

Longitudinal forces in concrete structures. An ignored phenomenon which severely changes the structure behavior

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Abstract:

Tension forces are practically present in each concrete element. The phenomenon is due to the loss of hydration heat, concrete shrinkage and temperature drop which produces shortening of the components. As soon as such actions are constraint by stiff adjacent building cores, longitudinal walls etc. large tension forces are activated and through cracks produced. Such cracks frequently affect structure behavior due to the phenomena: water intrusion due to the loss of compression zones, large deflections due to the decrease of stiffness and low shear bearing capacity due to the crack yielding to the vertical displacement. These facts indicate that longitudinal forces should not be ignored in modern design of concrete structures. The following investigations are based on generally accepted design methods by the author which found entrance into research work, standards and engineering practice.

Keywords:

advanced design, stiffness-oriented design, superposition of load and temperature, constraint

1. Introduction

Human-centric lighting Practical application of the stiffness-oriented design methods by the author [9] is presented in this paper. Due to their closeness to reality these methods found wide acceptance in the research [1,5-9,16-18], regulations [3] and, most of all, in the complex engineering practice [2,4,10-20]. To demonstrate the latter two typical design tasks from the author's activities are analyzed in this paper.

2. Stiffness oriented determination of moments

The investigations described in the paper were gained with own computation programs based on the Continuous Deformation Theory (CDT) described in [5]. The stiffness oriented, numeric procedures consider the following nonlinear stages of the r/c structures: no cracking, first cracking, developed cracking and steel yielding. The respective searches for the internal forces and for compliance with the design criteria proceed the following 7 steps:

- Step 1: The structure is subdivided by computation nodes, whose stiffness depends on M & N.
- Step 2: The nodes are provided with actions like loads, temperatures and with boundary conditions.
- Step 3: The nodes are described by the structural features – dimensions, reinforcement, material, etc.
- Step 4: The node behavior is defined by the initial stiffnesses EI & EA and deformation laws M-k & N-e.
- Step 5: The internal forces M & N and the deformation values k & e are determined.
- Step 6: The improved secant stiffnesses EI & EA are determined and if these do not change the computation is finished, otherwise it must be repeated from Step 5 on.
- Step 7: The behavioral features d, s, w and x are determined and if the design criteria are satisfied the

dimensioning is finished, otherwise it must be repeated from Step 3 on.

3. Floor slabs subjected to bending and tension

In floor slab areas located between stiff stairwells constraint-oriented tension forces are activated in addition to the load-oriented bending moments. The phenomenon is a consequence of constrained shortening caused by loss of hydration heat, shrinkage and cooling. In such structures early cracking occurs which results in drop of stiffness, redistribution of moments and drop of forced moments and tension forces. In case of insufficient reinforcement, the threat of loss of compression zones, not tight cracks and large deflections emerge. A corresponding case of a beam fixed to stair wells and subjected to cooling down is analyzed in the following.

In this spirit, the following beams, Fig. 1, are analyzed:

- System: Three span beam with fixed ends.
- Concrete: Strength 25 MN/m² or 50 MN/m².
- Dimensions: Span 3 x 7.80 m, height 0.20 m and 0.40 m.
- Actions: Dead load and service load. Uniform temperature drop of $0 < \Delta T < 20$ K capturing cooling and shrinkage.
- Reinforcement: Determined conventionally without consideration of tension.
- Internal Forces: Bending moments due to the external loads. Tension forces imposed by cooling and fixation.
- Behavior criteria: Steel stress above the support: $\sigma_s < 400$ MN/m². Crack width above the support: $w_k < 0,30$ mm. Compression zone above support: $x_d > 50$ mm. Deflection: $\delta < 15$ mm (1/500)

The most important findings, Figures 2 to 4, are as follows:

STUDY 1, Fig. 2:

- Slender slab $h = 0.20$ m. Steep increase of deflections δ along with cooling ΔT_m .
- Floors of low thickness 0.20 m and large span 7.80 m subjected to tension tend to high deflections.
- The reason is formation of numerous cracks which successively decrease the slab stiffness.
- This is especially the case at high concrete strength 50 MN/m² which doesn't matter after cracking.

