13th International Brick and
Block Masonry Conference
Amsterdam, July 4-7, 2004

DETERMINATION OF LOAD ECCENTRICITY FOR MASONRY WALLS IN MULTI-STORY STRUCTURES WITH RC-SLABS

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Abstract

In the paper methods of calculating the out-of-plane eccentricity of loading on masonry walls given in EC 6 (prENV, prEN) and the Polish code PN-B-03002:1999 are analysed. For a 4-story building computations were performed using the frame analysis, the single joint analysis and the FEM model (an analysis in plane strain state).

Key Words

Load eccentricity, frame analysis, FEM analysis

1 Introduction

The conventional analytical model for design of masonry structures for the vertical load is one in which the walls and the slabs are effectively interconnected by hinged joints. In this approach it is generally assumed that the load from RC slabs may be considered to act at 1/2 or 1/3 of the depth of the bearing area from the face of the wall (BS 5628, PN/B-03002:1987). In the new Polish standard for masonry structures PN-B-03002(1999) the frame analysis has been introduced but not for all cases of masonry walls. In calculation of load eccentricity for walls using frame analysis, the joint between the wall and the RC slab may be simplified (like in EC6) by using uncracked cross sections and assuming elastic behavior of the materials. The results of typical calculation with fixed joint are conservative. The reduction moments proposed in recommendations of the Eurocode 6 (prENV, prEN) and PN-B-03002:1999 are very different – this question will be more widely discussed in further parts of this paper. The reason for these differences is limited number of the experimental investigations in relation to the presently used joint construction. So far, the uniform method for determining the wall-slab joint fixity has not been worked out. The investigations of full-scale tests are expensive and hard to execute because of safety reasons for the high load levels. The tests on the cantilever models do not take into account wall and slab rigidities. This paper gives results of analyses of structures in plane strain state. The non-tension elements are applied on interface between the masonry wall and the RC

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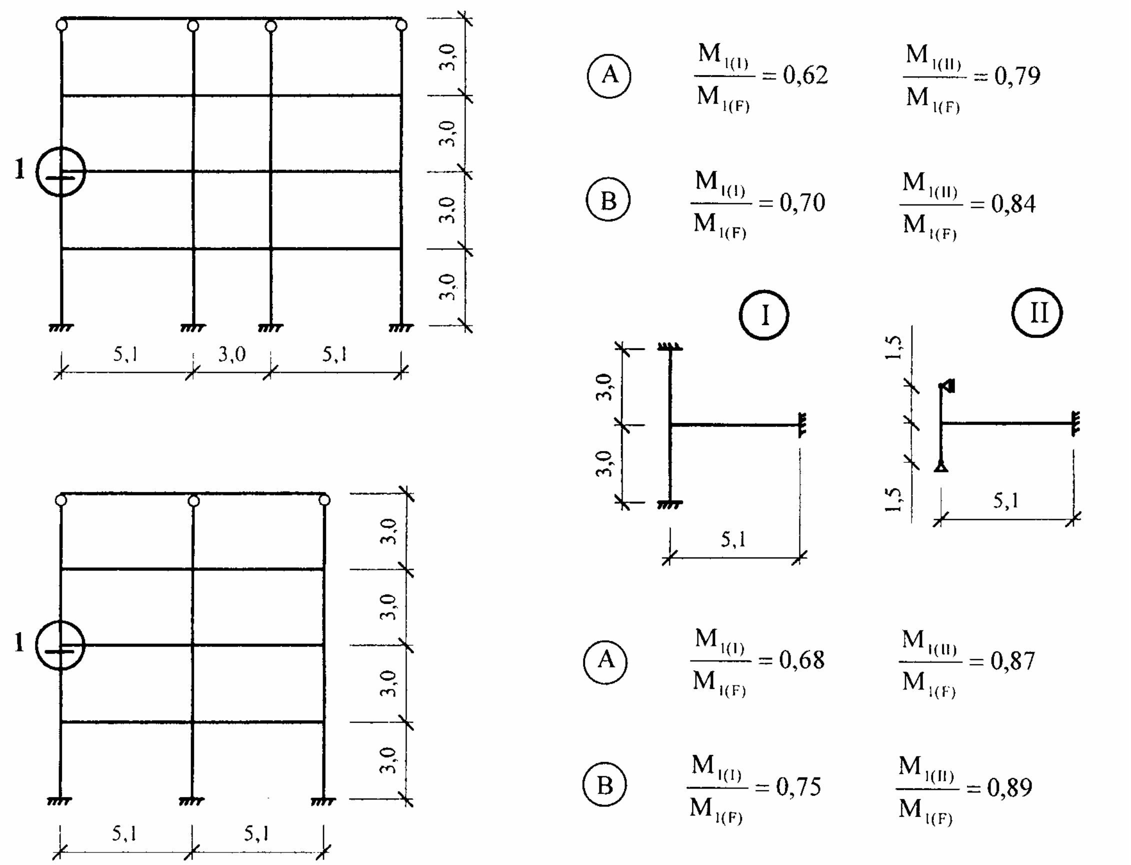
slab. That makes it possible to estimate the influence of cracking effect on the wall-end bending moments and rotation of wall under slab.

