Corrosion Control in Reinforced Masonry

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Much research work and many practical applications have proven in the last decades the favorable behavior of reinforced masonry. Nevertheless, there are some questions about the requirements necessary to ascertain a reliable and durable corrosion protection of the reinforcement, embedded in masonry joints. In this report, an example of the long time performance of a partially reinforced masonry structure is presented. The following proposals for corrosion protection of reinforcement are based on experimental investigations into the corrosion behavior of masonry reinforcement.

To study the favorable influence of reinforcement in masonry structures on the crack development in an exterior wall during service, a 3 - story apartment building made of masonry with lightweight concrete hollow blocks was constructed in the years 1957 to 1958, using steel reinforcement in the bed joints in the first joint below the window openings. Two types of reinforcement were applied: smooth steel bars, diameter 8 mm with end hooks and welded wire fabric , wire spacing 50 mm, diameter of the wires 3 mm. Figure 1 shows the two types of reinforcement and Fig. 2 illustrates the placement in the wall section.

The investigation of the crack development due to external loads, shrinkage and creep deformations after 18 and 36 months of service showed that reinforcement in one mortar joint below the window openings reduced the crack development substantially, thus contributing to the integrity of the wall /1/.

In the course of renovation, this building was revisited in 1980 and a third study of the crack development after longterm exposure to service conditions could be conducted. Furthermore, the corrosion behavior was investigated by inspection of the reinforcement.

Crack development in the exterior wall

In order to quantify the crack development of a wall section, the vertical projection of the surface cracks and the maximum crack width for each crack were measured in all wall sections with window openings. For each window opening a characteristic value was calculated through the summation of the vertical crack projection multiplied by the crack width for each crack observed, thus yielding a total crack area for each window R:

$$R = \text{vertical projection of crack} \times \text{crack width} \quad [mm^2]$$

The results of this investigation together with the results from the two preceeding studies in 1959 and 1961, are summarized in Fig. 3. (First floor).

These results showed a substantial increase of R with time. From thus we may conclude that there was a considerable increase of deformations in the exterior walls even after the second inspection in 1961, due to longterm creep deformations and most likely due to differential settlement of the foundations. Window openings with welded wire fabric showed much lower values of R than window openings without reinforced mortar joints. Wall sections with window openings, where 2 smooth rebars, diameter 8 mm, were applied, did not perform as favorable as wall sections with welded wire fabric. However in most cases, a reduction of the crack development was observed as well.

Corrosion behavior of the reinforcement

In order to inspect the corrosion behavior of the reinforcement, the surface finish of the wall was removed and the reinforced bed joint was opened up to the mid section of the wall.

In all cases, the surface of the reinforcement was covered with a thick layer of rust, penetrating several millimeters into the joint mortar. A microscopic examination of the remaining steel diameter showed in an extreme case a reduction of the cross section by 43 percent (Fig. 4). When phenolphthalein was applied to the mortar, no indication of a high alkalinity of the mortar could be observed. The corrosion protection of the reinforcement in an alkaline environment was lost due to carbonation of the joint mortar.

Laboratory tests on the building materials used, showed that the applied exterior surface finish had only a low resistivity to CO_2-diffusion into the interior sections of the wall. A chemical analysis of the joint mortar indicated a low content of cement and lime, so that in combination with a very high porosity of 42 percent, the carbonation of the mortar could proceed rapidly, leading to an early corrosion attack on the reinforcement. /2/

Experimental investigation of the corrosion behavior of joint reinforcement.

In experimental studies carried out in context with research work for the formulation of the new German Standard DIN 1053 - Part III Reinforced Masonry, the corrosion behavior of steel reinforcement embedded in masonry joints was investigated. In the first part of the experimental work, the corrosion protection of the reinforcement was investigated in masonry units, meeting the requirements according to DIN 1053 - Part I.
The results obtained proved the above mentioned requirements not to be sufficient for a longterm corrosion protection of a steel reinforcement, due to a rapid carbonation progress in the mortar joint, which was mainly caused by a high CO_2-diffusivity of the cement mortar itself. (Cement : sand ratio = 1 : 4 by volume)
Also, masonry units with low compressive strength could not exhibit a sufficient CO_2-resistivity, so that considerable amounts of CO_2 could penetrate the bricks and cause a carbonation progress in direction of the minimum joint extension, i.e. the height of the bed joint /3/.

Proposals for corrosion protection requirements

Further experimental investigations were directed towards a more detailed formulation of measures for corrosion protection of the reinforcement. Two different approaches appear to be promissing:

1. The progress of carbonation has to be restricted, so that the reinforcement is always embedded in mortar of high alkalinity.

