ENGINEERING MODELS FOR SHEAR WALLS MADE OF MASONRY

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ABSTRACT

Walls of buildings do not only bear vertical forces but also act as stiffening members such as shear walls. Applied horizontal forces result primarily from wind, as well as imperfections and in earthquake-prone areas from earthquake actions.

In the case of capacity verification of masonry shear walls, where the bearing horizontal force depends mainly on the size and location of the normal force, the partial safety concept leads to unfavourable results and smaller load bearing capacities than the approach of the global safety concept using service loads.

For the common model to calculate internal forces of the shear wall, a simple cantilever beam with vertical forces from slabs and horizontal forces from wind is used. Due to this, the maximum bending moment is situated at the bottom of the cantilever. But the resulting cutting forces of a shear wall can be decreased by means of improved engineering models like frames and interactions between wall and slab. Consequently, a possibly former unstable shear wall can now be verified by using new models.

KEYWORDS: engineering modelling, shear wall, model comparison

INTRODUCTION

This report shows several options for the mobilization of structure-relieving recourses primarily considering the assessment of the state of strain on shear walls. This is based on a truss model [1], which is modified by different approaches. Consequently a shear wall, which gets too high bending moments from the cutting force determination on the classical cantilever beam with horizontal wind loads, can be brought closer to the real state.

The simplest determination for the capacity of a shear wall is to calculate the load eccentricity *e* (see Fig. 1 and Eq. 1) and to verify that it remains within the cross section of the wall. For the Ultimate Limit State the value of *e* should be smaller than half of the wall length *t*, otherwise the wall overturns, acc. EN 1996-1-1 [2].