2 Frame analysis – discussion of codes recommendations

Subsequent versions of the EC6 and Polish code PN-B-03002:1999 give simplified method for calculating the out-of-plane eccentricities of loading on walls – the single joint analysis may be used. In Fig.1 the wall-end moment values for external wall determined for the frame analysis for the whole structures and for single joints are compared.



RC slabs: h=180mm; E_s=27.5GPa
Internal and external masonry walls
Variant: A t=190mm, E_w=3.9GPa
Variant B: t=250mm, E_w=3.3GPa
Total slabs load (including RC slabs dead load) 8.5kN/m^2
Notation:
$M_{1(F)}$ – the bending moment in cross-section 1-1 (under slab) determined from the frame analysis for the whole structures
$M_{1(I)}$, $M_{1(II)}$ – respectively the bending moments in cross-section 1-1 determined for scheme I and II

Figure 1 Comparison of results for different types of frame analysis for calculating the wall-end bending moments

The joint analysis (scheme I) gives the lowest values of wall-end moment. Differences with moments estimated in full frame analysis exceed 30 %. Results of calculation using scheme II (the German code DIN1053 T.2 recommends assumption of the hinged supports at mid-height of walls) are close to those obtained in full frame analysis. Similar relationships were obtained by Starosolski (2003) for five-story

buildings with brick walls. The differences between moment values determined based on analysis of the whole structure and for single joints decreases with the reduction of slab/wall stiffness ratio.
Proposed reduction levels for the wall-end moments values which are included in code recommendations are presented in Fig.2.

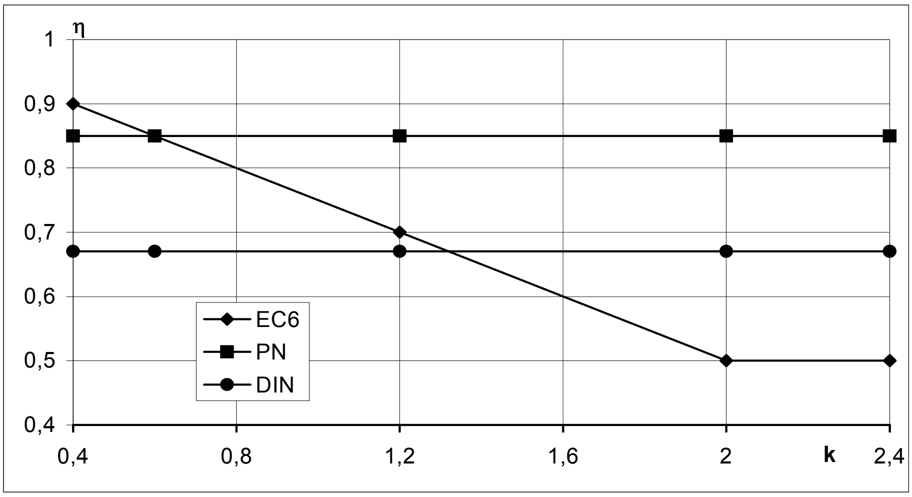


Figure 2 Reduction ratio for wall-end moments proposed in EC6, PN-B-03002:1999 and DIN 1053

Values η determined from relationship given in the subsequent versions of EC6:

$$\eta = 1 - k/4 \qquad (1)$$

k is the slab/wall stiffness ratio

are close to the ones calculated based on formula proposed by Hendry (1990):

$$\eta = 1/(0.44k + 1.1) \qquad (2)$$

Equation (2) was derived as the estimation of experimental results for tests carried out on structures in scale 1:1 and 1:2. Much higher levels of bending moments reduction than those resulted from equation (1) were obtained from tests by Awni, Hendry (1982), Stokle, Bell (1987) – for slenderer walls η<0.3. Considerable reduction of eccentricity with time was obtained in tests made on sub-frames by Bell et al (1998). However, for the time being, a number of investigations of realistic structural frames in full scale is too small to change the safe estimation given in EC6.
According to the Polish code PN-B-03002:1999 frame analysis may be carried out under the condition that compressive stress in the joint is not less than 0.25 MPa and load eccentricity does not exceed 0.33t. Reduction levels for bending moments in walls were determined based on cantilever models. Results of these tests were presented by Lewicki et al (2001). Mean value for moment reduction equal to 15% was obtained for walls made of ceramic masonry units (wall thickness 370 mm, concrete slab height 240 mm). As the sections of walls and slabs were relatively short in experimental model (1.5 of wall thickness) it may be assumed that determined in tests moment reduction level is the result of plastic effects in the joint. Tests on cantilever models for estimation joint fixity were proposed by Sahlin (2003) as well.
In multi-story masonry buildings with reinforced concrete slabs two materials are present in the joint and their moduli of elasticity differ significantly (for structure presented in Fig.1 E_s/E_w>7). Because of its high deformability the wall mainly determines the bending moment value. Moment reduction level proposed in the PN-B-