2. The reinforcing steel itself is protected against corrosion.

Dense, high strength building materials

The progress of carbonation of the mortar joint is controlled by the diffusion of carbon dioxide into the mortar. Because the diffusion depends on the presence and the amount of continuous capillary pores in the matrix, an increased carbonation resistance of the mortar can be accomplished by a reduced water cement ratio, which determines the amount of continuous capillary pores.

Experiments on 20 different mortar mixes with water:cement ratios ranging from 0.5 to 1.0 were carried out. The tests showed, that masonry mortars with a low w/c-ratio and therefore with a low CO_2-permeability can be made. However, sufficient workability can be obtained only through an increase of the cement content. Table 1 shows the composition, compressive strength and the experimentally determined diffusion coefficients for CO_2-diffusion for 5 different mortar mixes.

The investigation of different mortar mixes indicated, that favorable mortars for reinforced masonry should have a cement:sand ratio of 1:2.5 to 1:3 by volume. The water:cement ratio should not exceed 0.75 for ordinary portland cement (OPC).
The use of such dense, high strength mortars is favorable, however, only in combination with dense high strength masonry units with a high resistivity towards CO_2-diffusion, so that a CO_2-transport through the bricks is strongly restricted, and no carbonation progress in the vertical direction takes place in the reinforced bed joint. E. g. clay bricks and sand-lime bricks with compressive strengths > 28 MN/m^2 meet this requirements. The minimum mortar cover of the reinforcement towards the surface of the wall should be at least 40 mm.

For high strength masonry, where the thermal insulation properties of the masonry itself are not the primary parameters for material selection, the use of these building materials with superior quality appears to be promissing.

Cement based plaster with low porosity

An extensive carbonation of the mortar joint can be prevented, when the masonry is protected against the carbon dioxide from the surrounding atmosphere by means of an apropriate surface finish on the entire structure. Cement based plasters of sufficient thickness can limit the carbonation attack to the surface finish itself. However, this requires a composition of the surface finish comparable to the mix proportions of the dense, high strength masonry mortars. Thus the water:cement ratio should be limited to 0.75. A thickness of the surface finish of at least 20 mm seems necessary.

Impermeable coatings

Modern lightweight building materials for housing projects need improved thermal insulation properties which are often achieved by means of a high porosity of the material. Such materials cannot effectively restrict the carbon dioxide diffusion. In order to prevent CO_2 penetration into the interior of the masonry, special surface coatings with very high resistivity to CO_2-diffusion can be applied to the surface of the wall.
Two of these epoxy-based coatings, which are normally used in the repair of reinforced concrete structures, were investigated. In the diffusion experiments, no CO_2-penetration was observed. Thus, these surface coatings, which are almost impermeable for CO_2, can provide a carbonation protection for mortar joints in porous lightweight structures.

Coated reinforcement

In all cases, where dense, high strength building materials cannot be used and where suitable surface finishes are not provided, additional means for corrosion protection of the reinforcement are necessary.
Corrosion resistance of steel reinforcement can be accomplished e. g. by durable coatings. Galvanized steel or organic coatings, as they are applied to reinforcement for expanded lightweight concrete, can provide a reliable corrosion protection, however all coatings should be applied to the prefabricated bars, because subsequent bending may crack the coatings.

When corrosion protection of the reinforcement is provided by durable coatings on the surface of the steel, no special requirements for the quality of the other building materials with regard to corrosion protection is necessary. Reinforced masonry can be designed also with modern lightweight building materials with improved thermal insulation properties.

Reinforced masonry structures, exposed to severe service conditions - for example where corrosive ions such as chlorides or sulphates etc. are present, may need a combination of the above mentioned requirements for a sufficient corrosion protection.

Summary

In the case of a 3 - story apartment building, the beneficial influence of a joint reinforcement on the crack development in the surface of the walls was demonstrated. However, due to the high porosity of the building materials used, no long term corrosion protection of the reinforcement was provided, so that all reinforcement showed corrosion attack.
Requirements for a durable and reliable corrosion protection of the reinforcement, embedded in masonry mortar should consider the quality of all building materials used.
Plain reinforcement can be applied only, when dense, high strength masonry mortars with limited w/c - ratio are used in combination with dense masonry bricks. A minimum mortar cover of 40 mm appears reasonable.

Apropriate cement based plasters on a masonry structure can contribute to the corrosion protection of the reinforcement in preventing carbonation of the mortar joint.

When durable coatings are applied to the reinforcement, the corrosion protection is independent of the quality of the building materials.

