Zu Ber. Nr. 2183

Summary
of the
Research Project
"Avoiding of Crack Damages in Masonry - and Reinforced Concrete Buildings"

The aim of the research project is to give to the common user in civil engineering some help in recognizing the weak points of a building and in avoiding crack damages in masonry and reinforced concrete buildings. Therefore, the possible causes (shrinkage, temperature, etc.) have to be shown. Simple calculation methods and rules for construction must be given.

First, all main crack damages known from literature and from own experiences are collected. Then, the causes of these crack damages are examined. For some of these causes calculation methods are developed. Simple rules of construction are derived from these methods. Some well-known rules are explained.

Cracks appear under tensile forces by exceeding a certain deformation. The main causes are elastic deformations, deformations caused by creep, shrinkage and differences in temperature. They can produce linear expansions or deflections. The magnitudes of these causes are dependent of the material.

<u>Cracking caused by rotation at the end support:</u>
Cracks in outer walls, which arise from the rotation of slabs at the end support, can be rendered harmless with certain preventive constructional actions. The limitation of the slenderness ratio, l_i/h, to 25 for roof slabs, given by Pfefferkorn, is verified. In addition, cracking in the slabs during the serviceability state should be avoided.

The calculation shows that the crack width mainly depends on the deflection of the slab. By avoiding the cracking during the serviceability state, a strong increase of the deflection can be prevented. Rules for the construction, some of them originating from Pfefferkorn, are the following ones:

- A thin foil with a softening band at the inner side of the wall should be placed between the outer wall and the slab. In this case a ring beam is not necessary.
- Protecting the crack by a fascia board
- If a slide bearing becomes necessary, a ring beam should be put in place. The cross section of the ring beam should be as small as possible.

<u>Cracking caused by uplifting corners of slabs:</u>
To avoid crack damages arising from uplifting corners of slabs, a slenderness ratio of $l_i/h = 20$ should not be exceeded. In addition, cracking in the slab during the serviceability state should be avoided.

For the crack width, the elastic part and the creep part of the uplifting corner is dominant. The elastic part is taken from the literature for different kinds of surrounding supports of the slab. The creep part is simply fixed. With a sufficient heat insulation on the outer side of the roof (as foreseen in the Wärmeschutzverordnung), an increasing of the crack width caused by a temperature gradient can be neglected.

A stiffening at the edges of the roof (fascia) is not recommended because the possible temperature gradient in the stiffening beam can increase the crack width at the uplifting corner. A reentering corner should be regarded carefully, in some special cases softening bands have to be used (Figs. 1 and 2).

