Fundamental Rules for Earthquake Resistant Design

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After every large earthquake in any part of the world, field - missions of experts are carried out. Damages are analysed and correlations between damages, structural type, structural materials and quality of workmanship are elaborated. This is done since several decades, resulting in the following fundamental rules. Considering these rules as much as possible will help to reduce the necessary amount of analysis and increase the overall earthquake resistance.

Many of the following figures have a left side (bad solution) and a right side (good solution). Most of the figures are self-explaining.

On this first page the situation of the ground – plan is analysed. L, U and H-shaped cross –sections should not be used in order to avoid stress concentrations in the areas connecting the different sections. It is preferable to provide joints.

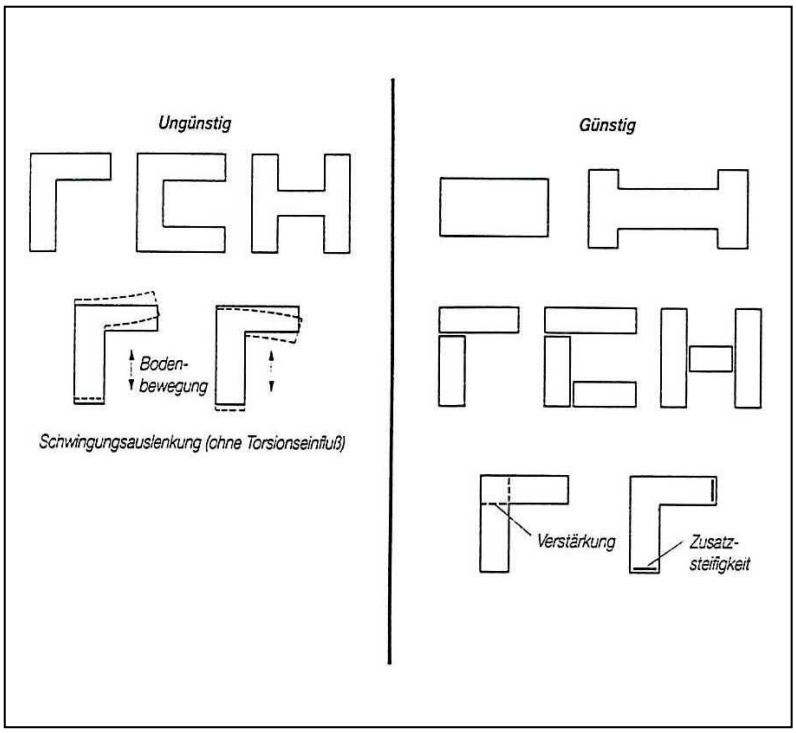


Fig. 1: Bad and good design in ground plan

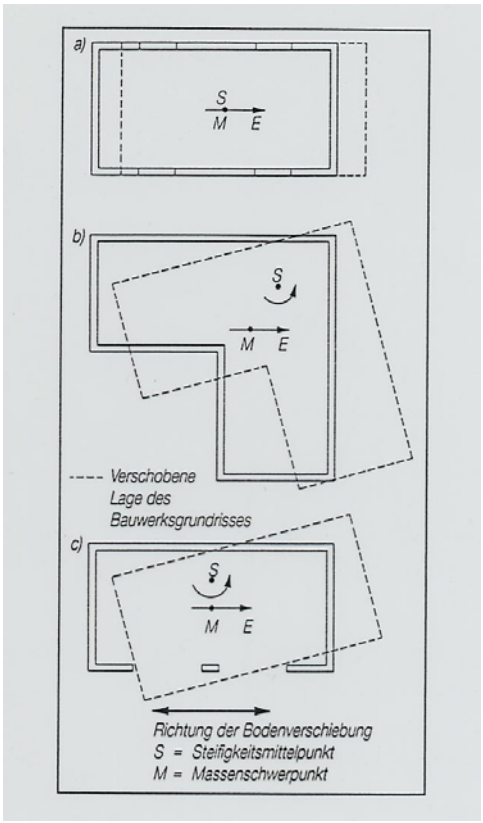


Fig. 2: Problem of eccentricity between center of mass and center of stiffness (of horizontal resisting forces)

