Cracks and crack control of concrete slabs

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Bachelor’s thesis

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Abstract
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A reinforced concrete slab is a very important structural element in the building which is constructed to provide a flat surface. To feel safe and comfortable, the slab should fulfill its intended design requirements. The idea for the thesis arose during my summer job where I was fixing cracks in concrete slab intermediate floors.

The primary goal of this thesis is to conduct a case study of the reinforced slab and to investigate all possibilities that can cause early-age cracking on the slab, such as material properties, construction procedures, external loading conditions, and environmental conditions. In addition, the goal is to perform a reinforcement design for both Ultimate Limit State (ULS) and Serviceability Limit State (SLS) as well as to deduce whether it is possible to control cracking by calculating crack widths according to EC2. Furthermore, particular attention is paid to shrinkage and creep and their role in the designing process.

A result of this bachelor’s thesis showed that practical calculation methods for the Ultimate Limit States (ULS) and Serviceability Limit States (SLS) fulfilled the design requirements of Eurocodes. The influence of temperature, at the time of casting and curing the slab, causes the loss of moisture from the concrete slab and results in a reduction in volume, so drying out occurs from the surface.
Therefore, the surface layer of the slab is cracked, due to temperature differences.
In conclusion, it was suggested to use the Epoxy injection method after the drying period to seal and bond inside the crack.

Keywords Concrete, slab design, crack, crack control.
Pages 20 pages and appendices 18 pages

Contents

Appendices

1 Introduction

1.1 Background

Concrete is a composite material, which contains aggregate, cement, water, air, and admixture, and its properties change through time. The rate of those changes depends on external factors such as loading conditions or environmental conditions, and internal factors such as reinforcement or the proportion of the mix.

To achieve the goal of this thesis, one-way concrete slab was selected as a case study and the strategies for examining the causes of early age cracking will be as follows: Designing process, material and mix parameters, construction procedures, environmental condition, and external loading condition. Particular attention is given to shrinkage, creep, and their role in the designing process.

1.2 Problem

Cracking of concrete structure is a common problem that will appear when the tensile stress reaches the tensile strength in the section. This bachelor's thesis focuses on studying why early-age cracks occur on the surface of the slab, and how cracks can be handled. The question of whether there is any factor that affects the rate of cracking is also analyzed.

1.3 Methodology and literature review

Attention will be paid to the study case of the slab, and the strategies for examining the causes of early age cracking will be demonstrated. AutoCAD Software will be used to draw the cross-section area of the slab and it is detailed reinforcement, and Mathcad prime will be used to facilitate all the calculations needed for the slab.

This thesis is limited to only the five factors mentioned in section 1.1. causing early cracking in a concrete slab and the slab will be designed according to Eurocode EC2. The thesis is also limited to the knowledge gained during bachelor's degree studies, as well as some articles and books are written by experts. More focus in the thesis will be given to the design process.

Note that all the references in the provided calculation are based on Eurocodes and the Finnish national annex.

2 Phenomenal related to cracks

Concrete is a brittle material, which is weak under tensile stress, and when it is loaded or affected by environmental conditions, the development of tensile stress in the concrete is expected. The cracks may develop if the concrete ingredients are not mixed properly.

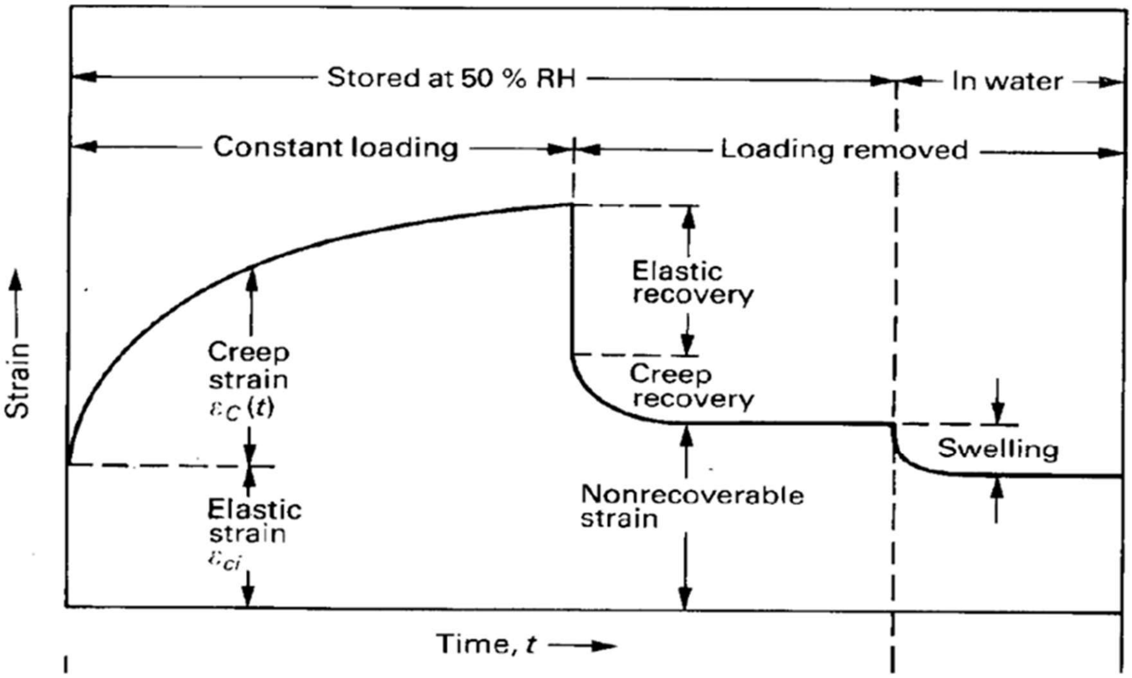
The purpose of this section is to understand the uncertainties related to the behavior of reinforced concrete slabs and their relation to shrinkage and creep, which are considered to be the main factors that affect concrete material.