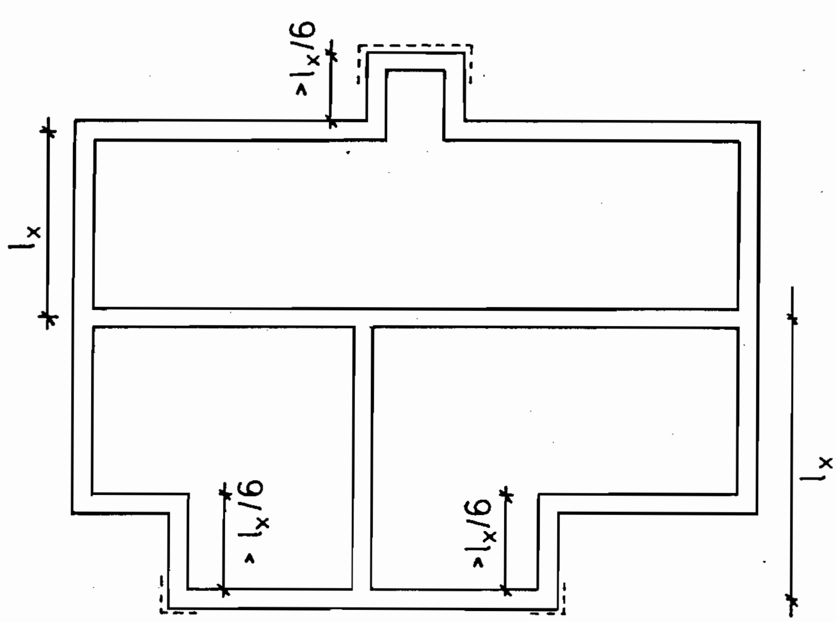

Fig. 1: Possible cracking in case of reentering corners

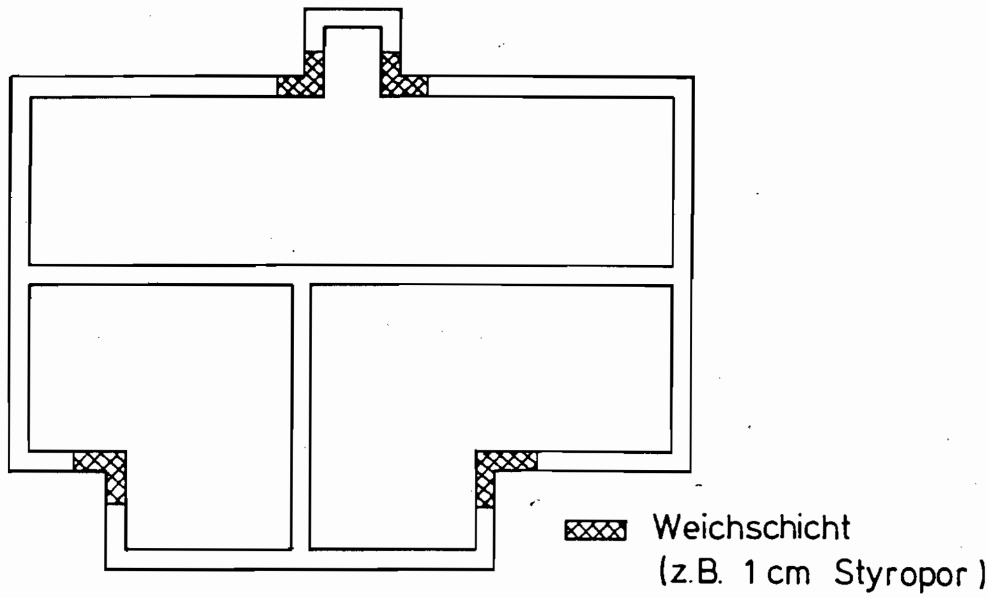

Fig. 2: Softening bands to avoid cracking in case of reentering corners

<u>Cracks in buildings with mixed masonry:</u>
In the case of different masonry within one floor, cracks caused by the difference in deformation between the two kinds of masonry may appear. If the masonry of the outer wall for example consist of leight-weight bricks and the inner wall of chalky sandstone (case A), then inclined cracks as shown in Fig. 3 can appear. The crack width increases in the upper floors.

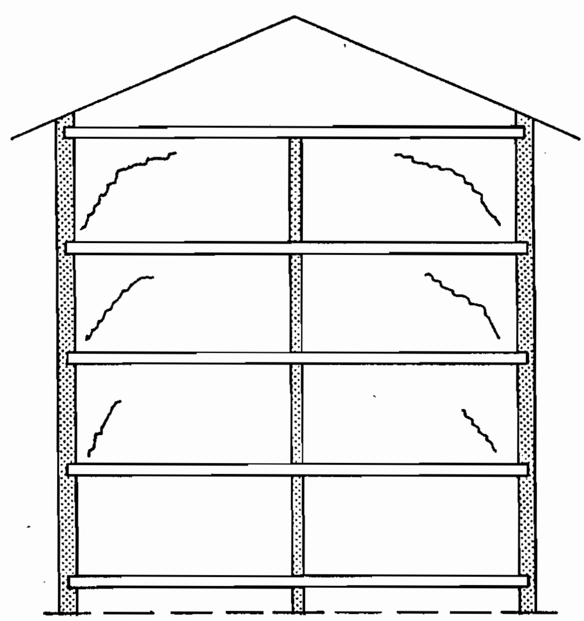

Fig. 3: Crack in a multistorey-building with higher shrinkage of the inner wall

In the opposite case (case B), if the masonry of the outer walls has a higher shrinkage, then cracks can appear in the outer walls, in most cases horizontal between the windows. In addition to the shrinkage, further deformations of other causes are possible. The calculation methods for case A presented by Schubert and Wesche [1] are discussed. From this discussion a new calculation method was developed. The method is based on the elastic membrane-theory. The calculation was made with a finite element program.