$$e = \frac{M}{N} \quad ; \quad e \leq t / 2 \tag{1}$$

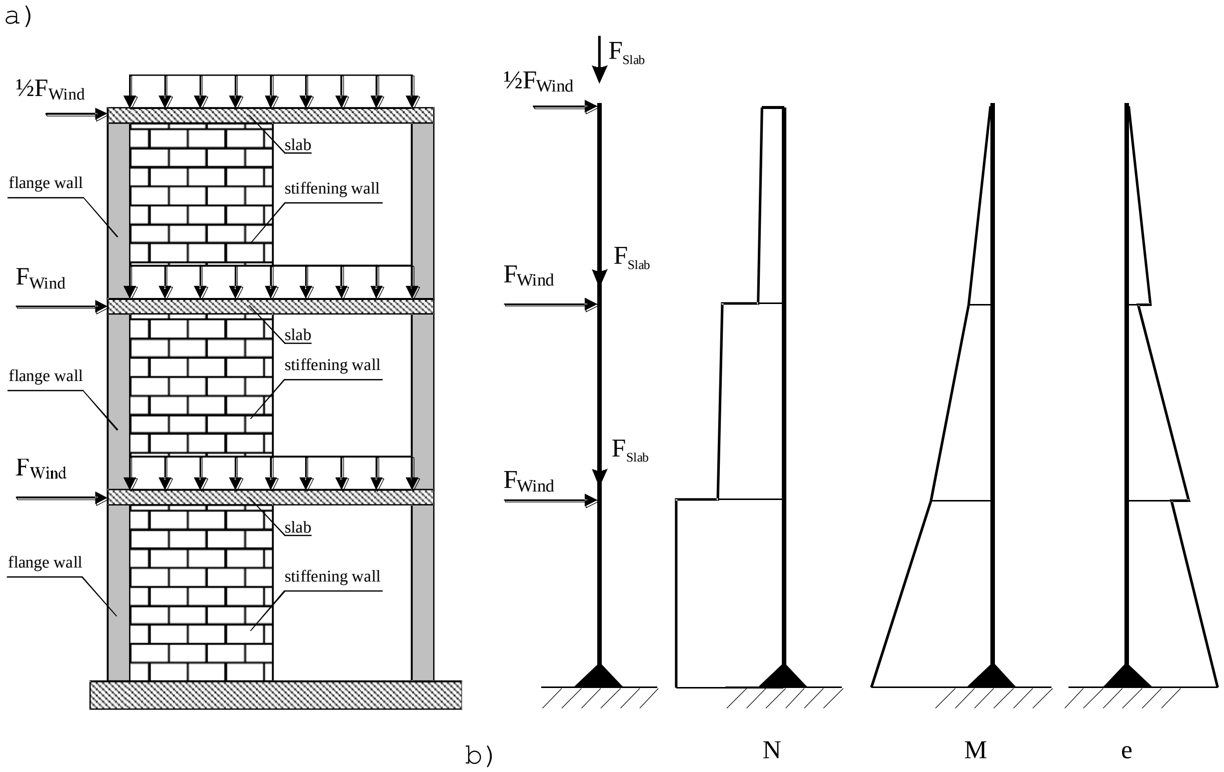


Figure 1: a) multi storey shear wall, b) simple model and cutting forces

For the following approach, the strength of the wall is not of interest. This should be a general proposal for the determination of internal forces, close to the reality.

CANTILEVER WITH RESTORING FORCES

The conventional cantilever model remains unchanged. In addition, restoring forces of components (e.g. present flange walls) are considered. These forces create an opposite bending moment to the moment resulting from the slab supports and wind, see Figure 2.

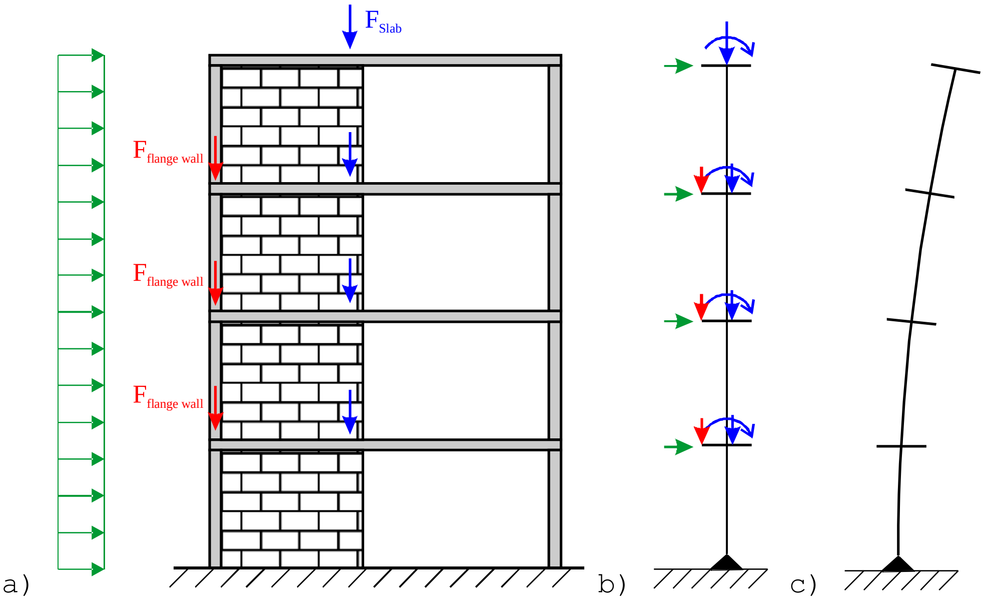


Figure 2: a) Model, b) Structural system with restoring forces (red), c) Deformation

Steps

- determination of vertical and horizontal loads including possible restoring forces,
- load eccentricity resulting from the normal force and moment summation downwards,
- verification of the shear wall and
- verification of restoring forces in the reinforced concrete elements

CANTILEVER WITH SPRINGS

For the determination of the restoring forces, the attachment of the slab is considered. Additional springs (torsion and / or slide springs) take into account the load transfer from the slab. Since the model of the cantilever is applied again, an easy programmability is given. Nonlinear calculation algorithms (gaping of the joint between the slab and the wall) can be taken into account [4]. To replace the slab stiffness by an acting spring is still problematic, because the degree of fixation between wall and slab is unknown. The slab might deform more than the wall. Thus, the slab might act more in a loading than a supporting manor onto the wall (Figure 3). Consequently, this kind of reserve is only to be considered with reasonable certainty if slab and wall rotate differently and at minimum one full storey above is present (Figure 4 and Figure 5). This ensures that the slab is clamped sufficiently in the stiffening wall and can be used for the reduction of the bending moment.