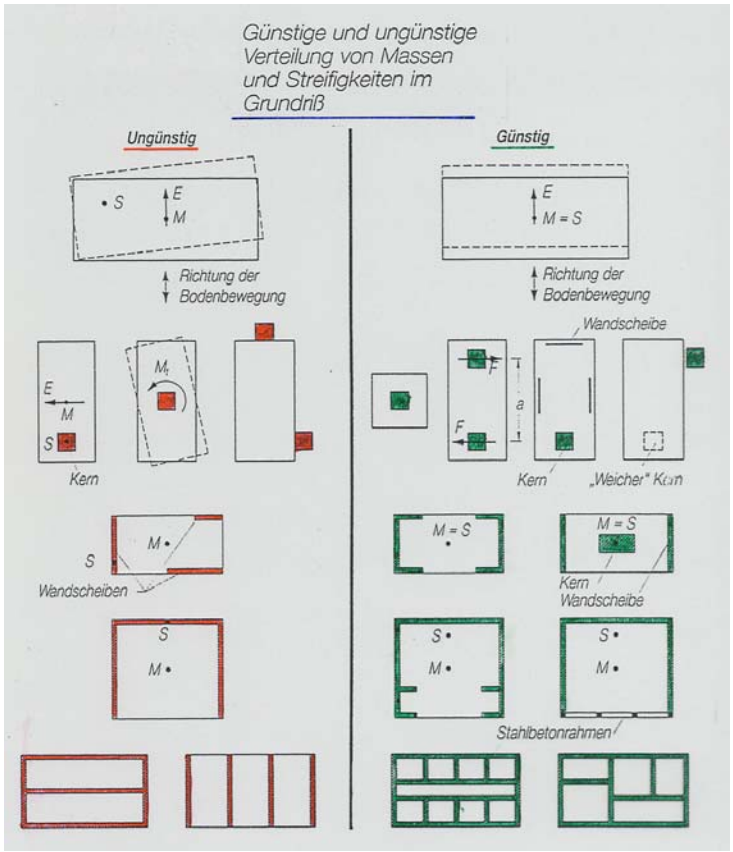


Fig. 3: Distribution of mass and stiffness in ground plan - problem of eccentricity between center of mass and center of stiffness

When a structure is excited by earthquakes it is preferable, that it undergoes only translatorial vibrations. If an eccentricity between center of mass and center of stiffness exists, also torsional vibrations about the vertical axis will occur, which is a very undesirable situation. In „real“ buildings, there will be always some eccentricity, but it should be kept as small as possible.

Fig. 3 and 4 analyse the situation in elevation. The following main conclusions can be drawn:

- There should be no large masses at the top of a building
- It is advantageous to reduce mass (and stiffness) towards the top steadily
- There must not be large differences of stiffness and strength between the single floors, which creates weak floors. It is evident from many earthquakes, that weak floors lead to heavy damage or even collapse
- Also in elevation irregular shapes should be avoided. Sections with different height should be seperated by adequate joints
- The vertical load bearing elements should run continuously between top and foundation. If a column ends at a horizontal beam or slab at a certain storey level, it is necessary to consider the „specific“ vertical excitation of the building - section above.

In general, it is advisable to take into account the „fundamental rules“ as much as possible. This will decrease the necessary amount of analysis and increase the overall earthquake resistance of the building. But by the use of mechanical energy dissipating even a „bad geometric layout“ in elevation could be „turned“ to a satisfactory solution, eg in the case of two adjacent buildings with different heights and a too small joint – wide in between, a damping device could be installed, making use of the different horizontal displacements of both structures.
In the case of a heavy upper floor (or any heavy mass at the top) one could consider to design it as a „tuned mass damper“.