STUDY 2, Fig. 3:

- Compact slab $h = 0.40$ m. High increase of crack width w along with cooling ΔT_m .
- Floors of large thickness 0.40 m and low span 3.90 m subjected to tension tend to wide cracks.
- The reason is the weak reinforcement designed for low moments and large internal lever arm.
- This reinforcement is not in the position to bear the additional tension forces.

STUDY 3, Fig. 4:

- Compact slab $h = 0.40$ m. Decrease of the compr. zone x_d along with cooling ΔT_m .
- Floors of large thickness 0.40 m and low span 3.90 m subjected to tension tend to through cracks.
- The reason is low moments producing low eccentricity which leads to loss of x_d .
- The wide separating cracks make the slab not tight and are not able to withstand shear forces.

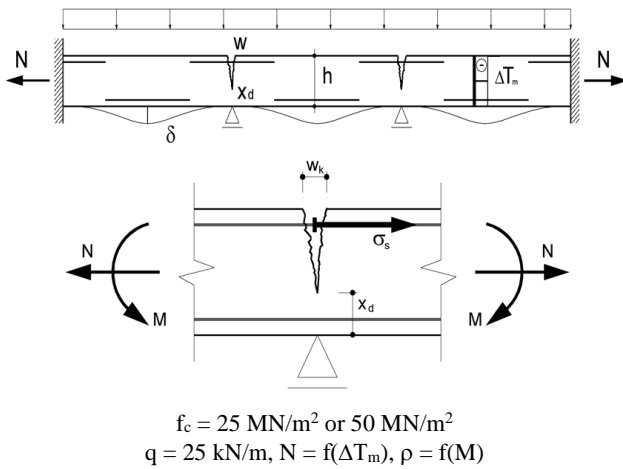


Fig. 1. Investigated floor slab

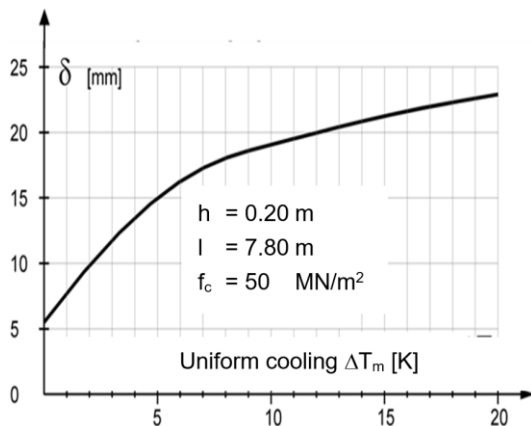


Fig. 2. STUDY 1: Slender slab. Steep increase of the deflections δ along with cooling ΔT_m

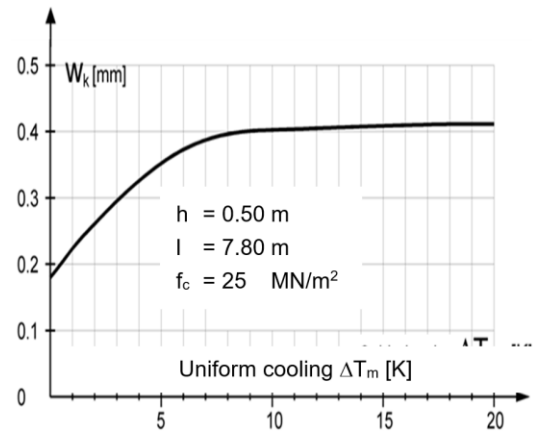


Fig. 3. STUDY 2: Compact slab. Steep increase of the crack width w along with cooling ΔT_m