03002:1999 is therefore very low (acceptable only for structures with low slab/wall stiffness ratio). The German code DIN1053 T.2 recommends the reduction of moments calculated from the frame analysis of 1/3 that is essentialy more than the PN-B-03002:1999. Comparing results from Fig. 1 and graphs in Fig. 2 one can state, that moment estimated from the analysed code recommendations may differ very significantly.
Smaller differences in code recommendations appear in estimation of the maximal eccentricity in masonry wall. It is shown in a list below.

prENV (1994)	0.4t
prEN (2002)	0.45t
PN-B-03002:1999	0.4t for last floor
	0.33t for other floors
DIN 1053 T.2 (1984)	0.33t

In the light of information given in the present section a matter of the fundamental importance is to elaborate unified testing methods (appropriate EN) of wall-slab joints.

3 Model of the wall-slab joint – analysis in plane strain state

In calculations of frame structures for which results are given in section 2 (see Fig. 1) the influence of cracking effect onto wall-end moments and deformations has not been taken into account. Cracking at the joint between masonry wall and RC slab can be modeled by the means of elements that carry no tensile stresses (non-tension elements). Analysis of the whole structure presented in Fig.1 shows that for intermediate floor (see Fig.1 cross-section 1-1) a change of sign for bending moments takes place approximately at the midheight of the wall (Matysek, Seręga 2002). Hence, the model presented in Fig.3 was taken for the further FEM analysis.
Material characteristics for walls and slabs are the same as those in section 2.

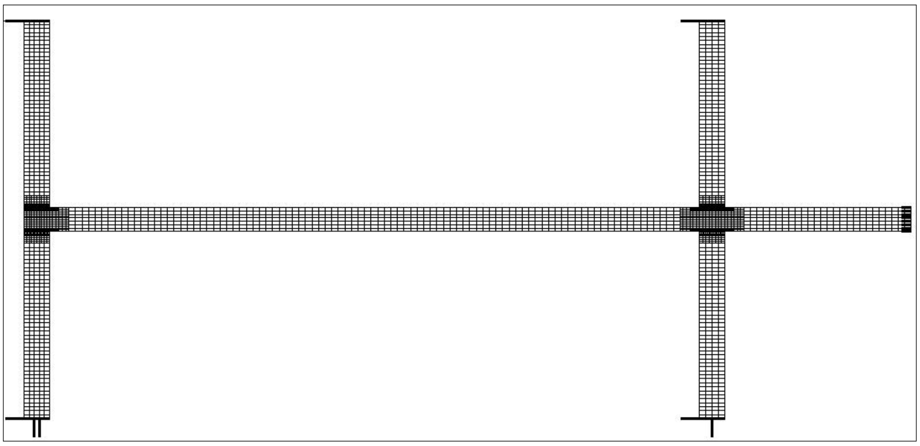
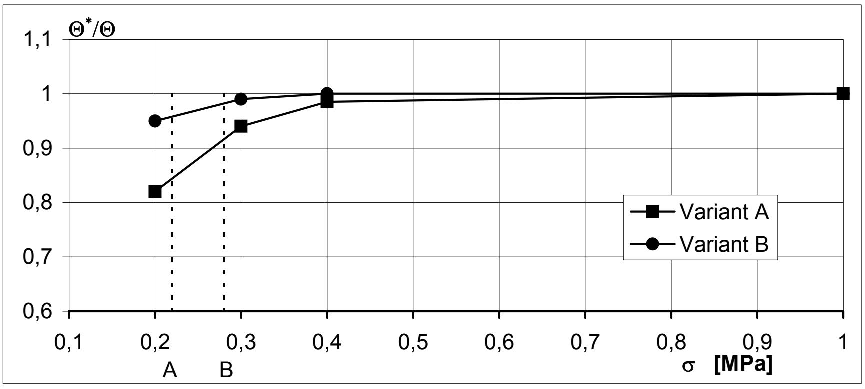
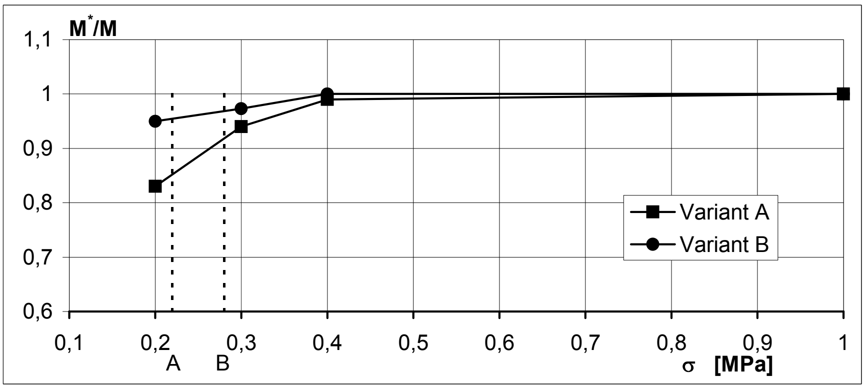


