

# The crack formation of concrete slabs embedded along two sides with minimum area of steel reinforcement

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**Abstract.** The article deals with crack formation of concrete slabs embedded along two sides, after monitoring the shrinking of concrete slabs under laboratory conditions. The paper presents result of laboratory test focused on monitoring the crack formation of concrete slabs. The concrete slabs were reinforced asymmetrically only on one side. The slabs were loaded by four-point bending. The formation and development of cracks was monitored during loading of concrete slabs. The deflections on the concrete slab were measured and the formation of cracks and the width of the cracks were monitored. The position of the cracks on the concrete slab was checked and compared with the position of the transverse reinforcement.

## 1 Introduction

The process of cracking in concrete slabs has been monitored for a long time. Cracks may be caused by stress or environmental influences. Cracks always affect the durability and reliability of building structures. The need to investigate these phenomena is also included in regulations and standards. Our task is therefore to be able to correctly design the building structure so that the crack widths are smaller than the limit. The building structures have to be designed so that the crack widths are smaller than the established limit.

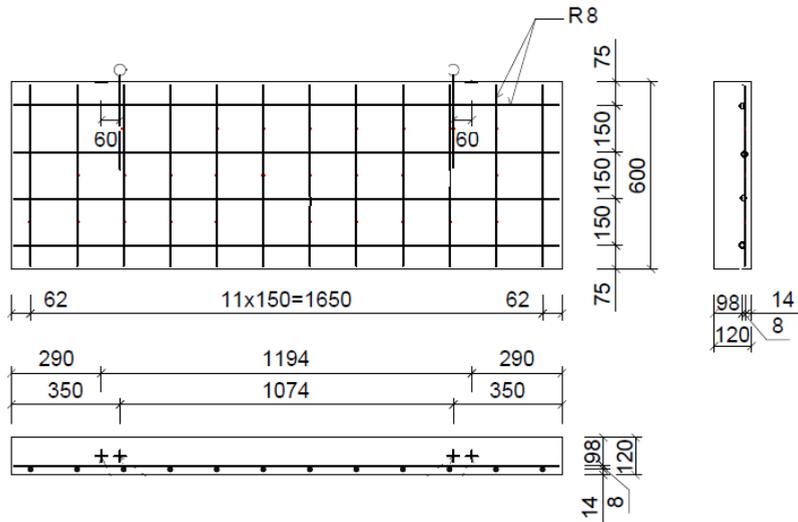
## 2 Subject and methodology of the tests

The 20 pcs of slabs were concreted and placed in an environment with a relative humidity of  $RH = 53\%$ . The cube strength of concrete  $f_{c, cube} = 43.1$  MPa, tensile strength of concrete  $f_{ctm} = 2.23$  MPa and value of modulus of elasticity  $E_c = 34.34$  GPa were determinate at the time  $t = 28$  days.

Slabs were reinforced by steel reinforcement, with minimum reinforcing ratio in longitudinal direction – 4x diameter of reinforcement  $d_s = 8$ mm (welded wire: diameter of reinforcement  $d_s = 8$ mm, and 150x150 mm mesh) (Fig.1) and value of modulus of elasticity  $E_s = 211$  GPa.