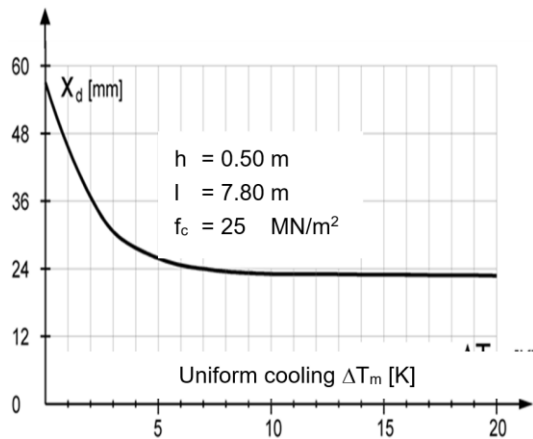


Fig. 4. STUDY 3: Compact slab. Narrowing of the compr. zone x_d along with cooling ΔT_m

4. Beam subjected to bending and tension

Highly loaded beams are frequently subjected to additional constraints due to shrinkage or temperature difference. Cracks forming in the most stressed areas cause redistribution of the load-oriented moments and reduction of the constraint-oriented ones. Despite favorable drop of moments such structures tend to formation of through cracks and large deflections. The proper coverage of these phenomena is very important for the design practice in terms of its safety and economy. The corresponding case analyzed in the following regards a two-field slab differently reinforced and subjected to different actions.

In this spirit, the following beams, Figures 5, 6 and 7 are analyzed:

- System: Three span beams with optionally fixed ends.
- Concrete: Strength 25 MN/m².
- Dimensions: Span 2 x 10.00 m, thickness 1.00 m, width 0.50 m.
- Reinforcement: $\rho = 0.40\%$ or $\rho = 1.2\%$.
- Actions: Uniformly distributed load $q = 20$ kN/m or $q = 40$ kN/m. One sided temperature drop $\Delta T = 15$ K capturing cooling and shrinkage. Tension force $N = 0$ or $N = 600$ kN
- Internal forces: Moments from uniform load: M_q . Moments due to temperature: $M_{\Delta T}$.
- Behavior criteria: Moment redistribution and reduction. Deflection: δ .



Fig. 5. Designed office building

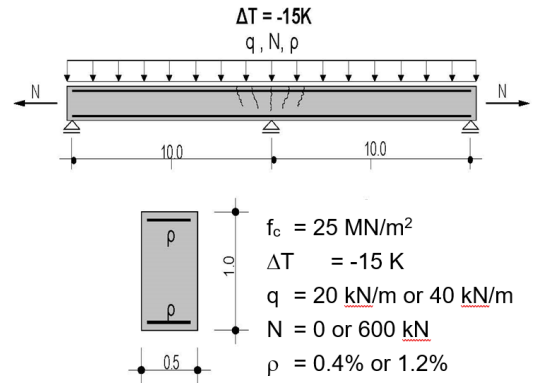


Fig. 6. Investigated binding beam

The most important findings, Figures 7 to 10, are as follows:

STUDY 1, Fig. 7:	Temp. $\Delta T = 15 \text{ K}$, load $q = 20 \text{ kN/m}$, tension $N = 0$, reinforcement $\rho = 0.40\%$
Neglect of cracking	$M_q = 250 \text{ kNm}$, $M_{\Delta T} = 349 \text{ kNm}$, $\delta = 123 \text{ mm}$
Count of cracking	$M_q = 149 \text{ kNm}$, $M_{\Delta T} = 176 \text{ kNm}$, $\delta = 211 \text{ mm}$
Real cracking	Formation in support area
Results	Large redistribution of M_q , large drop of $M_{\Delta T}$, large increase of δ

