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Seismic design of a multistory reinforced concrete frame structure: Comparison of the effect of conventional brick masonry and advanced dry-walling infill on the seismic response

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Abstract: *In this paper, the influence of the infill in reinforced concrete frame structures on the seismic response of a five story dwelling structure is investigated. The effect of brick masonry infill and dry-walling infill are compared. The structure is modeled by finite beam and plate elements and analyzed by use of the simplified lateral force method according Eurocode 8 [1]. The advantages of dry-walling infill are stated and an outlook on further investigations is given.*

Keywords: Earthquake analysis of reinforced concrete frame structures with infill, comparison of brick masonry infill and dry-walling infill

1 Introduction

The conventional design of multistory dwelling structures are reinforced concrete frames with brick masonry infill. Although the infill panels significantly influence both the stiffness and strength of the structure, their contribution is normally not taken into account. The required strength and ductility of the structure to resist the earthquake loads are attributed to the reinforced concrete frame only. This quite often results in a misunderstanding of the real seismic response of the structure. Especially the conventional use of brick masonry with low ductility for the infill cause a partial stiffening of the structure with local overload of supporting members, which may cause disastrous damage or collapse in case of an earthquake. This effect can be avoided by use of more ductile material like advanced dry-walling infill.

To study the effect of the infill on the seismic response, a medium sized five-story dwelling structure is analyzed with different characteristics of the infill. The structure is designed to withstand an earthquake of high intensity in accordance with the code requirements by negligence of the infill. A 3D-finite element model idealizes the structure. With this model at first the seismic response of the frame structure without participation of the infill is analyzed. Then the effect of the infill on the seismic response is investigated by a parametric study. The requirements on the infill for an adequate seismic design are stated. These requirements are checked for the use of conventional brick masonry infill in comparison to the use of advanced lightweight dry-walling infill.

2 Basic Design of the Frame Structure

A common 5 story dwelling structure is used to demonstrate the influence of the infill on the earthquake response of the structure. The ground plan consists of an U-shaped elevator tower with wall thickness 0,2 m as main stiffening element, 7 rectangular inner columns and 4 L-shaped corner columns, see Fig. 1. The floor consists of reinforced concrete slabs of thickness 0,2 m with additional girders. The design complies with the requirements of Eurocode 8 [1] as medium ductile structure.

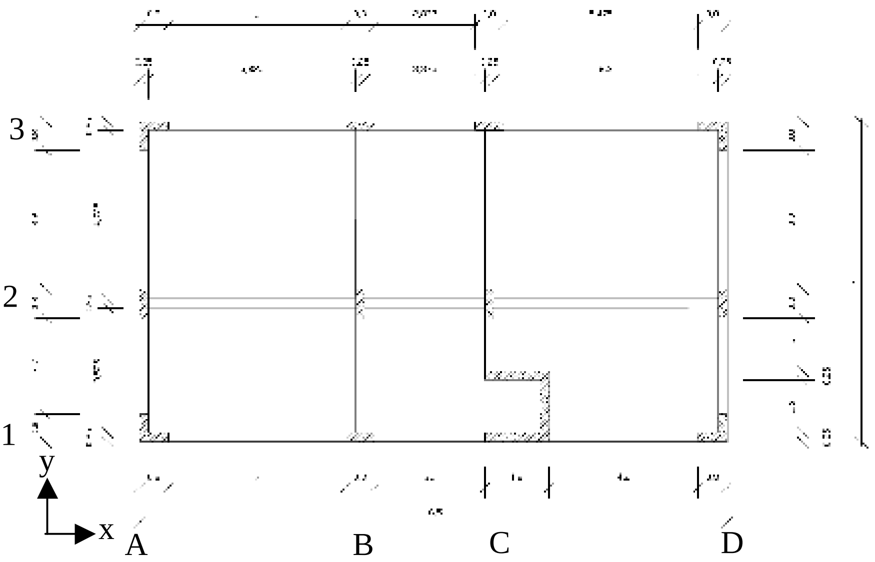


Fig. 1: Ground plan of 5 story dwelling structure

The strength of the structure against earthquake loads is checked in accordance with Eurocode 8 [1]. Only the reinforced frame is regarded for calculation of the stiffness and strength of the structure. The infill walls are taken into account by their masses only. For the analysis a finite element model is developed for the structure with beam elements for the columns and girders and plate elements for the elevator tower and floors, see Fig. 2. The basement as well as the soil-structure- interaction is neglected in this study. The columns are supposed to be clamped in the base plate. The earthquake load is represented by the elastic response spectrum type 2 for a surface magnitude not greater than 5,5 and ground type B according Eurocode 8 [1], see Fig. 3. The design ground acceleration is 2,4 m/s^2.