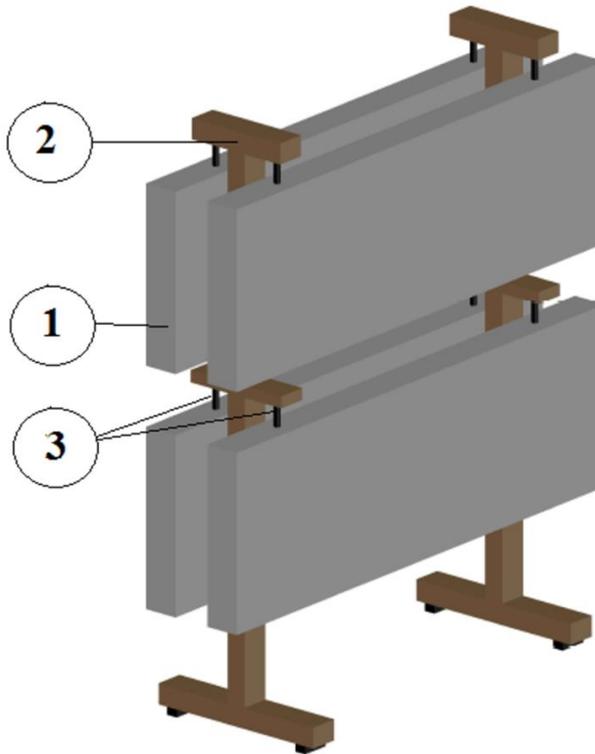
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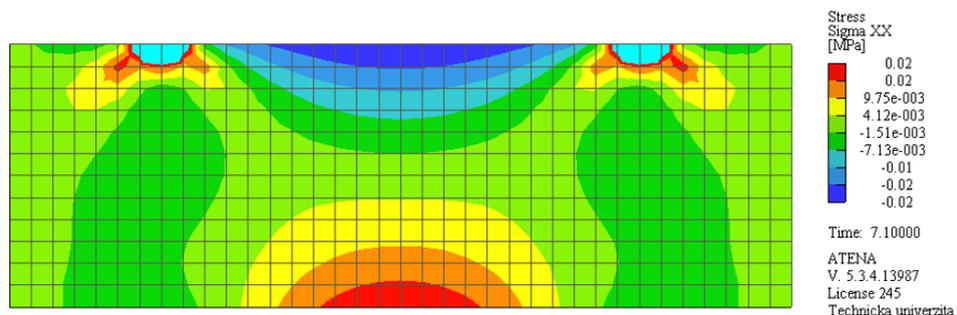
**Fig. 1.** Reinforcement of slabs - welded wire: diameter of reinforcement  $d_s=8$ mm, and 150x150 mm mesh.

Altogether, there were 10 slabs tested under the conditions of fully developed cracks and 10 slabs in the final destructive tests.



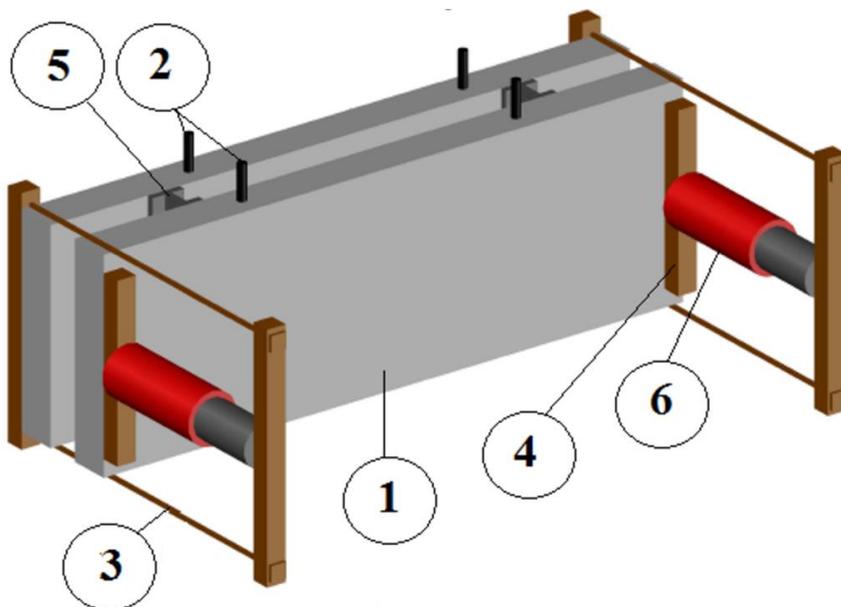
**Fig. 2.** Set-up diagram for slab samples: 1- slab samples, 2- stands, 3- suspension elements.