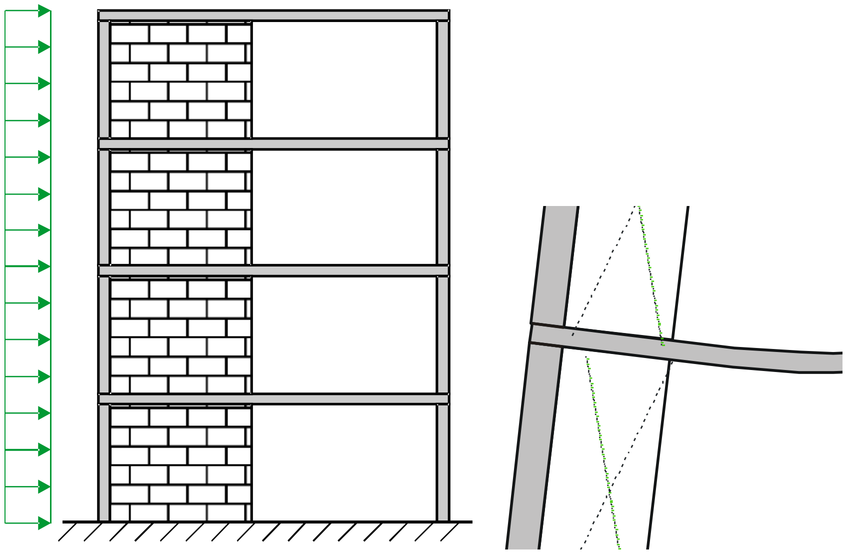


Figure 3: Wind from the left – model and structural system. There are no restoring springs applicable

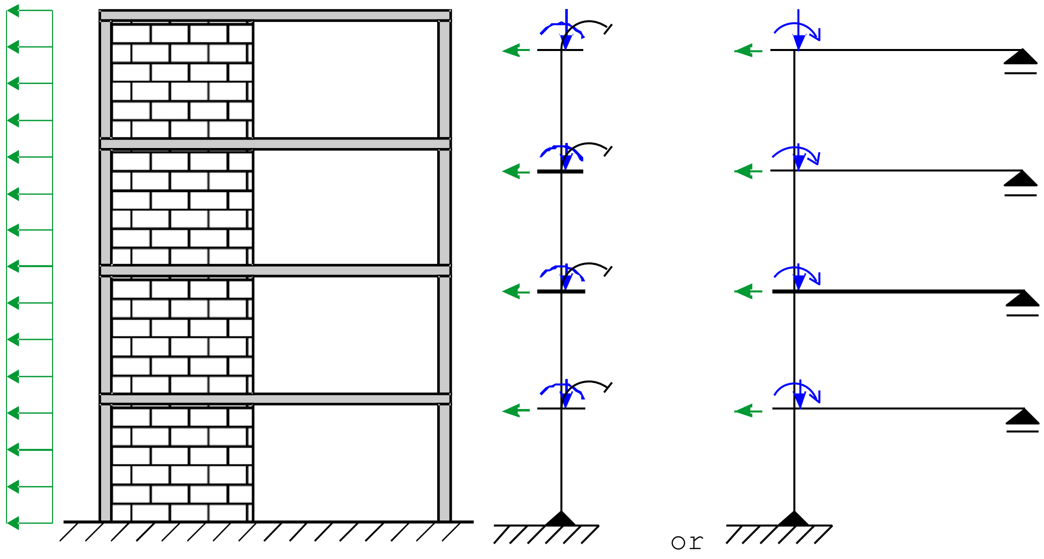


Figure 4: Wind from the right – model and structural system with springs and respectively with connected floor strips

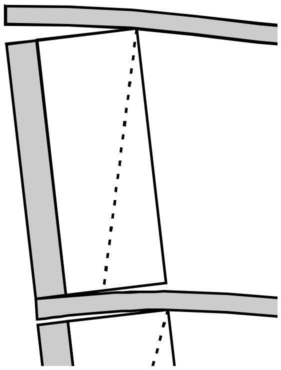


Figure 5: Hinged support of the top floor slab and restrained floor slab in all lower storeys (sketch without scale)

Due to its static indeterminacy, the model is unsuitable for manual calculation, however this system can be solved by using simple 2D truss programs that are available as freeware. For the common cantilever beam, software based on Excel is published in [3].