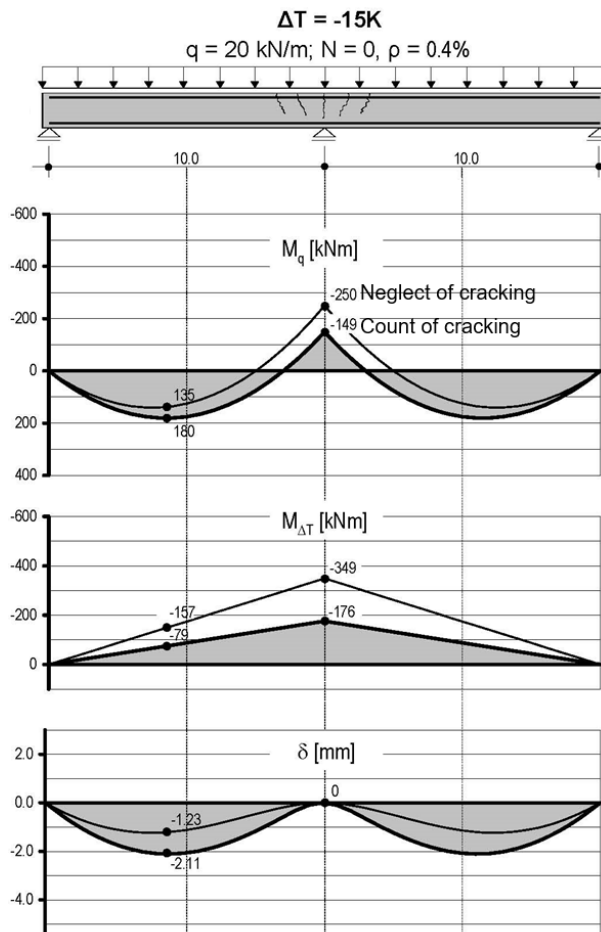


Fig. 7. STUDY 1: Load $q=20\text{kN/m}$, Tension $N = 0$, Steel $\rho = 0.40\%$;
Large redistribution of M_q , large drop of $M_{\Delta T}$ and increase of δ due to cracking

STUDY 2, Fig. 8: Temp. $\Delta T = 15K$,
load $q = 40 \text{ kN/m}$,
 tension $N = 0$,
 reinforcement $\rho = 0.40\%$

Neglect of cracking $M_q = 499 \text{ kNm}$,
 $M_{\Delta T} = 349 \text{ kNm}$,
 $\delta = 192 \text{ mm}$

Count of cracking $M_q = 425 \text{ kNm}$,
 $M_{\Delta T} = 114 \text{ kNm}$,
 $\delta = 627 \text{ mm}$

Real cracking Formation in support and span areas

Results: Low redistribution M_q , extreme drop of $M_{\Delta T}$, extreme increase of δ