In the calculation, the height of the wall and the stiffness ratio between the inner and outer wall are varied. It was observed that the cracks are mainly caused by shrinkage and temperature deformations. Differences in the deformations caused by creep are negligible. For the simple determination of the safety against cracking, the tensile action in the wall inclusive the relaxation can be obtained by a given diagram (Fig. 4).

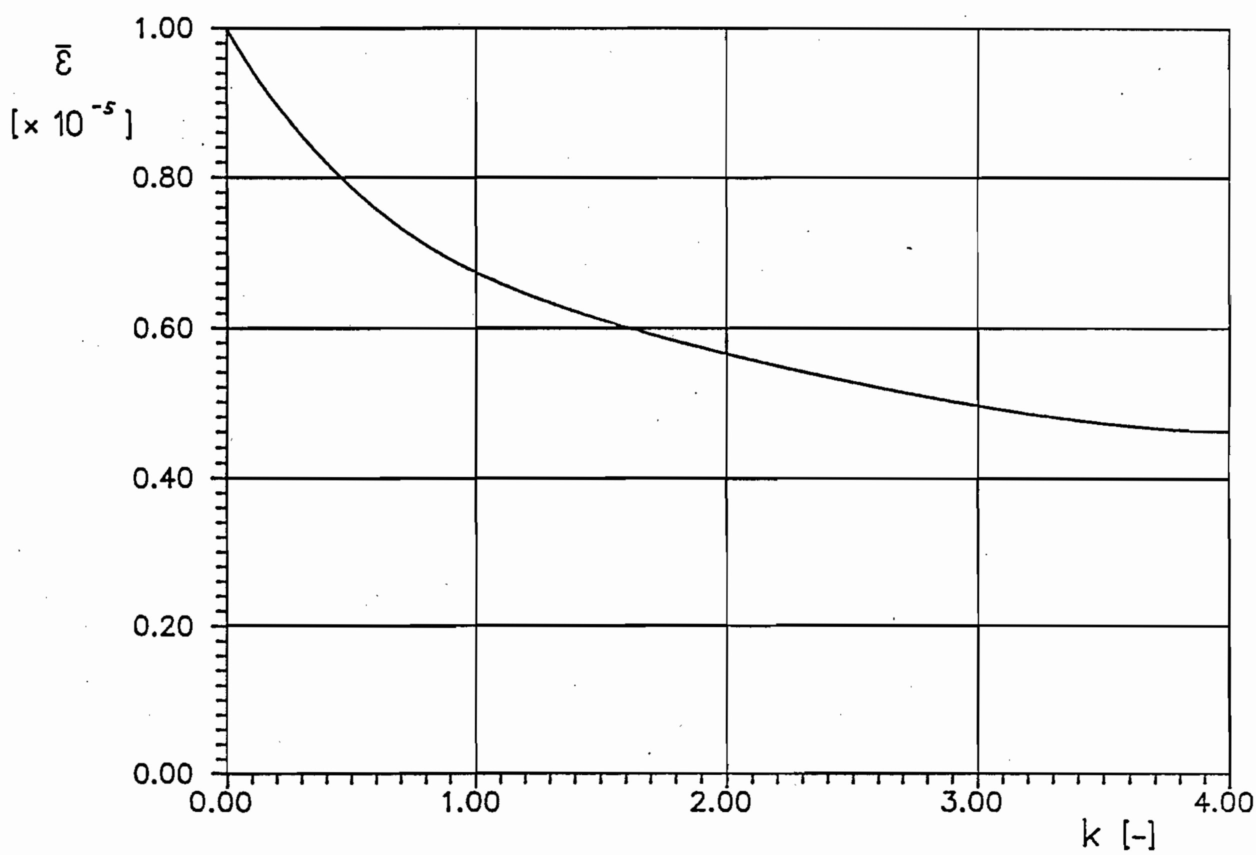

Fig. 4: Diagram for the determination of the maximum vertical restraint caused by differences in shrinkage or temperature