Steps
- determination of vertical and horizontal loads including possible restoring forces,
- determination of the spring stiffness of the slab,
- perform calculations
- verification of the shear wall and
- verification of the restraining bending moment of the slab

FRAME WITH BRUSHES FOR CONTACT CONNECTIONS

In addition to the consideration of the framework effect, the separation of the connecting wall-slab is considered separately within this model. Currently this model can only be used in a truss model, where single bars fail due to tension.. Many truss models can already consider this type of bar failure by default (Figure 6). The optional support effect of a flange wall is achieved by a further strut on the outside of the "brush". Dead loads from this flange wall are only active as a backward rotating moment, if the cross section lifts up, whereupon the outer tie rod fails. Otherwise, the dead load will be transferred by this rod directly down to the foundation.

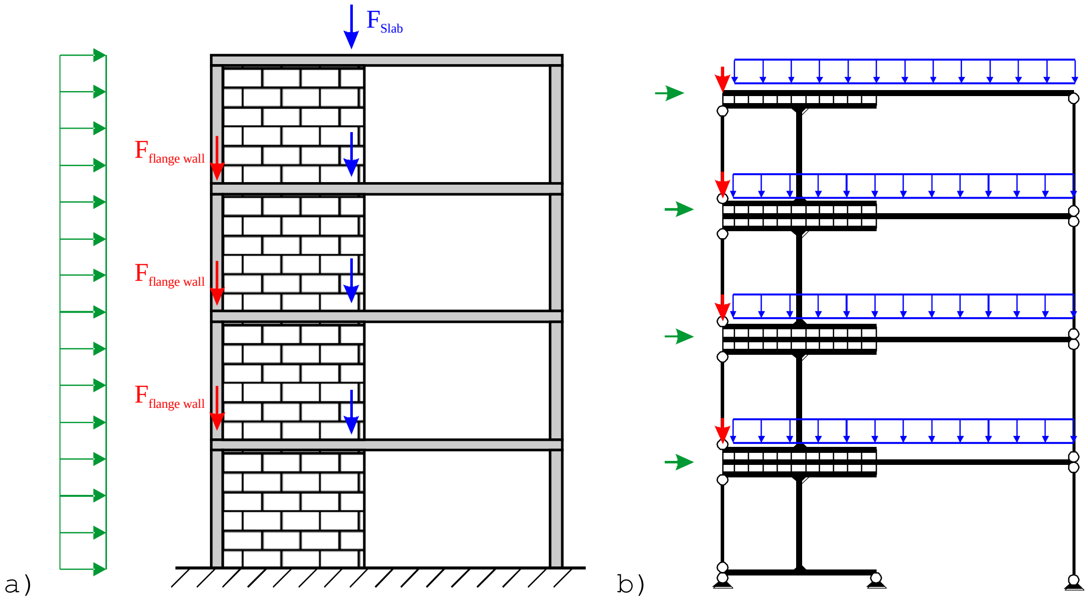


Figure 6: a) Model, b) Structural system with brushes for contact connections to the stiffening wall

Due to the high degree of non-linearity of this model it is not suitable for manual calculation. It requires software for modelling the strut-and-tie structure which supports the failure of tension rods. For the input data, further details of boundary conditions (stiffness of the brush, spacing, length, etc.) are required, if the brushes are not generated automatically. This model includes structural nonlinearities of wall-slab-node, whereby the restraining of the slab can be accurately mapped.

Steps
- determination of vertical and horizontal loads including possible restoring forces,
- entering data (including brush) and perform calculations
- designing the slab for shear forces

COMPARISON OF THE MODELS ON AN INNER SHEAR WALL

The comparison of the different models will be shown on the example of a single-family house (see [3]). In each case, the internal force values from the various models are compared. The calculation of the cantilever requires the supporting forces of the slab.
The load determination of the frame is described in detail in [3]. Figure 6 shows the final loads in vertical and horizontal direction.