Usually, cracks occur in a concrete member where the tensile stress approaches its tensile strength. Cracks damage the durability of the slab as well as its appearance, therefore the cracking must be controlled to ensure the design working life of the structure.

2.1 Creep

Creep in concrete is defined as the deformation of structure under sustained load. In other words, creep in concrete is a time-dependent strain of excessive elastic strain as to the course of action in a material subjected to continuous stress. If the load is released after some time, the initial elastic strain is recovered shortly, and only the instantaneous elastic deformation will recover. A part of the creep strain is little by little recovered with time and the remaining part is non-revisable. Furthermore, the creep of concrete depends on relative humidity, type of aggregate, mix proportions, age of concrete at the time of loading, and the size or the shape of the concrete member. Usually, an increase under a constant load of creep strain $\varepsilon C(t)$ with time is shown in this Figure 1, demonstrates how relative humidity is affecting creep in the concrete structure, the higher relative humidity, the lower is the creep. (Tanabe, 2009)

Figure 1 shows Recoverable and irrecoverable creep, and the higher relative humidity, the lower is the creep.



It is important to note that creep is also influenced by the environment: creep increases in thin members, such as slabs, and humidity is one of the environmental effects on the concrete slab curing process.

Factors affecting the creep of concrete slab:

Quality of aggregate: A good quality of aggregate delays the creep, in that grading and the size affect indirectly creep from the aggregate content of concrete.

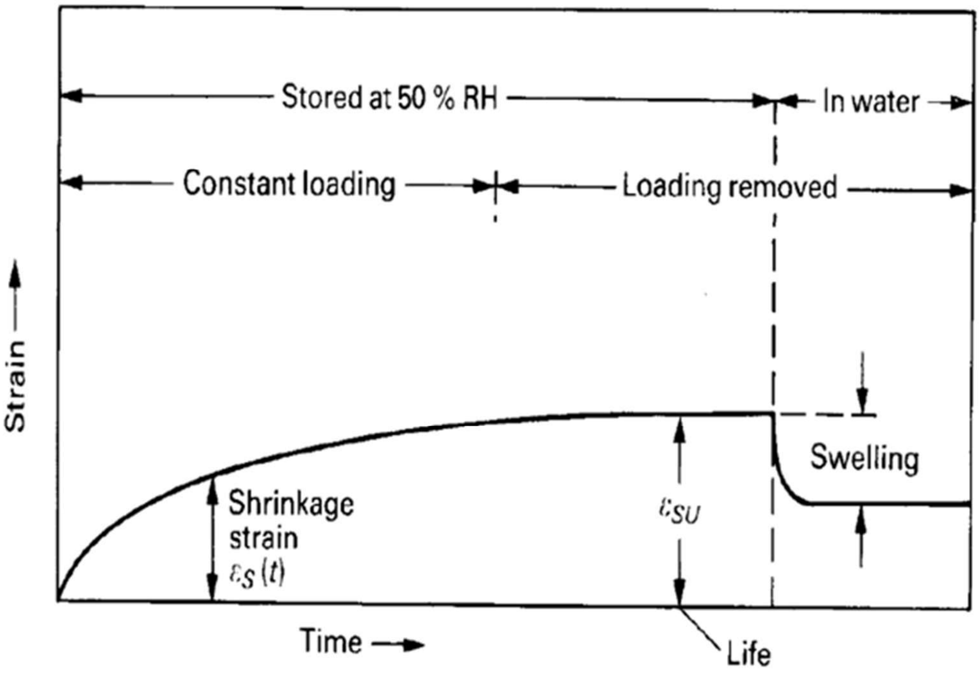
Influence of concrete mix ratio: The quality and the quantity of past material is one of the most important facts affecting creep, which means a poor paste of the concrete slab will increase excessive creep, and with a high water-cement ratio, therefore, creep is symmetrically proportional to the strength of concrete; when the creep increases, the strength of concrete decreases. In general terms, all other factors affecting the concrete as water/cement ratio also affect the creep.