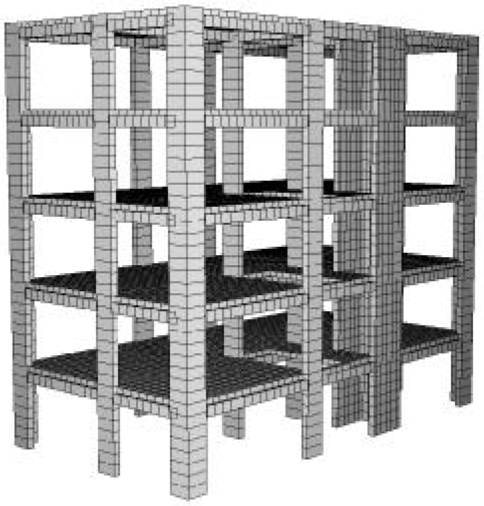


Fig. 2: Finite element model of the structure

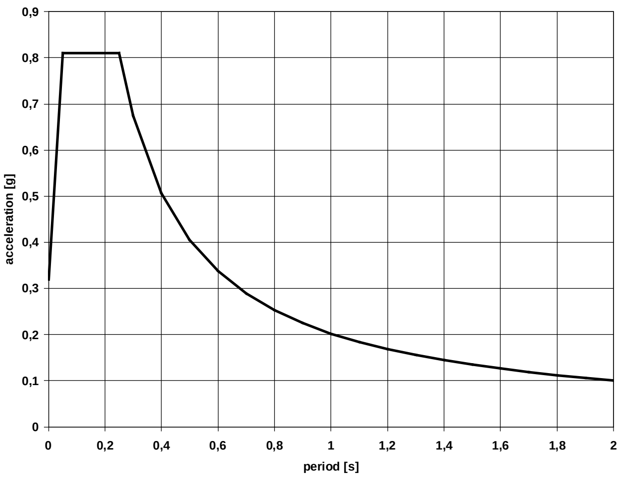


Fig. 3: Elastic response spectrum

The main parameters that control the behavior during earthquake are the fundamental periods and the ductility of the structure. The first three normal modes are shown in Fig. 4. The belonging periods are at 0,42 s, 0,37 s and 0,29 s. These periods are already in the declining branch of the earthquake spectrum. The ductility of the structure is accounted for by the so called behavior factor q. This factor is used to reduce the effective earthquake load. It depends on the type and structural form. A factor of q = 4 is appropriate for reinforced concrete frame structures with medium ductility.

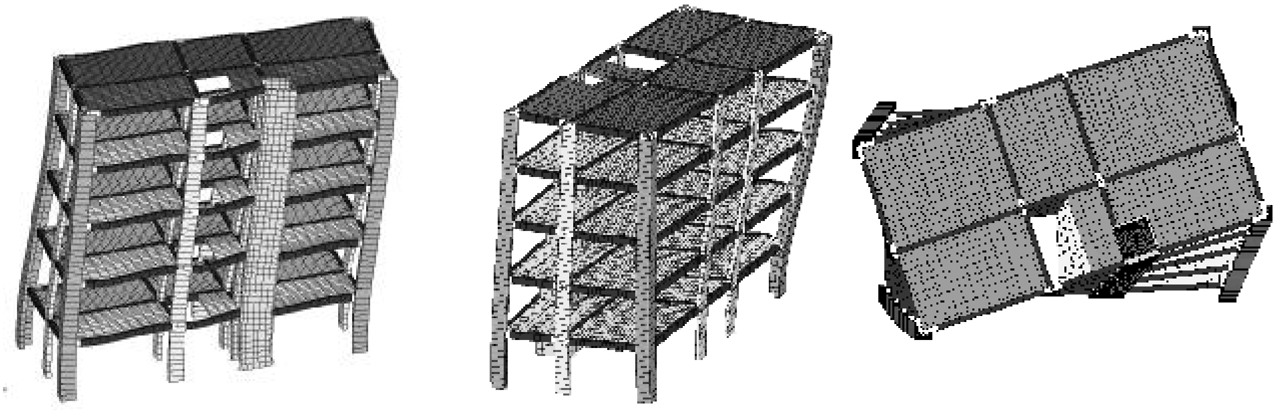


Fig 4: Fundamental modes of the structure

The design of the structure finally is accomplished by use of the simplified lateral force method of analysis, that is the overall horizontal mass forces (base shear forces) are calculated for each direction and appropriately distributed over the height of the structure. The ruling forces for the strength of the structure are the shear forces at the base of the columns and elevator tower. The distribution of these forces is shown in Fig. 5