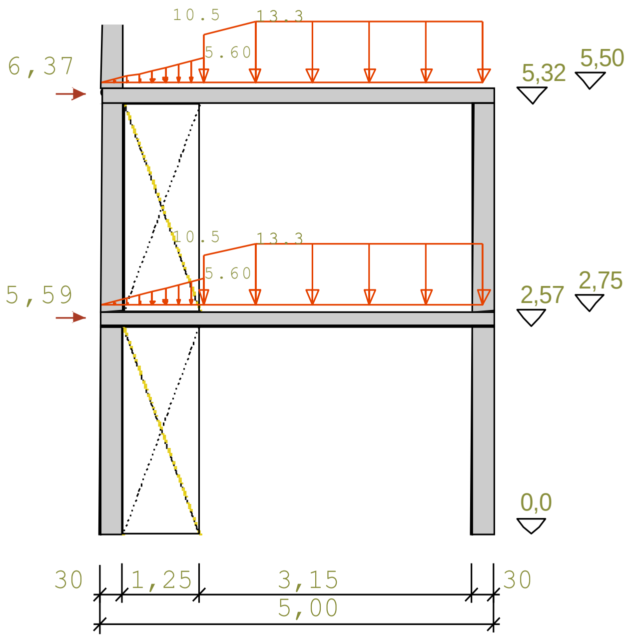
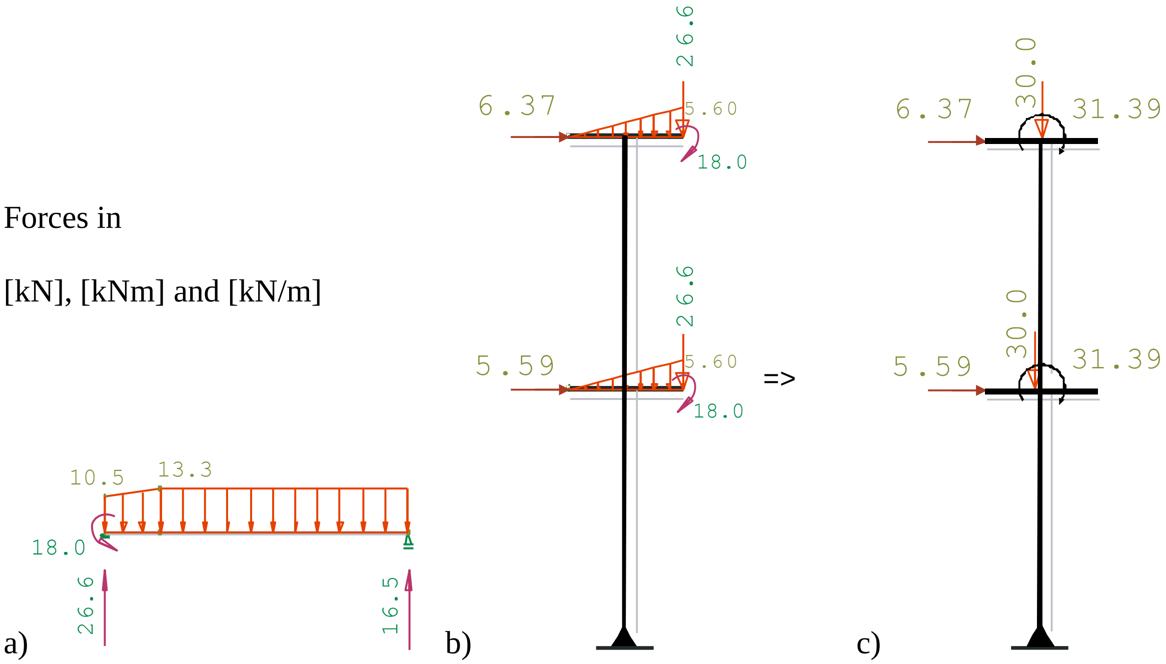


Figure 7: Loading scheme of the whole frame (Load unit [kN] respectively [kN/m]) [3]

USING THE COMMON CANTILEVER BEAM

The cantilever is assumed as fully fixed into the wall, because above the upper floor slab exists a gable and the lower floor slab is loaded by the wall above. The bending moment of the slab, which is restrained at the left could be determined with a value of 18 kNm, see Figure 7a. This bending moment acts on the cantilever in addition to the support load.



