If we consider models 2 and 3, compared to the respective group of models, it can be seen that with two underground levels for the building, the bending moments decrease and the shear forces increase significantly at +0,10 m level along the height of the shear wall. In models 4 and 5, compared to the respective group of models, the same is observed.

In models 3 and 5 the modelling of a rigid basement at two levels creates reduced bending moments at the models (no rigid basement), at the expense of the shear forces that also increase.

At –2,90 m level, there is no difference in the values of the internal forces of the individual models of the groups, which is analogous at level +3,10 m.

In general, from the presented results for the considered models, it can be concluded that the models presented in groups I, III and V behave in the same mode, which is observed in the types presented in diagrams. The same is observed for the models in groups II and IV.

Adequate reading of the rigid basement leads to a significant difference in the internal forces acting at +0,10 m above ground level, which is expressed as several times lower values of bending moments, and higher values of the shear forces, when the ground level is not calculated.

4. Conclusions

According to the location of the so-called critical zone, it can be clearly seen that when a rigid basement is modelled, the internal forces in the considered sections, i.e. the bending moments respectively decrease, and the shear force increases, regardless of the constructive system for the models.

The adoption of different computational models in the design of reinforced concrete walls leads to different results, which must be analysed and processed with greater care.

There is no significant difference in the values of bending moments and shear forces between the adoption of the two structural systems (wall system and mixed).
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