The placement of the slabs in the vertical position (Fig. 2) was chosen to eliminate the influence of the self-weight on the slab deformations and deflections. The actual weight of the slabs acts in the centre plane of the slabs and withstands a very high cross-section. The very small negligible stresses are given in the slabs, about 0.02MPa, it is documented in Fig. 3 - ATENA Science out. It was possible to observe the almost net effect of concrete shrinkage on the stress and deformation of the elements by this way.



**Fig. 3.** Stress of concrete caused by the self-weight of the slab.

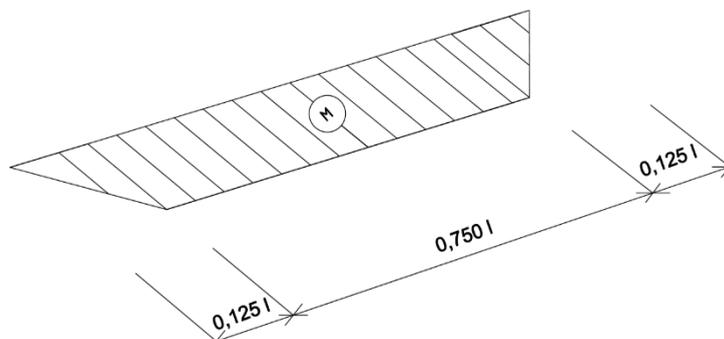
The static short-term loading was arranged directly on the stands by means of concentrated forces linearly distributed in a transversal direction and acting symmetrically in relation to the centre of a slab. The distance of the loading points from the front parts of slabs was chosen in order to achieve the maximum length of simple bending [Fig. 4,5].



**Fig. 4.** Statically loading sample diagram: reinforced concrete slabs, 2- suspension elements, 3- tension rod, 4- load distribution element, 5- bracing bar, 6- hydraulic press.

The program focused on the formation and development of cracks, which was carried out on 10 samples (marking ZT – Tab. 1.) at the chosen time  $t_1 = 7, 15, 30, 60$  and 90 days (stress level 0,6).

Since it was only a load to draw a fully developed system of cracks that was approximately at the level of 0.6, we could simultaneously load two samples lying parallel to each other at a distance of 100 mm. At supports spaced 270 mm away from the edges, they were spread with steel jigs and a line load across the sample width at the ends of the samples was exerted by a hydraulic press through stirrups providing an action-reaction load (Fig. 4). As the edge parts of the slabs with the triangular distribution of bending moment remained very short, for further consideration the testing samples were regarded as loaded by a constant bending moment [Fig.4,5].



**Fig. 5.** Bending moment after loading.

The loading was applied by the gradual increase in deflection. By single loading steps, which were chosen with the sufficient density, the controlling deflection was maintained in the midspan, and at the same time, if occurred, the decrease in the pressure in hydraulic presses was observed by a manometer. The time limit between the single loading steps was settled for 5 minutes according to the experiences gained from the first test. During that time period, the slab surface, the formation and development of cracks in a bleached strip of a third of the whole slab width were observed and the measured deformations from the deflectometers and manometers were put down. Besides, during the final destructive tests, the changes in length of two compressed slab surface were also investigated and measured. The first group of samples marked as ZT was exposed to static short-term load at the age of concrete  $t_1=7,15,30,60$  and 90 days (Table 1.), the other group of samples marked as ZB at the age of concrete  $t_1=410$  a 470 days.

**Table 1.** The first group of samples marked as ZT

The age of concrete $t_1$ (days)	Slabs at loading		
	Number of slabs (pcs)	Marking of boards	
7	2	ZT-7.1	ZT-7.2
15	2	ZT-15.1	ZT-15.2
30	2	ZT-30.1	ZT-30.2
60	2	ZT-60.1	ZT-60.2
90	2	ZT-90.1	ZT-90.2

Altogether, there were 10 slabs (ZT) tested under the conditions of fully developed cracks and 10 (ZB) in the final destructive tests.

### 3 Analysis of crack

The crack density in the base  $\delta_r$ , which was considered to be the overall slab length, was defined by the following expression

$$\delta_r = \frac{m_r}{l_r}, \tag{1}$$

where:  $m_r$  – the number of cracks in the base,  
 $l_r$  – the base length (1774 mm).