Forces in

[kN], [kNm] and [kN/m]

Figure 8: a) Supporting forces from the floor slabs, b) Load on the cantilever beam, c) Transformation into node loads

The restoring forces out of the gable are assumed with a maximum of 23 kN at the upper floor, and 20 kN at the lower floor (see [2]).

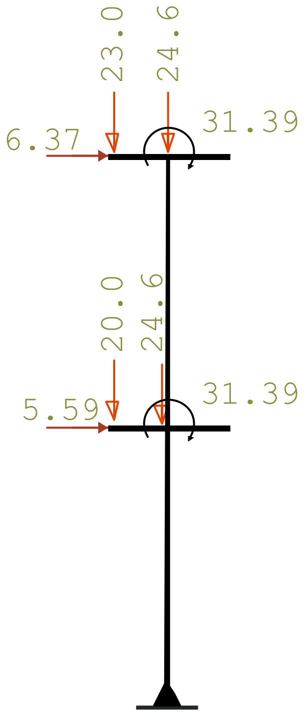


Figure 9: Cantilever beam with restoring force

APPLICATION OF THE FRAMEWORK MODEL

By considering the entire floor frame the deformation of the slab has an influence. The amount of the restraining for the slab is now determined by the node stiffness, which leads to a lower bending moment. Here, the actual fixation of the slab into the wall is considered (but without taking into account the nonlinear behaviour). Thus, this model is more realistic than the simple cantilever beam, where a 100% rigid restraining of the slab was assumed.

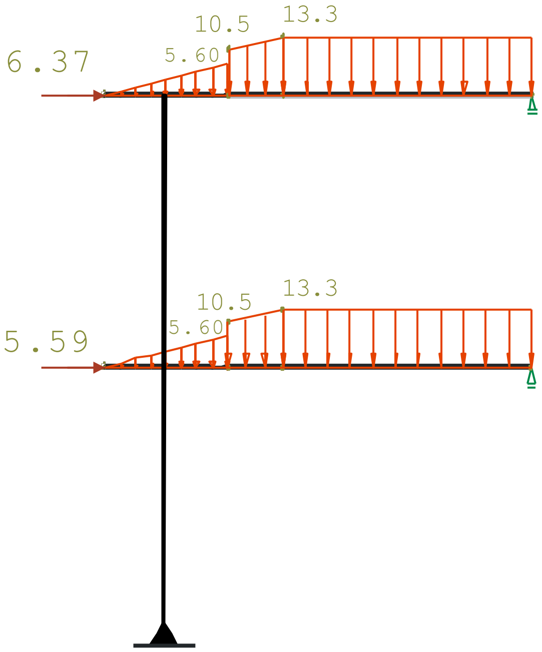


Figure 10: Frame model including shear walls and slab strips

With this model the exact determination of the actual position of the load introduction into the wall is not possible. The node of the model can transfer tensile stresses, which is not the case in a real structure. The cracking of the slab-wall connection is not considered.

USING THE BRUSH MODEL

The brush model can consider both, the restoring forces from the gable and the loading from the slab. Simultaneously bars, which fail due to tensile stresses, can take the exact state of the support area of the slab to the wall (gapping of the "joint" is possible) into account.