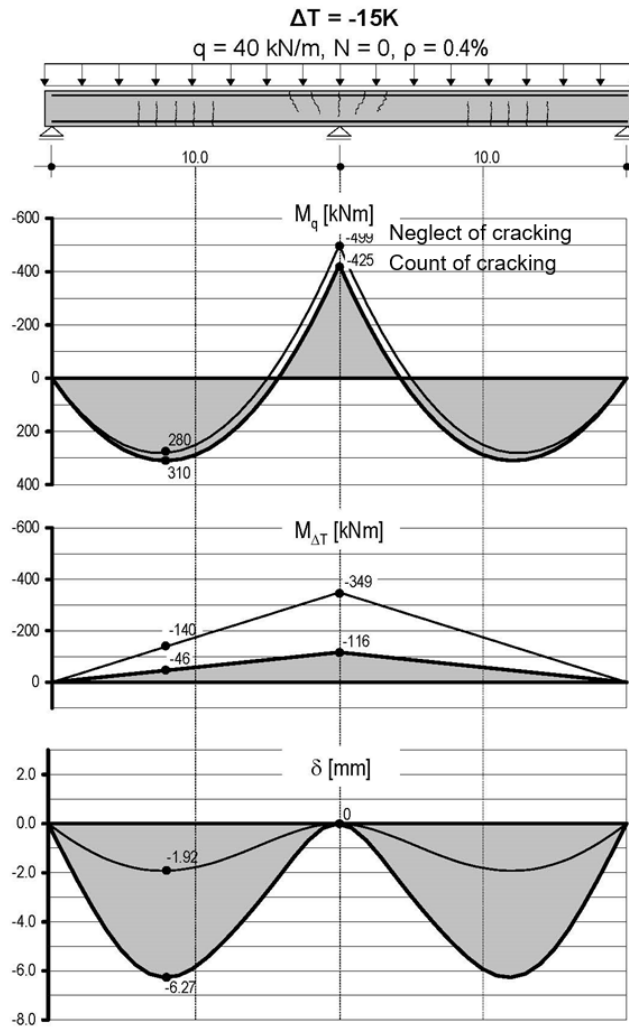


Fig. 8. STUDY 2: Load $q=40\text{kN/m}$, Tension $N = 0$, Steel $\rho = 0.40\%$;
 Low redistribution of M_q , extreme drop of $M_{\Delta T}$, extreme increase of δ due to cracking

STUDY 3, Fig. 9: Temp. $\Delta T = 15K$,
load $q = 40 \text{ kN/m}$,
 tension $N = 600kN$,
 reinforcement $\rho = 0.40\%$

Neglect of cracking $M_q = 250 \text{ kNm}$,
 $M_{\Delta T} = 349 \text{ kNm}$,
 $\delta = 123 \text{ mm}$

Count of cracking $M_q = 213 \text{ kNm}$,
 $M_{\Delta T} = 66 \text{ kNm}$,
 $\delta = 560 \text{ mm}$

Real cracking Formation in support and span areas

Results: Low redistribution M_q , extreme drop of $M_{\Delta T}$, extreme increase of δ

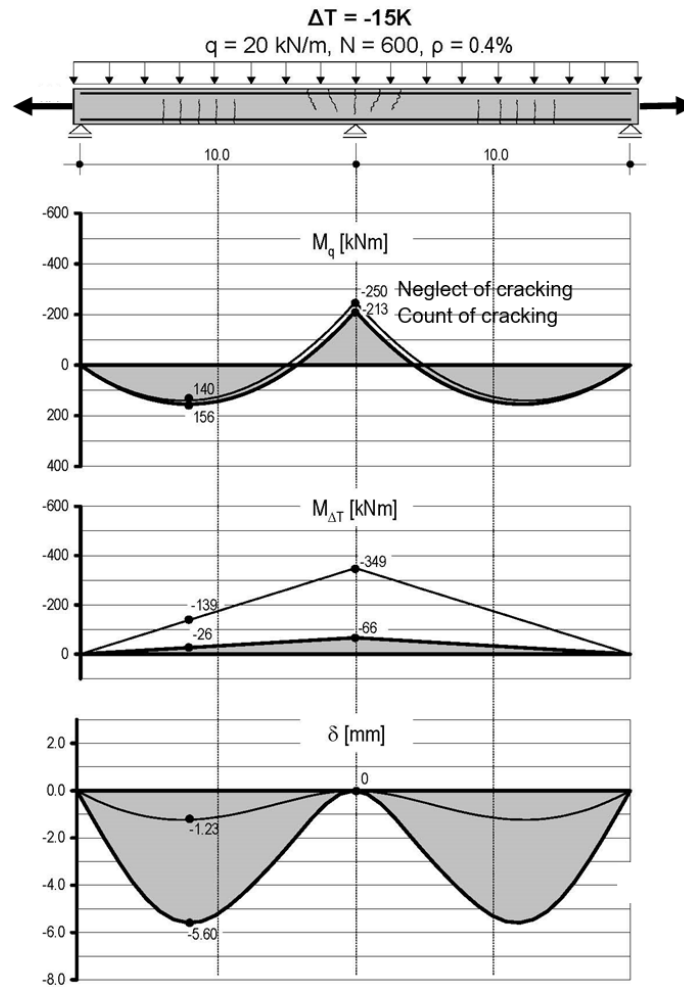


Fig. 9. STUDY 3: Load $q=20kN/m$, Tension $N=600$, Steel $\rho=0.40\%$;
 Low redistribution of M_q , extreme drop of $M_{\Delta T}$ and extreme increase of δ due to cracking

STUDY 4, Fig. 10: Temp. $\Delta T = 15K$,
load $q = 40 \text{ kN/m}$,
 tension $N = 0$,
 reinforcement $\rho = 1.20\%$