Additional influence: The creeps of concrete depend on many more additional factors, such as the size and the shape of the slab, and relative humidity.

2.2 Shrinkage

Shrinkage of concrete by definition is the time-dependent strain measured in an unloaded and unrestrained at a constant temperature. Concrete performances are affected and cracks are formed because of drying shrinkage and autogenous shrinkage. Generally concrete has more water than is required for chemical reaction hydration of the cement, and the loss of water due to evaporation results in shortening of the concrete member with time. (T. Tanabe, 2009)

Figure 2 Shows shrinkage depends on the relative humidity of the ambient air. The loss of water causes a decrease in volume.



When the concrete contains excess moisture and high relative humidity levels, it can lead to cracking in the section of the concrete member. Generally, shrinkage depends on many reasons, such as the amount of free water, relative humidity, ambient temperature, size, and shape which are the most critical factors that causing shrinkage.

Shrinkage would not occur when concrete is kept at 100% relative humidity, and it is assumed to be free from the influence of loading. Shrinkage in concrete results mainly from the shrinkage of the cement paste; the aggregates shrink very little. Therefore differential internal stresses are formed in the slab of concrete, leading to compression on the aggregates and tension in the paste accompanied by microcracking. The shrinkage strain of concrete under consistent environmental conditions will increase with time and tends to be asymptotically closer to a final maximum value called ultimate shrinkage strain. For all practical purposes, the ultimate shrinkage strain is assumed to occur at the estimated life of the structure. Practically, for moist-cured concrete, about 50% of total shrinkage takes place inside a month and about 90% within a year of exposure. As soon as shrinkage has taken place, total recovery will happen, even if the member has been placed again in water. (Tanabe, 2009)

Factors affecting concrete shrinkage:

Water/cement ratio: shrinkage increases by increasing this factor.

Relative humidity: The extra humidity the much less shrinkage.

Time: Over the time shrinkage decreases.

Type of aggregate: increasing the aggregate size leads to a shrinkage decrease.

Admixture: The shrinkage increases with the addition of accelerating admixture due to the presence of calcium chloride. It can be decreased through the lime replacement, and other elements such as a specific type of cement, aggregate composition, concrete class, curing method, and element dimension.

The concrete slab is vulnerable to shrinkage cracks due to its thin sectioning and being exposed to evaporation because of its large surface area.

3 A study case of one-way RC slab

The idea for this case of study arose during my work placement, where there were five-story buildings in Helsinki in which all the components of the structure were pre-cast elements, except the slab which was cast in place.

While we were working on a slab, what was noticed is, that during the casting and drying of the concrete slab, cracks appears on the surface of the slab so early. Why do cracks occur, and what caused this early age cracking.

Structural cracks can result from incorrect design, faults during the construction, un-proportional concrete material, unexpected external load, or environmental conditions. Excessive cracks can impact the serviceability of the structure, however, cracking is always unfavorable to the appearance of the slab, and for this reason, should be kept to a minimum.

This case study will analyze all the possibilities that can cause early cracking. To achieve this goal, five main causes of early cracking will be discussed as factors affecting early age cracking, and more focus will be given to the designing process.

1. Designing prosses
2. Material and mix parameter
3. Construction procedures
4. Environmental condition
5. External loading condition

3.1 Designing prosses

General information about the case study:

One-way intermediate floor slab of 200 mm thickness will be analyzed, and subjected to a live load of 2.5Kn/m2. The slab concrete is from C35/45 and the support is assumed to be hinged.

Throughout the process of designing the slab following factors are considered:

It is a rectangular slab supported on four edges with a ratio of Ly/Lx greater than 2. Is 2.16 in this slab, so the bending moment is calculated similary to beams.

The slab in this case study is designed based on consequences class two. The consequences class two means medium consequence for loss of human life, economic, social or environmental consequences considerable.

An appropriate load combination of the slab is applied to finalize the critical bending design moments and design shear forces.

A proper longitudinal reinforcement bar is designed to protect the slab from tensile stresses.

Control serviceability of the slab is calculated.

Finally, the control detailing of designed reinforcement complying with detailing chapter 9 of EC-2-1-1 are calculated.

Generally, a one-way slab is designed as a flexural member, for the sake of calculation in the designing process one-meter width is considered due to a satisfactory designing process.

The exposure classes related to environmental conditions are selected X3 by SFS-EN 1992-1-1, concrete inside a building with moderate or high air humidity.

Figure 3 Shows the cross-section of the slab.