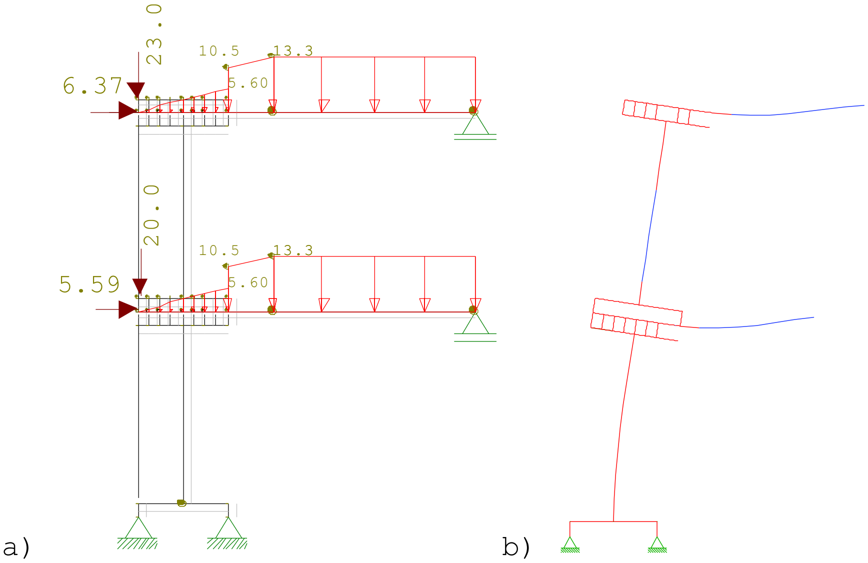


Figure 11: Cantilever beam with brushes a) Model, b) Deformation and failing tension bars

MODEL COMPARISION

Depending on the used model, different values with an enormous variation are achieved.
Figure 12 shows the comparison of the values of several cutting forces for all three different models.

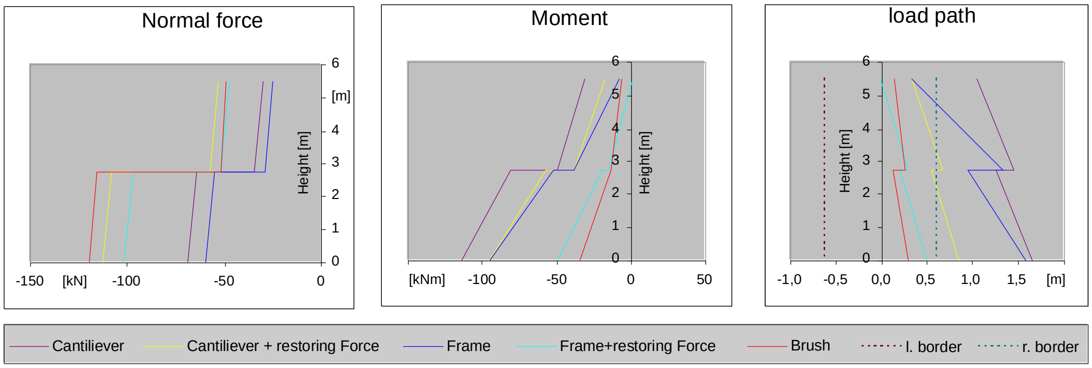


Figure 12: Internal forces due to wind from left in comparison of different models

It is to be noted that in some cases the load eccentricities are close to the cross section border or even outside of it, hence in this case no verification of the shear wall is possible. Strictly, only the models ‘frame with restoring forces’ and ‘brush model’ can satisfy, that the load path remains inside the wall cross section.
By the stepwise activation of the system reserves, the design-dependent load eccentricity is successively reduced in the shear wall. As a prediction for the model closest to the reality, the brush model (according to [3]) is suggested, which can take into consideration the load distribution and nonlinear properties of the entire system.

CONCLUSION

By considering the wind load from the left one achieves results, which are acceptable and useful. Using the common cantilever beam model, the used example cannot be checked in case of wind load because the resultant force is situated outside of the wall. With the enhanced models ‘frame and restoring forces’ and ‘brush system’; the verification condition improves satisfyingly, as the force resultant of the wall is shifted into the cross section.
The enhanced models can achieve better results, which are nevertheless on the safe side. However, both wind directions must consider finding the worst cutting forces for the verification.
Strictly, the cantilever beam model is far away from reality. The enhanced models approach better the reality, but still do not reach the real state of the shear wall. This shows the modelling of the entire building [3] with finite elements with nonlinear material and contact properties.

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