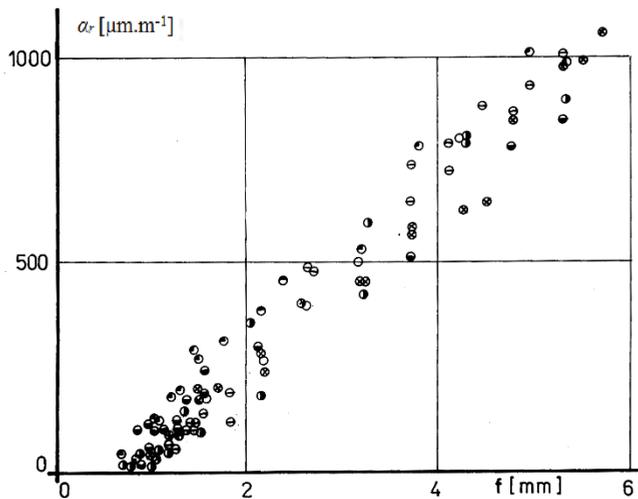
The crack opening density  $\alpha_r$  is considered the quantity

$$\alpha_r = \frac{\sum w_{r,i}}{l_r}, \tag{2}$$

where:  $w_{r,i} - i=1 \dots m_r/$  - are the crack widths in the base,  
 $l_r$  - the base length (1774 mm).

### 4 Result and discussion

This means, the total of the crack widths per length unit is regarded as the crack opening density, while the length is calculated in a perpendicular line in relation to the cracking direction.

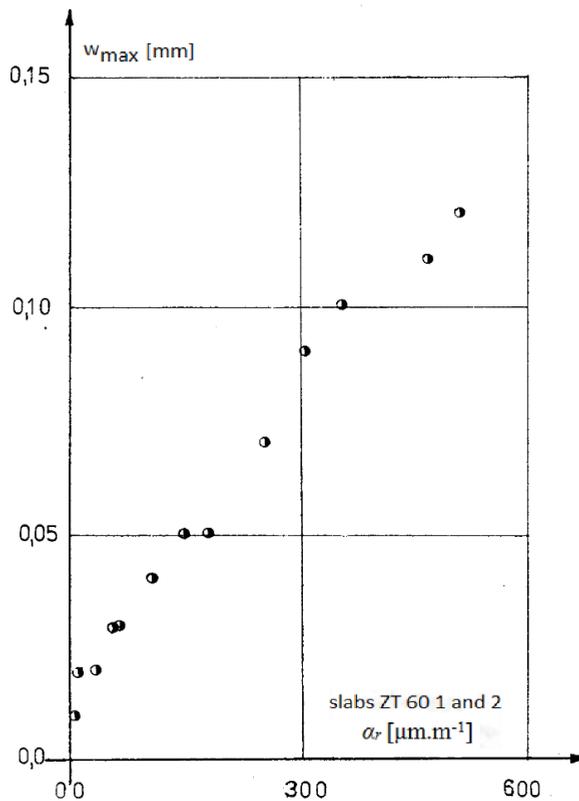


**Fig. 6.** Relationship between the mid-span deflection  $f$  and crack opening density  $\alpha_r$ .

The crack opening density was calculated out of totals of the crack widths for the single loading steps. Out of numerous results the total relationship between the mid-span deflection and the crack opening density  $f \times \alpha_r$  was specified, shown in figure 6 for the ZT slabs. It was calculated for each loading step till the load level 0,6 was achieved. The figure 6 shows a very clear linear relationship between  $f$  and  $\alpha_r$ . The results gained for the ZB slabs loaded practically till the level 0,95 can prove the same linear dependence.