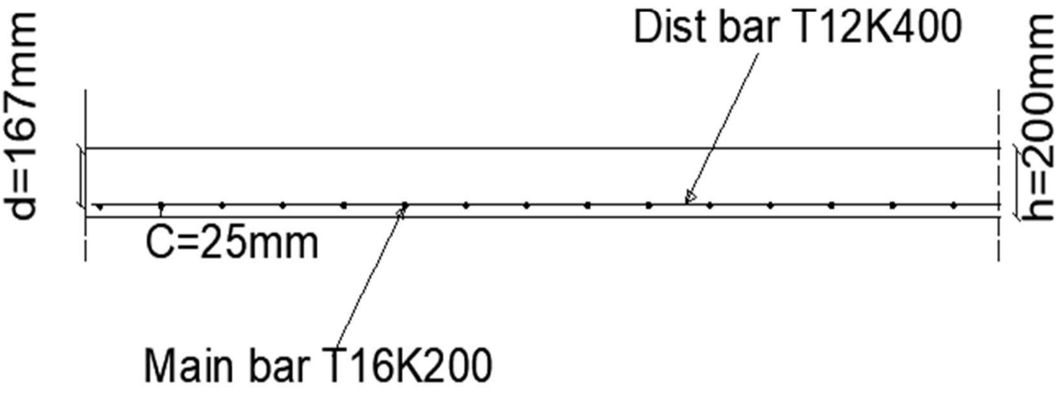
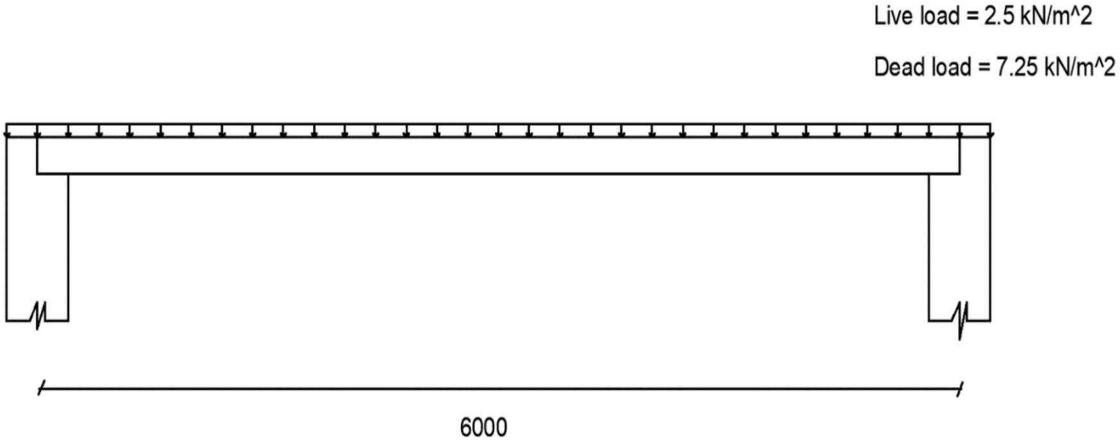


Figure 4 Shows the distribution of the load, live load and dead load.



Considering all the calculations done while designing the slab, both the serviceability limit state and ultimate limit state indicate that, in this study case, no defect from the designing process is found.

Provided Mathcad sheet indicates that all the load analysis detailed process and utilization ratio fulfills the requirements needed in Eurocode.

Note that all the calculations are provided in the appendix (1).

3.2 Material and mix parameters

The general substances that make up concrete mix are water, cement, aggregate, chemical or mineral admixture as well air.

Aggregate is one of the main ingredients of concrete, the amount of aggregates in the concrete is proximally 60% to 75%, which means that the aggregates have a significant effect on the properties of concrete. Aggregate size and shape affect the concreting process. Aggregates with higher density are stronger than those with low density. (Kosmatka & Wilson, 2011, p.95)

Although cement makes up the smallest percentage of the concrete mixture, it is an essential ingredient in concrete, and has a significant impact on the strength of the concrete. Using high-grade cement allows the user to achieve higher strength with the same water-to-cement ratio. However, lower-grade cement can be used to make concrete stronger than higher-grade cement that has been stored for a long time in a degradable state. (Kosmatka & Wilson, 2011, p.7-8)

Admixtures in concrete are extremely important ingredients in the mixture. They are used when mixing concrete for many reasons. Usually, different admixtures serve a different purpose when the concrete production process happens. The concrete used in the construction site must be workable, durable, strong, and wear-resistant, therefore using suitable admixture can be achieved simply and cost-effective all these properties. Using a proper admixture the desired concrete strength and workability of the fresh concrete can be achieved. (Kosmatka & Wilson, 2011, p.117)