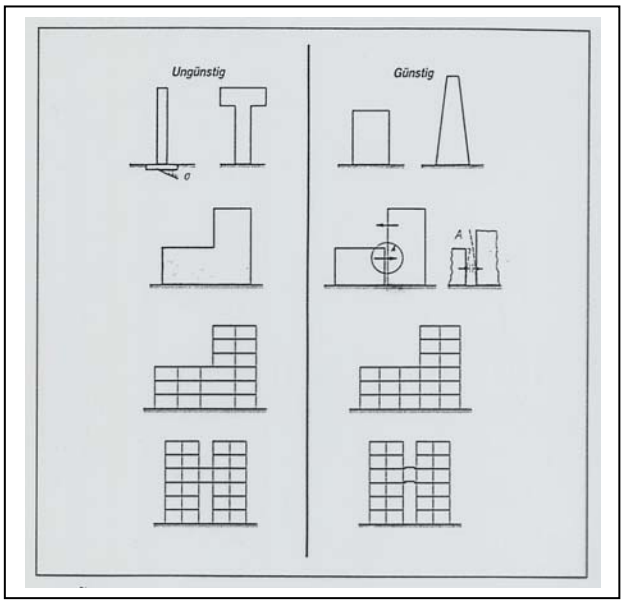


Fig. 4: Bad and good geometrical design in elevation

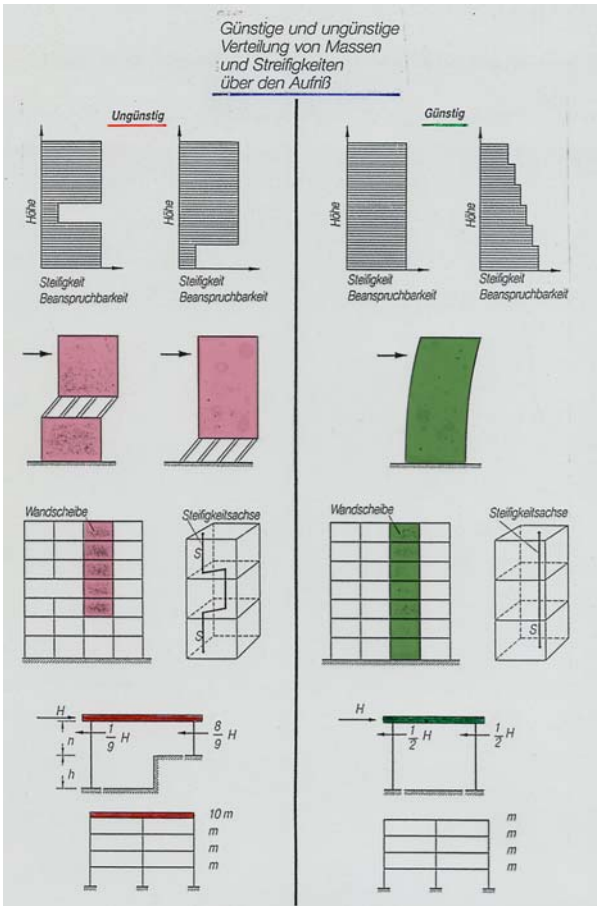
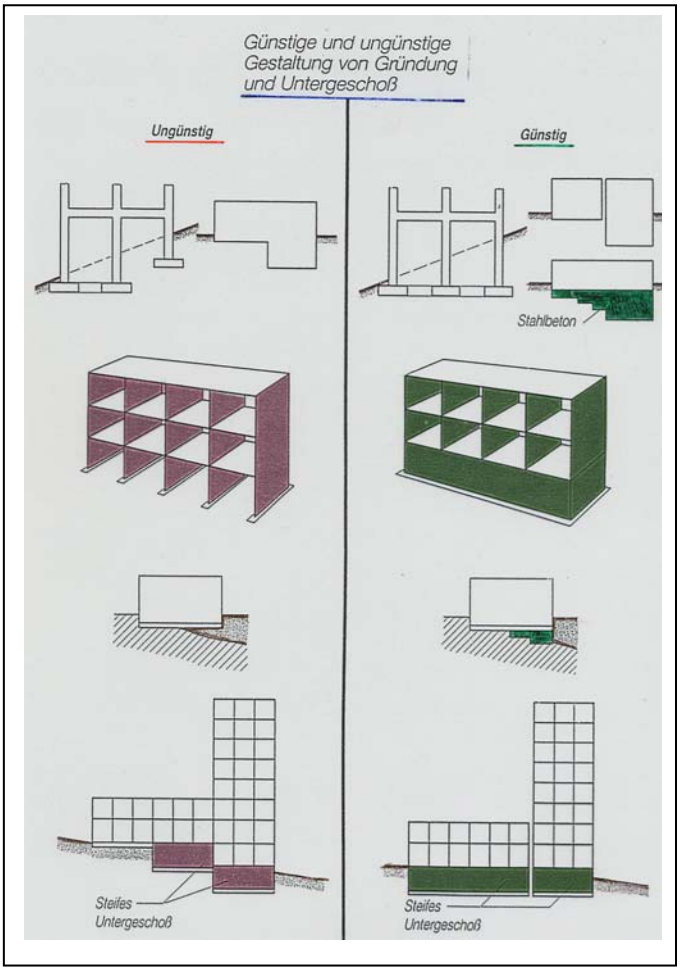


Fig. 5: Bad and good distribution of stiffness in elevation



A good earthquake resistance starts with an adequate foundation (see Fig. 6). The best solution is a rigid box, which produces unique movements at the base, which is good for the distribution of the horizontal loads.
It must be avoided, that foundations of a building lie at different heights or directly on different soil types.

Fig. 7 demonstrates the importance of the floor slabs as load distributing and horizontally stiffening elements. There should be an unique horizontal floor level running over the whole ground plan. The number of holes in slabs and their total area should be kept as small as possible.

Fig. 6: Bad and good design of foundations

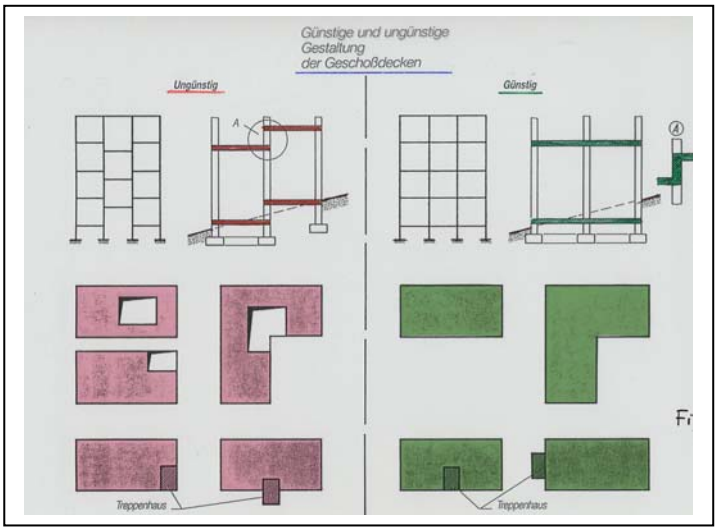


Fig. 7: The importance of floor slabs as load distributing and horizontally stiffening elements