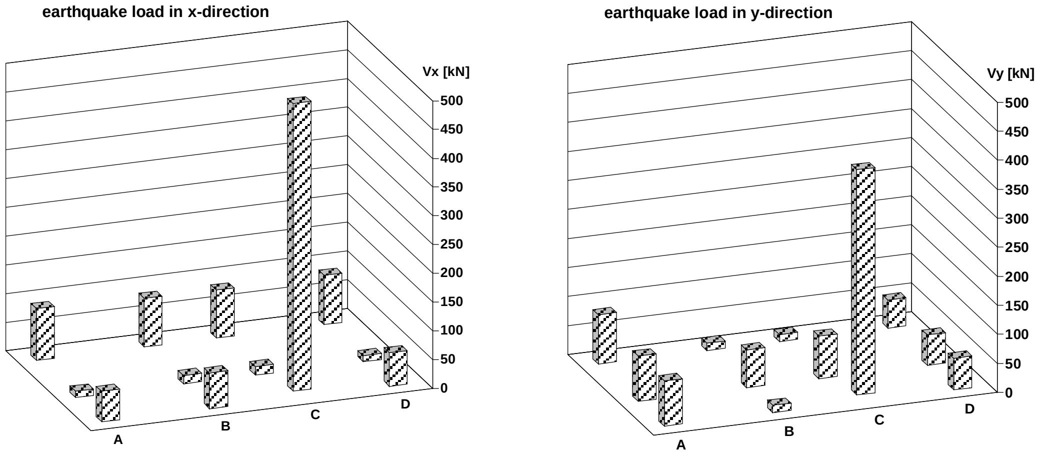


Fig 5: Shear forces at base of columns and elevator tower, reinforced concrete frame only

3 Influence of Brick Masonry Infill on the Earthquake Response

The infill of the reinforced concrete frame will increase the strength of the structure against static loads. The increase of the strength, however, will also increase the stiffness of the structure and lower the fundamental periods. For investigation of the influence of brick masonry infill, the finite element model of the frame structure is supplemented by plate elements for the masonry walls as shown in Fig 6. Only the outer walls are considered for simplicity. Because the masonry walls are installed after completion of the reinforced frame, only the joints at the base to the floors and at the sides to the columns are capable to transmit forces. This is regarded in the model by a gap between reinforced concrete structure and masonry at the top of the walls. Furthermore the transfer of shear forces between the infill walls and the base-mat is omitted.