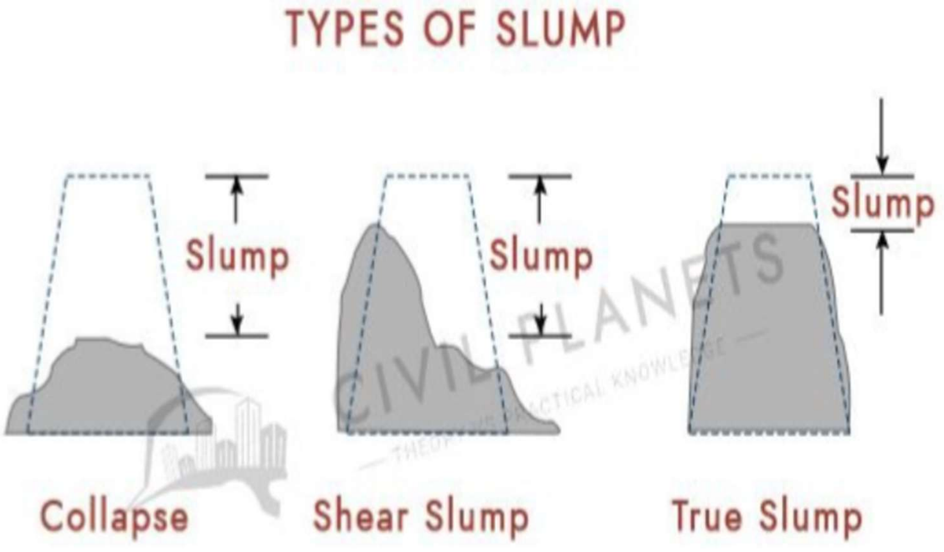
Water: With all the essential ingredients involved in making a mixture of concrete, water tends to have the biggest impact. As a general rule, the more water you add to the mixture, the less stable the hardening mixture will be. Shrinkage and cracking can also occur when there is too much water present in the concrete. Excess water will gradually evaporate from the hardened concrete causing the concrete to shrink and eventually crack. An ideal amount of water can be measured by the ratio of water to cement, and the higher the ratio is, the weaker is the concrete. Adding more than that it will also increase the setting time of cement.

Concrete properties and their effect on early-age cracking

The density of fresh concrete, slump, and air content affect the properties of the concrete during hardening. The first important step after the production of fresh concrete is to determine its density. The density of fresh concrete is essential information that can affect the physical, aesthetic, economic, and engineering characteristics of the concrete member.

The slump test of fresh concrete is one of the most important tests during the trail mix design, because it determines the workability of concrete. Workability means how the property of freshly mixed concrete is that determines how easily and consistently it can be mixed, set, solidified, and finished. The workability is proportional to the water-cement ratio. The increased water-cement ratio increases the workability of the concrete. Concrete slumps can take many different forms when performing slump testing. Based on the profile of slump concrete, it can be classified into one of three types: a collapse slump, shear slump, and true slump.

Figure 5 Slump test of concrete (https://civilplanets.com/slump-test-of-concrete/)



A collapse slump occurs when concrete completely collapses when poured into a cone of a slump. it usually means that the mixture contains a lot of water and has high workability that is not suitable for slump testing. The slump that causes the top of the concrete to loosen and the other parts to slide or slide down is called a shear slump. This can happen because of a lack of cohesion in the mix. The true slump is when the cone subsides and the concrete does not lose the shape of the stump cone (Engineering Civil World, September 9, 2020.)

For the mixture to be effective, a certain amount of air entrainment is needed in the concrete. The air content in fresh concrete causes air voids in the concrete that cannot be repaired after the concrete has been set. This is why air content affects the strength of the concrete when is hardened. The entrained air content of the concrete is important to reduce the cycle of freezing and thawing. The materials used in the manufacturing of concrete such as additional binders to concrete, admixtures, aggregates, and water are important factors affecting the air content of concrete.

The concrete itself must be rightly proportioned, and properly mixed, for instance, too little cement can cause cracks, or using too much water will weaken the concrete, which leads to cracking, whereas the quality of the aggregate will produce a decrease in shrinkage of the concrete. Hard, dense aggregate, the large top size of the aggregate, and optimizing the gradation of the aggregate will reduce the shrinkage of the concrete.

According to CEN-EN 206-1 the common terminology, classes, basic requirements, and delivery information including conformity, production, and evaluation of conformity requirements are standardized across Europe. It sets out the fundamental specification for designed, prescribed, and standardized of concrete.

As creep and shrinkage mentioned in section two, they are influenced by the material of the slab and its properties. The key to achieving durable, strong concrete depends on how it is made and the proportionality of mixing its ingredients. Due to the typical characteristics of the concrete, it is the responsibility of the producer to comply to the Eurocode standards. In this study, the material and mix parameters are not the reasons for early-age cracking, because they complies with the instruction of the manufacturer to the Eurocode.

3.3 Construction procedures

Construction procedures of concrete slabs are essential for the prevention of cracks. Those procedures include preparation of formwork, compaction of a slab, placement of reinforcement, pouring, compacting, finishing the concrete, removing formwork, and curing the concrete slabs.

SS-EN 13670 :2009 demonstrates procedures for good practice in concreting operations such as: handling the concrete and placing it properly, as well as compaction, and curing it. (SS-EN 13670 :2009, 2009, p.25)

The formwork must be erected correctly, during concrete pouring and hardening so that, it can withstand pressure from concrete. All surface holes and joints must be sealed and secured.