Neglect of cracking $M_q = 250 \text{ kNm}$,
 $M_{\Delta T} = 409 \text{ kNm}$,
 $\delta = 113 \text{ mm}$

Count of cracking $M_q = 187 \text{ kNm}$,
 $M_{\Delta T} = 262 \text{ kNm}$,
 $\delta = 165 \text{ mm}$

Real cracking Formation in support area

Results Low redistribution of M_q , moderate drop of $M_{\Delta T}$, low increase of δ

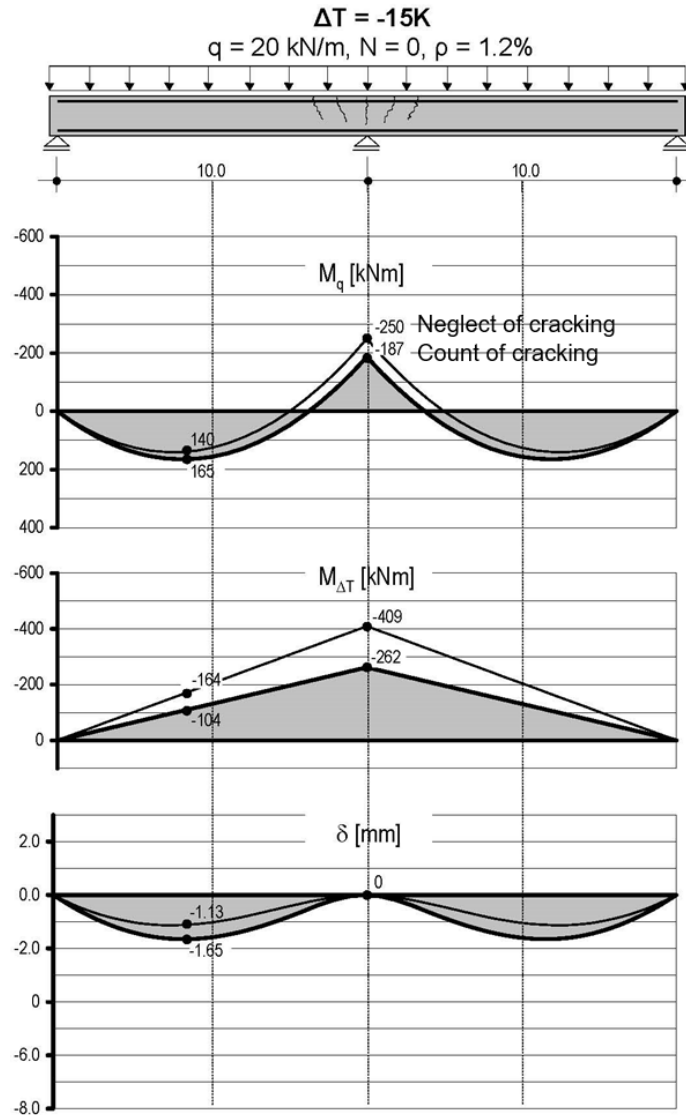


Fig. 10. STUDY 4: Load $q=40\text{kN/m}$, Tension $N=0$, Steel $\rho=1.20\%$;
 Low redistribution of M_q , moderate drop of $M_{\Delta T}$ and low increase of δ due to cracking

5. Conclusions

Tension forces are activated in floor slab areas between stair wells due to cooling and shrinkage. The phenomenon changes unfavorably the behavior of the structure:

- Slender slabs develop extreme deflections due to substantial drops of the overall stiffness.
- Compact slabs may lose the compression zones and so their tightness and shear bearing strength.

Redistribution of load-oriented and reduction of constraint-oriented moments occur in redundant structures due to cracking. The phenomenon changes favorably and unfavorably the floor's behavior:

- Large reduction of moments in lowly loaded, weakly reinforced and tensioned beams
- Extreme increase of deflections in highly loaded, weakly reinforced and tensioned beams

These findings prove that economic and safe analysis of r/c structures is only possible in connection with considering the stiffness decrease due to cracking.

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