Figure 3 FEM model used for calculations

Results of calculations for different levels of precompression (σ) are presented in Fig.4. The effect of cracking on wall-end moment is the highest for A variant of structure and for relatively low levels of precompression. If precompression is greater than 0.3MPa then influence of cracking on wall-end moment and rotation of the wall is negligible (only few percents). For joint marked in Fig.1 the reduction of fixity resulted from cracking may be estimated as less than 10% for A variant and about 5% for B variant of structures.

The afore-mentioned results coincide with a relation obtained in experimental investigations – the larger slab/wall stiffness ratio is then the larger level of reduction of wall-end moments.





M^*, θ^* - bending moment and rotation angle of wall in cross-section under slab determined with taking into account the possibility of cracking at the joint: masonry wall-slab, respectively,

M, θ - as above but for the case of rigid joint.

Figure 4 Influence of cracking effect on values of moments and rotation angle of wall

In Fig. 5 the values of ratio of maximum edge compressive stresses with taking into account cracking at the joint (σ^*_{edge}) to analogical ones, but determined without taking the effect of cracking (σ_{edge}) are presented.

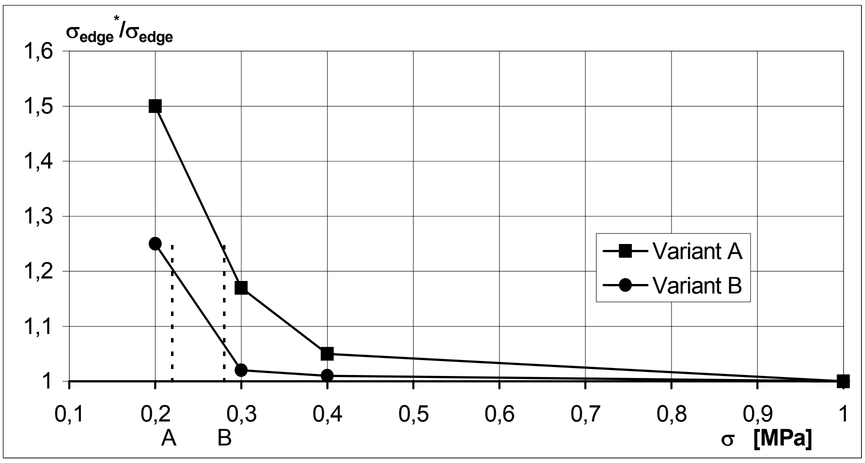


Figure 5 Ratio of $\sigma^*_{edge}/\sigma_{edge}$ against precompression

For precompression levels higher than 0.3MPa the differences between values of stresses are within the range of 20%.

Influence of the cracking effect in joints on values of bending moments and rotation angles of masonry walls determined for the analyzed structure was very small and diminished fast with precompression increase. In examination of the afore-mentioned results of computations it is necessary to keep in mind that they were performed with an assumption of the linear stress-strain relationships for materials.
More realistic results may be achieved using models taking into account reductions of masonry walls and RC slabs flexural rigidity due to cracking and plastic effects in wall-slab joint (research with application of the ANSYS program is being conducted at present by author).

4 Conclusions

The results of calculations presented in the paper indicate the possibilities of determining the eccentricities in walls in multi-story masonry buildings with applications of frame models. Taking into account the current offer of engineering computer programs, the analysis of single joint for determining eccentricities in masonry walls should be limited only to cases where high accuracy of calculation is not required. Computations performed for an exemplary structure with four floors proved that the differences in moment values for masonry walls determined on the basis of the full frame analysis and the single joint analysis can exceed 30%. This effect is the more pronounced the larger the slab/wall stiffness ratio is. Numerical analysis carried out for part of structure (see Fig.3) in plane strain state with taking into account the cracking at the wall-slab joint made it possible to estimate the influence of precompression and flexural rigidities of walls and slabs onto degree of joint fixity. Reduction levels of wall-end bending moments in two variants of analysed structures for precompression > 0.3MPa due to the cracking effect in slab-wall joint were very low.

Acknowledgements

The computation were made using ABC program – author K.Grajek, Ph.D. (Silesium University of Technology at Gliwice).

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