The formwork must be erected correctly, during concrete pouring and hardening so that, it can withstand pressure from concrete. All surface holes and joints must be sealed and

secured. It is the responsibility of the building supervisor or site engineer to check that the correct building practices have been followed and checked.

Vibrating concrete is essential, because it removes air pockets and packs aggregate particles together for better density and strength.

In this study case, no defect in the construction procedures is found.

3.4 External loading conditions

The surrounding traffic affects the strength development of hardening concrete by decreasing the final bond of the new concrete to existing concrete elements and reinforcement. (Krell, 1979, p.31–34)

The vibration of a concrete slab is one of the causes of cracks, and it can arise from external sources such as machinery road traffic. To avoid such problems the building as a whole needs to be isolated. It is also important to consider the slab must not be loaded during the hardening stage, although concrete normally hardens soon after it is poured, but if it is loaded before it has hardened properly, cracks may appear due to damage from the external loads applied.

Driving slowly around concrete pouring site and avoiding heavy truck loading, unloading, drilling, and excavating around freshly casted slab are main factors in reducing the risk of damaging the drying concrete slab.

Traffic and vibration from the surrounding area is a critical issue and they must be considered it. In this study case, no defect from external loading is found.

3.5 Environmental conditions

The varying environmental conditions of concrete at the time of casting and during hardening affect the properties of the concrete. The influence of air temperature, relative humidity, and wind velocity are the main factors of rapid evaporation. The evaporation of water is always a challenging issue during concrete construction. The temperature is an important factor that affects the reaction of cement with water, as the temperature rises the rate of chemical reaction increases. The consequences of hot weather not only affect losing concrete workability, but they additionally can also decrease the long-time strength of the concrete. This is why temperature plays an important role. The rapid evaporative losses and high temperatures can introduce concrete at an initial age cracking.

The concrete slab experiences cracks, due to the loss of water during environmental exposure. The evaporation of the moisture at the surface of the slab was more than the availability of the rising bleed to fill the surface moisture, this process happened before the slab attains its tensile strength, and temperature differences between the top and the bottom of the slab occurred. Therefore, the cause of this early age cracking was due to environmental conditions.

3.6 Results and recommendations

After is analyzed the designing process, material and mix parameters, construction procedures, environmental conditions, and external loading conditions, the results indicate that the cracks are due to environmental conditions.

In general, it is recommended that cracking should be minimized by considering various types of appropriate measures to control surface evaporation.

It is recommended to do concreting during the morning or evening in hot weather.

Dampen the surface of the formwork with spring water before pouring the concrete.

Cover the concrete after pouring with a plastic sheet.

Have proper manpower, equipment, and supplies on hand so that the concrete can be placed and finished promptly.

4 Crack control

Generally, reinforcement concrete will eventually crack. The primary goal is avoiding the cracks since concrete inevitably cracks, but the cracks can be controlled, which is limiting the crack width, because wide cracks reduce the load carrying capacity of the structure, and its serviceability, the following chapters will demonstrate the approaches that can be used for controlling cracks.

4.1 Curing

The curing of concrete is one of the most important factors, which plays a critical role in maintaining the strength and durability of the concrete.

Curing is a process of keeping under control the rate of moisture loss from concrete slab during the cement hydration.

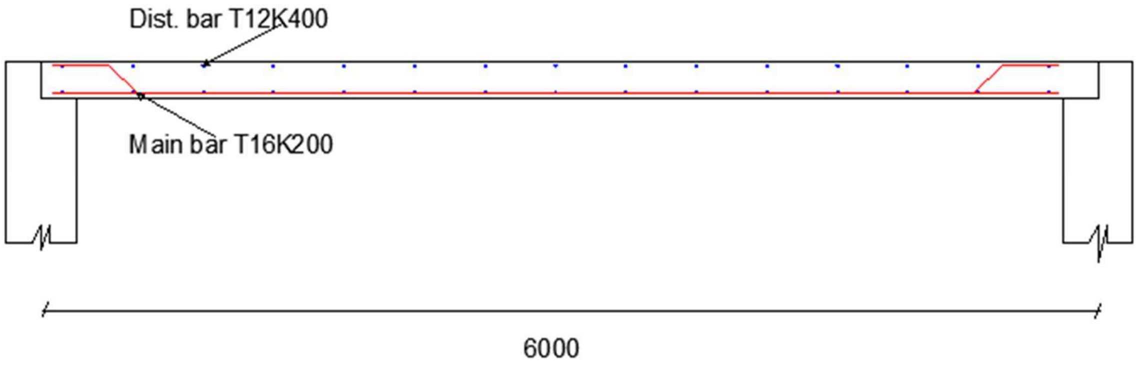
The slab is covered with plastic sheets for curing, and the temperature is crucial during this process due to how the chemical in the concrete slab reacts. Avoiding time pressure for the project scheduling management is essential in terms of the handling and managing of curing the slab.