Basic example: The stiffness ratio between the inner and outer wall with the consideration of the relaxation, k = 1,78, and the difference in shrinkage between inner and outer wall, $\Delta \epsilon_S = 0{,}20\ ^o/_{oo}$. From Fig. 4 the tensile strain of the inner wall in the upper floor can be derived as $\epsilon_{I,S}^{DG} = 20 \cdot 0{,}0058/(1+0{,}8 \cdot 2{,}0) = 0{,}045\ ^o/_{oo}$. The factor $1/(1+0{,}8 \cdot 2{,}0)$ takes into account the decrease of the stress due to relaxation. For a temperature difference the procedure is the same, but the effect of relaxation can not be taken into account. From this total restraint, the elastic part of the strain has to be subtracted. In order to determine the safety against cracking, the remaining value must be compared with an admissible value of the strain. For the admissible value of the strain $0{,}2\ ^o/_{oo}$ is proposed by the authors.

The conclusions for the constructions are:

- in the case of cracking in the inner wall (higher shrinkage of the inner walls):
  - taking masonry with little shrinkage or seasoned stones, especially in the upper floors.
  - soft outer wall (EA small) and stiff inner walls (EA big)
  - high loading of the inner wall
  - late plaster work
- in the case of cracking in the outer wall (higher shrinkage of the outer walls):
  - taking masonry with little shrinkage or seasoned stones, especially in the upper floors.
  - stiff outer walls (EA big) and soft inner walls (EA small)
  - high loading of the outer walls
  - late plaster work

<u>Cracking caused by differences in strain between the roof slab and masonry walls:</u>
Differences in the strain between roof slabs and masonry walls can produce vertical, horizontal, and diagonal cracks in the walls. By exceeding some certain limits, which are given in DIN 18530, slide bearings have to be installed between the wall and the roof slab. Slide bearings should be avoided as far as possible in favour of a thin foil to separate the wall from the roof slab.

Vertical cracks can appear, if the masonry has a higher shrinkage than the concrete of the neighbored slab. A high cooling of the outer wall increases the risk of cracking. Horizontal and diagonal cracks are caused by strain differences between the roof slab and the outer wall due to shrinkage and temperature.

Cracks in partitions:
Crack damages in partitions are described in the literature only for long spans where the additional limit $l_i/h < 150/l_i$ (DIN 1045) was not considered. This additional limit seems to be sufficient in the authors opinion because the cracking in partitions mainly depends on an absolute value of the deflection of the slab and not on the slenderness ratio. A comparison between the simplified methods according to DIN 1045 and EC2 is shown in Fig. 5.