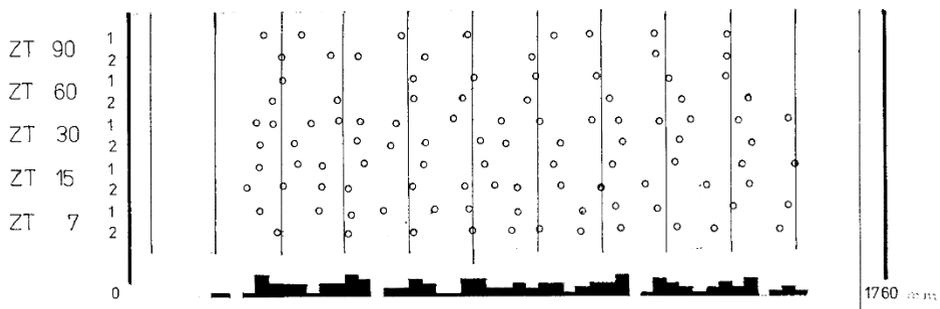
The authors of the paper [3] declare the linear relationship between the crack opening density and the maximum crack width for the concrete slabs embedded along three sides. They point out the possibility of designing an appropriate calculation model based on this linear dependence in the case of exclusive bending cracks, perpendicular to the middle plane of an element.

In addition, verification confirmed the linear relationship for the concrete slabs embedded in a girder way (see figure 7).



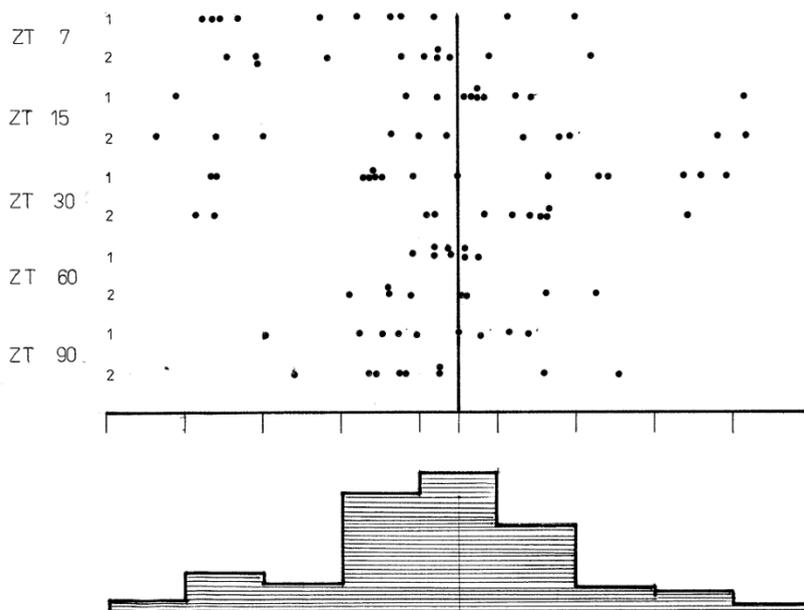
**Fig. 7.** Relationship between the crack opening density  $\alpha_r$  and the maximum crack width  $w_{max}$ .

The position of the cracks was determined on the concrete slab during the load test. Each crack was marked at each load stage and its position accurately determined. The detected crack position was compared with the transverse reinforcement position of the slab. The results of comparing of the cracks position in the concrete slab and the position of the reinforcement indicate that the transverse reinforcement significantly affects the formation of cracks, see Fig. 8.



**Fig. 8.** Position of cracks for individual bars in the slab.

The position of the cracks was determined on the concrete slab during the load test. Obtained the histogram of the frequency of crack position from testing of all concrete slabs – Fig.9. Assumptions were confirmed that, the formation and development of cracks is influenced by transverse reinforcement in concrete slabs.



**Fig. 9.** The frequency histogram – summary cracks position dependence for all slabs under load.

## 5 Conclusion

Finally, it is possible to conclude from verification that greater crack widths were observed for the lower crack opening density and the older age of concrete.

From the analysis of results that has been carried out for the observation of the process of cracking under the short-time load so far, the following conclusion can be drawn:

- There is a linear relationship between the deflection and the crack opening density
- The linear relationship between the crack opening density and the maximum crack width was proved for the concrete slabs embedded in a girder way.
- Confirm the well-known fact that the transverse reinforcement in the concrete slab contributes to the formation of cracks.

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## References

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