During curing of the slab, cracks on the surface of the slab appears due to shrinkage, temperature difference, or different temperatures of the concrete slab.

4.2 Casting arrangement

Before casting of concrete slab, all materials and machinery for slab casting must be available and ready to use. Slab reinforcement spacing and the cover of the concrete slab are all placed properly, according to the detailed drawing of the slab.

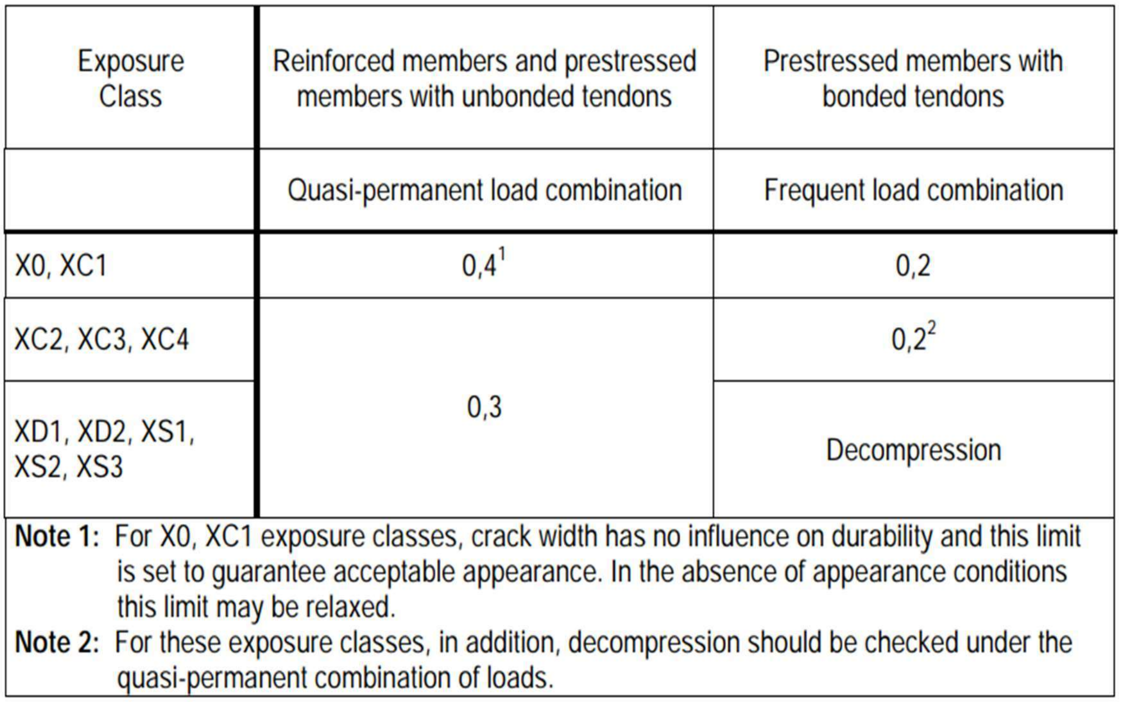
Figure 6 Detailing reinforcement of the slab



4.3 Limiting crack width

The main aspect of controlling cracks is limiting the crack width, and the factors that affect the crack width are the reinforcement bar diameter of the tension bars and spacing of the slab, the thickness of the concrete slab, and loading of the slab-like dead load and live load. After taking into consideration these factors, the crack width can be affected also. For limiting the crack width short spacing must be used as well as a small bar diameter for reinforcement. Eurocode presents acceptable crack width limit values, allowable crack width values according to The Finnish National Annex are shown in Table 4.1. (EN 1992-1-1:2004, 2004, p. 119)

Table 1 shows recommended maximum crack width values (mm), according to Finnish National Annex



Exposure Class	Reinforced members and prestressed members with unbonded tendons	Prestressed members with bonded tendons
	Quasi-permanent load combination	Frequent load combination
X0, XC1	0,4[1]	0,2
XC2, XC3, XC4	0,3	0,2[2]
XD1, XD2, XS1, XS2, XS3		Decompression

Note 1: For X0, XC1 exposure classes, crack width has no influence on durability and this limit is set to guarantee acceptable appearance. In the absence of appearance conditions this limit may be relaxed.

Note 2: For these exposure classes, in addition, decompression should be checked under the quasi-permanent combination of loads.

4.4 Minimum reinforcement for crack control

Minimum reinforcement is required for controlling cracks in the section where tension stress is expected. The appropriate amount of reinforcement may be estimated from the equilibrium between the tensile force in concrete just before cracking and the tensile force in the bar at yielding or at lower stress if necessary to limit the crack width. (EN 1992-1-1:2004, 2004, p. 119)

4.5 Calculation of crack width according to EC2

Crack width must be limited to a certain value, which in this case, is limited to 0.4 mm, since the concrete slab is inside a building with low air humidity. This case study slab is subjected to pure bending, and the neutral axis for the cracked section will be analyzed by using the elastic modulus of concrete for the short-term load.