References

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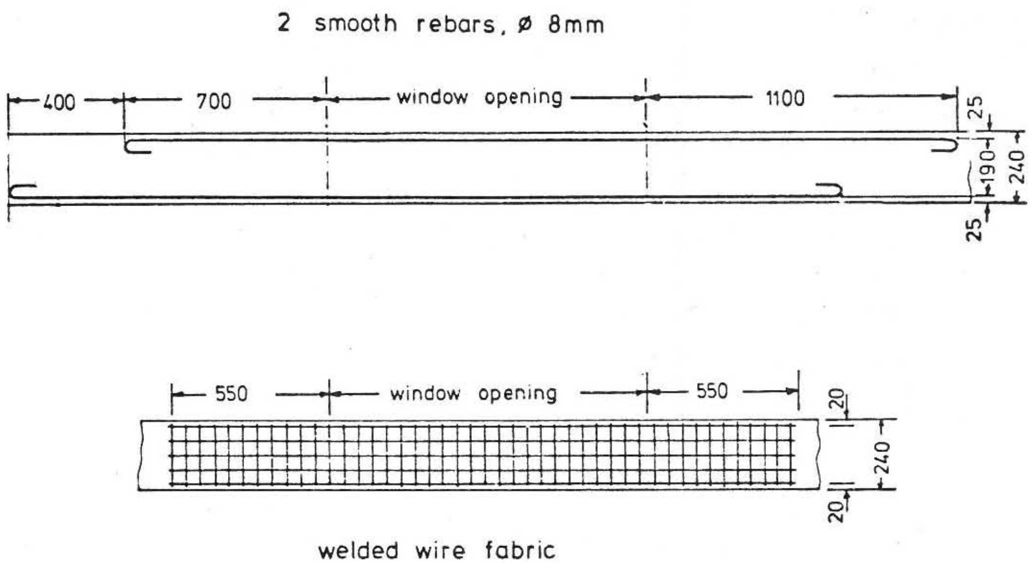


Fig. 1   Types of reininforcement

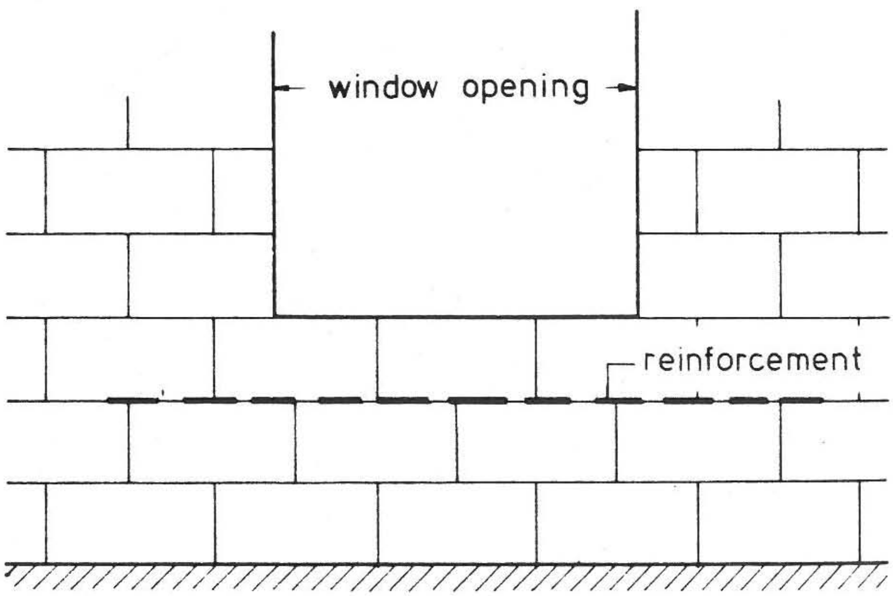
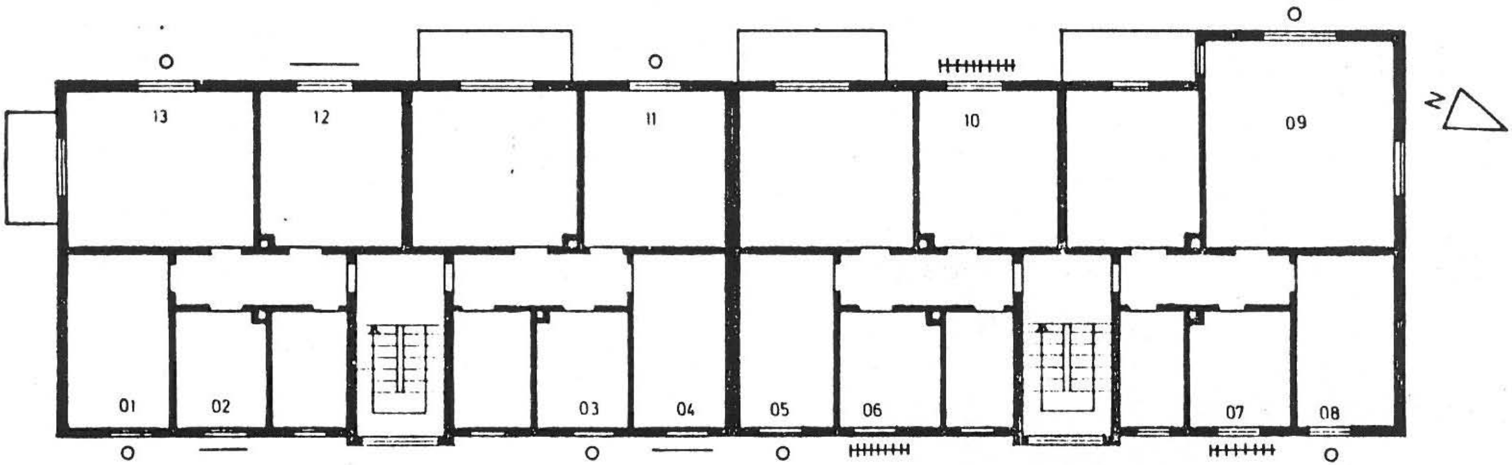