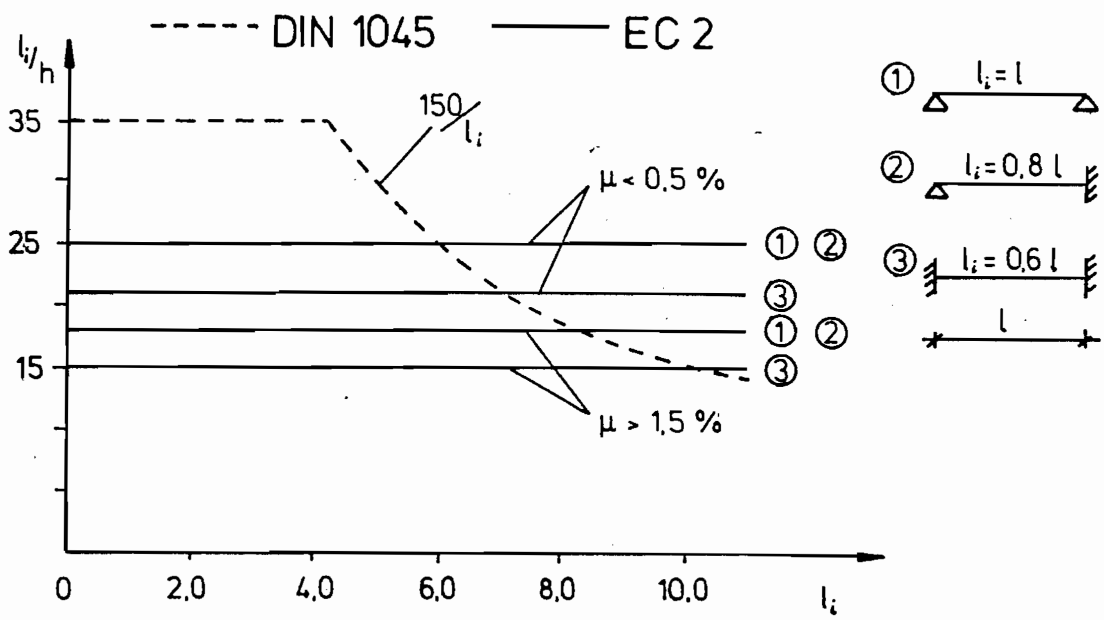

Fig. 5: Comparison of the slenderness ratios according to DIN 1045 and EC 2

Limit state of cracking for reinforced concrete:
In Annex A the bases of the crack width control are listed for simple use. The actions arising from load, restraint, or a combination of both are calculated separately from the calculation of the crack width. Clause 6 gives some explanation of Annex A.

Restraint in reinforced concrete members:
In the final clause, some special problems concerning restraint in reinforced concrete are treated. The examples chosen should help the designer to recognize restrained members and to show some possible calculation methods for the determination of restraint.

Membranes, which are restrained on one side, are treated with the example of a wall on a foundation. The restraint is mainly caused by the loss of hydration heat. But also shrinkage and later differences in temperature are possible causes. Proposals for the determination of the reinforcement, especially for thick walls, and their distribution in the member (Fig. 6) are given.

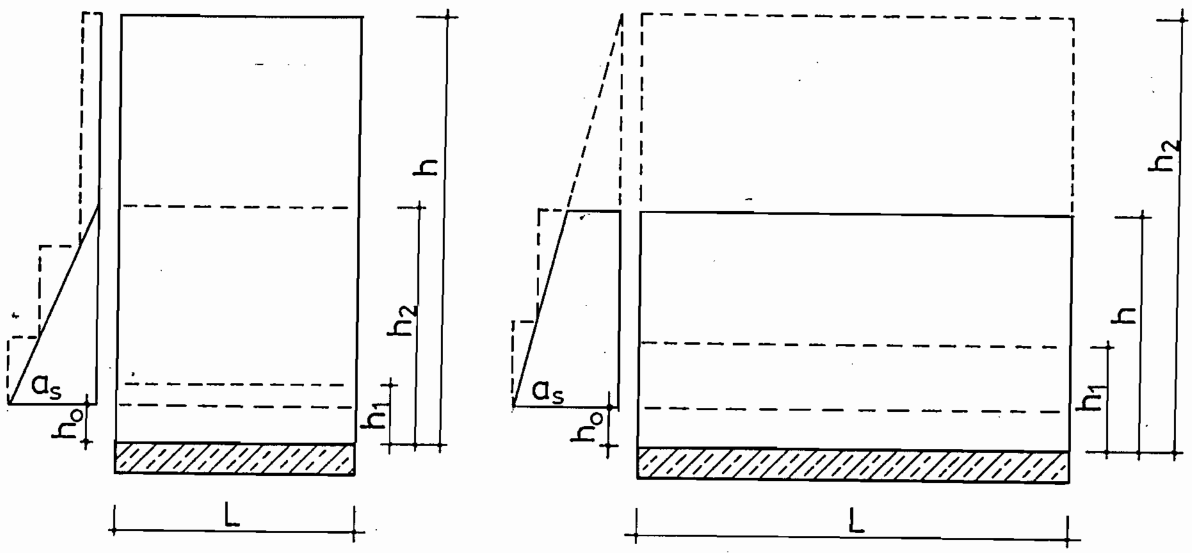

Fig. 6: Arrangement of the reinforcement for short walls
a) up to $h_1/L = 0,25$: 100 % of the calculated reinforcement
b) graduation up to $h_2 : L = 1$
c) above $h_2 : L = 1$ only a reinforcement according detailing rules is necessary
d) Up to h_0 no reinforcement is needed

In a second example a long jointless building is considered. The restraint depends on several possible deformations, the main ones being:

- deformation of the slabs with respect to cracking
- elastic deformation of the staircases, possibly increased by cracking
- creep deformations at the staircases
- deformations caused by an elastic restraint of the foundations for the staircases
- deformations of the ground under the building

[1] Schubert, P., Wesche, K.: Verformung und Rißsicherheit von Mauerwerk. In: Mauerwerk-Kalender 1982, Ernst & Sohn, Berlin 1982