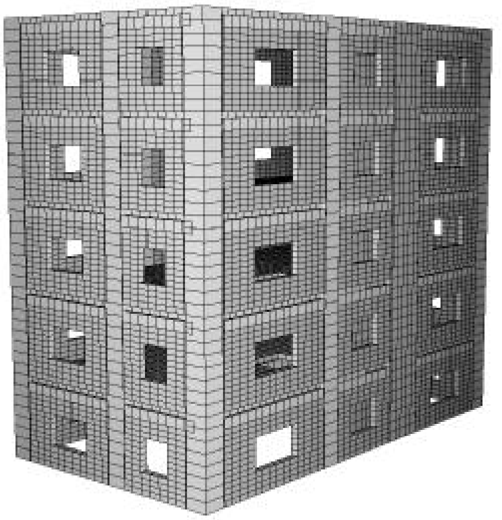


Fig 6: Finite element model of infilled frame structure

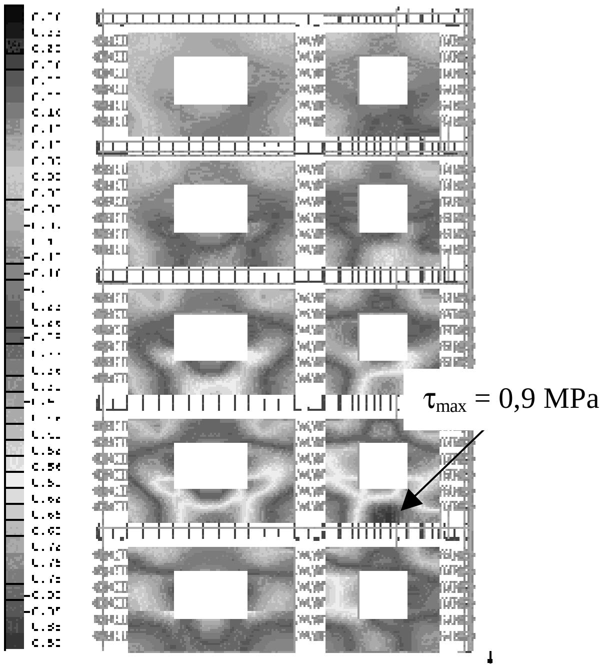


Fig 7: Shear stresses in front wall

The fundamental periods of the stiffened structure are reduced to 0,21 s, 0,16 s and 0,13 s. This causes an enlargement of the earthquake acceleration in the maximum magnification range of the spectrum. An even more serious influence on the dynamic behavior of the structure under earthquake loads is the reduction of the ductility because the brittle masonry walls. The codes in general allow a factor of q = 2 (for unreinforced masonry) to a maximum of q = 3 (for reinforced masonry). As result of these both effects, the base shear force is nearly twice the force as calculated for the reinforced concrete frame alone, see Fig. 8.

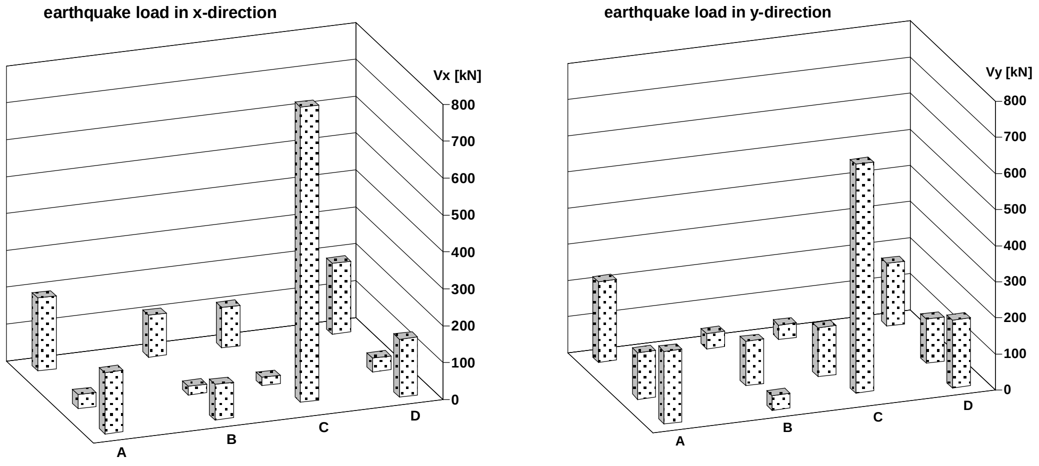


Fig 8: Shear forces at base of columns and elevator tower, stiffening by brick masonry infill

The stiffening of the structure by the infill causes in-plane forces in the masonry walls. The shear stresses of one of the front walls is shown in Fig. 7. The maximum shear stress is 0,9 Mpa, this is far above the allowable shear stress of 0,26 Mpa. A local failure of the wall is anticipated, which may be followed by an overload of the connected columns with total failure of the structure.

4 Advanced Lightweight Dry-walling as Alternative Infill

To avoid the disadvantages of brick masonry infill, it is proposed to use light weight, dry-walling infill. A typical structure of such a dry-walling infill [2] is shown in Fig.9. The major advantages of dry-walling infill are:

- less weight than brick masonry infill; the specific weight of dry-walls is about 20 to 30 % of brick masonry walls. In the present example, the total weight of the structure is reduced to about 75 % of the total weight with brick masonry walls. (However less weight will also reduce the fundamental periods)
- Less stiffness than brick masonry infill; in Fig. 10, the inplane deformations under horizontal shear forces at the top of the panels are compared for typical cases of a brick masonry wall (a) and a dry-wall (b). The stiffness as well as the strength of the dry-wall is much less than that of the brick masonry wall. (The stiffness and strength of the dry-wall depends largely on the type of the connection between wall and reinforced concrete frame)
- larger ductility than brick masonry infill; dry-walling allows shear deformations of several cm without failure, brick masonry walls may fail already at a few mm deformations in a brittle manner.