Fig. 2   Placement of reinforcement

year					1. floor
1980	9,9	27,3	75,2	77,9	189,5
1961	6,0	15,5	24,0	4,1	5,0
1959	0	7,8	9,1	2,3	2,7



1959	1,0	0	2,5	1,5	0	0	0	7,0
1961	1,0	2,0	1,2	1,5	3,2	2,9	0	10,2
1980	16,0	11,4	63,4	10,0	0	6,0	3,7	202,8

o no reinforcement ⧺⧺⧺ welded wire fabric —— 2 smooth rebars

Fig. 3 R-values of wall sections with window openings

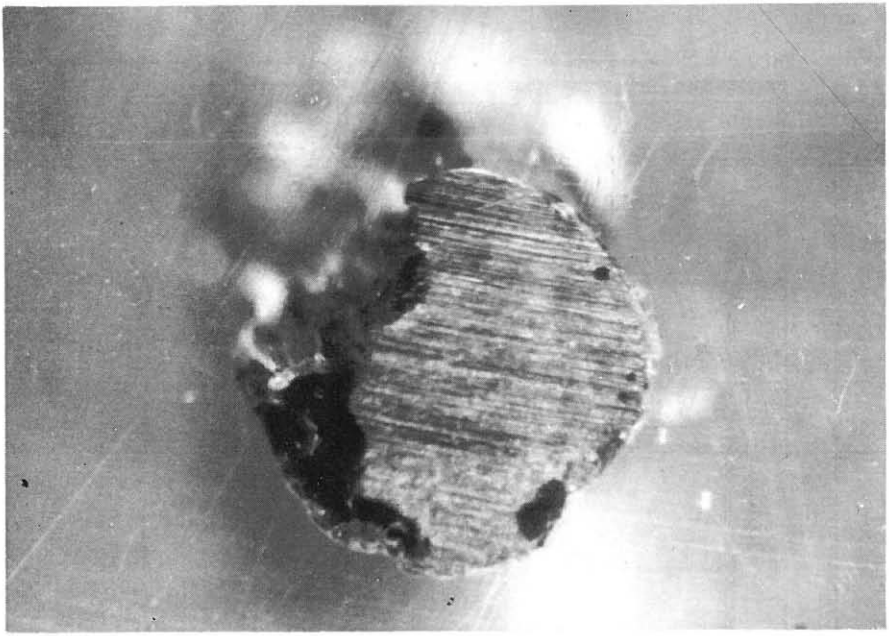


Fig. 4 Cross section of corroded reinforcement

Table 1 Mix proportions of masonry mortars

Mortar No.	Cement (Volume Parts)	Sand	Water / Cement	Additives	β_d (N/mm^2)	Dco_2 (mm^2/s)
1	1 OPC	3.5	0,75	2 % +	14.55	33×10^{-2}
2	1 OPC	2.5	0.75	-	30.24	13.5×10^{-2}
3	1 OPC	3.5	1.0	-	18.72	30×10^{-2}
4	1 HPC	3.0	0.85	-	28.05	11×10^{-2}
5	1 HPC	3.5	0.95	-	23.15	15×10^{-2}

OPC: ordinary portland cement + Plasticiser

HPC: high early strength portland cement