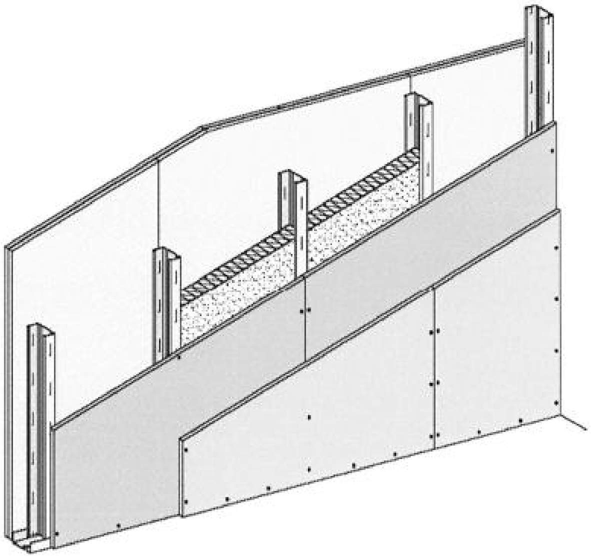
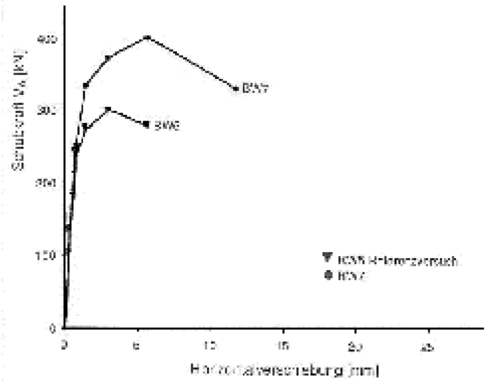
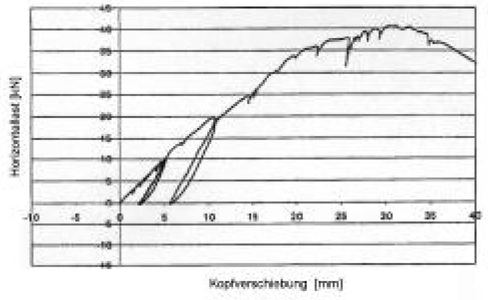


Fig. 9: Dry-walling infill [2]



a) brick masonry infill [3]



b) dry-walling infill [4]

Fig 10: Load-deformation characteristics

The lower stiffness of the dry-walling infill is accomplished in the finite element model by a lower shear modulus (G = 1.000 Mpa for dry-walling, G = 3.200 Mpa for brick masonry) and a smaller thickness (t = 0,025 m for dry-walling, t = 0,24 m for brick masonry) for the plate elements. Because the low stiffness of the dry-walling infill, the earthquake response of the structures approaches the response of the pure frame structure again. The fundamental periods are 0,31 s, 0,29 s and 0,22 s. Because no behavior factors for dry-walling infill are available yet, the factor q = 4,0 like for the pure frame structure is chosen. This is justified, because the earthquake response of the structure is dominated by the reinforced concrete frame. The large ductility of the dry-walling infill may even allow a larger behavior factor. The size and distribution of the shear forces at the base of the elevator tower and columns is nearly the same as for the pure frame structure, Fig 11. The straining forces on the dry-walling infill are low, so that the strength of the dry-walling is sufficient.

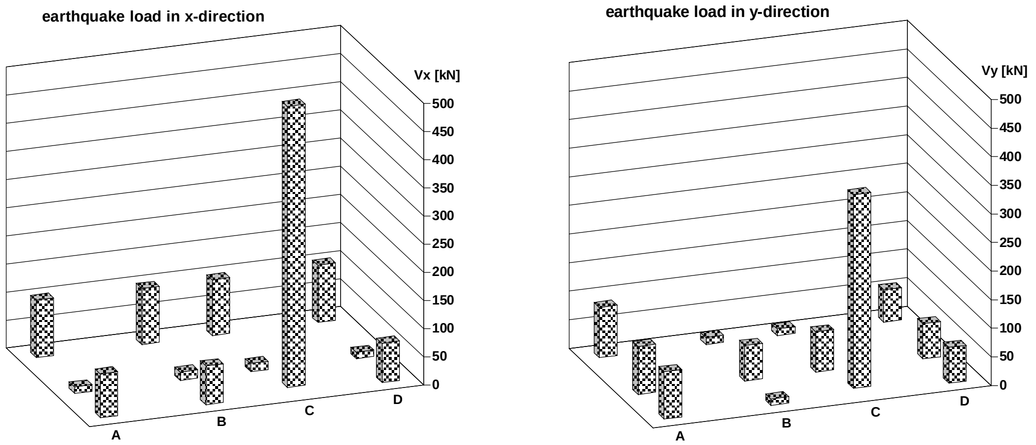


Fig 11: Shear forces at base of columns and elevator tower, stiffening by dry-walling infill

5 Comparison of the Results

In the following table, the main parameters of the structure for the three investigated cases: (1) only the reinforced frame is active, (2) stiffening by brick masonry infill and (3) stiffening by dry-walling infill, are compared. The response of the stiffening by the dry-walling infill approaches the response of the frame alone, while the stiffening by the brick masonry infill results in a much larger base shear.

		frame only	masonry infill	dry-walling infill
total weight [kN]		8013	7842	6020
fundamental periods [s]	x-direction	0,42	0,21	0,31
	y-direction	0,37	0,16	0,29
	torsion	0,29	0,13	0,22
spectral accelerations [m/s^2]	x-direction	4,8	8,1	6,5
	y-direction	5,5	8,1	8,1
behavior factor q		4,0	3,0	*4,0*
base shear	x-direction	961	2117	978
	y-direction	1102	2117	1219

An additional effect of the stiffening of the structure by the infill is a redistribution of the base shear from the elevator tower to the columns. This redistributionis demonstrated in Fig 12, which compares the portion of the shear forces in the elevator tower and the columns in percent of the total base shear. For brick masonry infill, the resulting shear forces in the elevator tower is reduced, while the maximum shear forces in the columns are enlarged. For dry-walling infill, the distribution of the shear forces is nearly the same as for the frame alone.

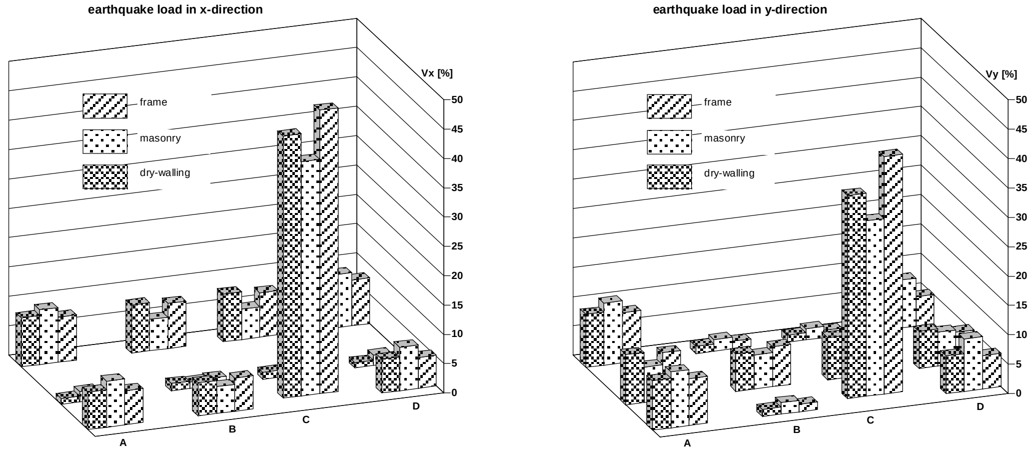


Fig 11: Shear forces at base of columns and elevator tower, comparison of the three systems

6 Conclusions and Outlook

The investigations show, that dry-walling infill is a powerful alternative to brick masonry infill for earthquake safer construction. The advantages are: less weight, less stiffness and larger ductility in particular. The latter attribute, however, needs further experimental and analytical investigations for the appropriate use in earthquake design. The experiments should concentrate on the investigation of the ductile behavior of dry-walling. Special attention must be drawn to the connection between the panels and the reinforced concrete frames. One result of the experiments should be the development of nonlinear force-deformation laws for shear panels under alternating horizontal loads. These force-deformation laws can be used in nonlinear analysis of different kind of structures, either by performance based analysis methods (push over analysis) or by nonlinear dynamic analysis in the time domain.

The scope of the investigations should be the development of behavior factors q as basis for the introduction into national and international earthquake codes.

Acknowledgements

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