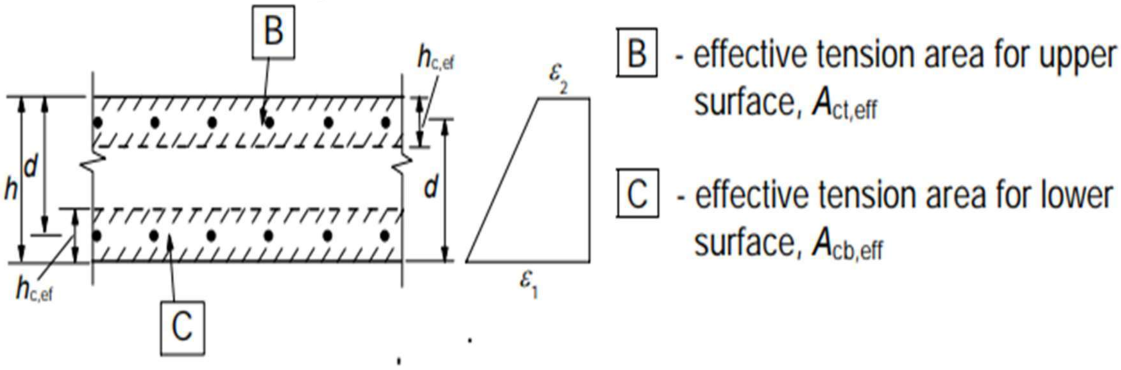
Calculating the cracking moment for the cross-section is needed to assess the steel stress caused by pure bending if cracking occurs. The effectiveness of tensile strength is assumed

as the mean value of the tensile strength of concrete, which is 3.2MPa for concrete C35/45.

$$\mathrm{M_{cr}} = \mathrm{f_{ct,eff}} * \frac{bh^2}{6} = 3.2MPa * \frac{1000mm * (200mm)^2}{6} = 21.33kNm$$

Therefore, if the bending moment is greater than a cracking moment, cracks will occur.

Figure 7 shows the effective tension area and effective height of slab



The procedure of calculation of the crack width according to EC2 follows:

Determining the parameter of the ratio between the elastic modulus of steel and concrete, and the reinforcement ratio.

Determining the ratio of reinforcement within the effective area of the concrete in tension.

Determining maximum crack.

Determining steel stress.

Finally calculating crack width.

All detailed calculation are provided in the appendix.

5 Conclusion

Slabs are vulnerable to shrinkage cracks, and air temperature, wind velocity, sunlight, and relative humidity play important role in the hydration and shrinkage of the slab.

Even though plastic shrinkage cracks develop at normal temperatures, this case is associated with concreting the slab under hot-weather conditions. A higher rate of water evaporation means that sufficient water may not be available for the hydration of cement. In this case study the various factors, were examined and it was discovered that cracks occurred due to loss of moisture on the surface of the slab, which results in a reduction in volume, as the stress of the slab concrete exceeds it is tensile capacity, therefore stress developed and finally cracks appeared on the surface of the slab. Shrinkage affects the durability of the concrete slab, and it is physical appearance, however, it is crucial to consider cracks that can potentially form weakness in the concrete slab, which may eventually cause moisture passageway and finally can lead to rusting reinforcement, for that reason treatment is needed.

There are different methods of crack repairing such as Epoxy injection, routing, sealing, drilling, plugging, etc. To preserve the integrity of the slab in long term, it was recommended that an appropriate method to fix cracking that measures 0.05 mm in width or bigger, Epoxy injection was selected to bond together the cracked section.

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Appendix 1: Name of Appendix

Made by Salman Ahmed

Data Input

$f_{yk} := 500\ \mathbf{MPa}$	EN 1991-1-1,2004, PP.31
$E_s := 210\ \mathbf{GPa}$	EN 1991-1-1,2004, PP.31
$\gamma_s := 1.15$	SFS-EN-1992-1-1 table 2.1N
$\phi_s := 16\ \mathbf{mm}$	Diameter of longitudinal reinforcement rebar
$f_{ck} := 35\ \mathbf{MPa}$	Characteristics of cylinder strength of
$f_{ctm} := 2.9\ \mathbf{MPa}$	Mean value of the tensile strength of concrete EN 1991-1-1,2004, PP.31
$\gamma_c := 1.5$	SFS-EN-1992-1-1 table 2.1N
$E_{cm} := 34\ \mathbf{GPa}$	Modulus of elasticity of concrete EN 1991-1-1,2004, PP.31
$acc := 0.85$	SFS-EN-1992-1-1
$\mu_{bd} := 0.49$	SFS-EN-1992-1-1
$\beta_{bd} := 0.493$	SFS-EN-1992-1-1
XC3	Exposure class
ULS	ultimate limit state design
SLS	serviceability limit state design

$c_{nom} := 25\ mm$	Asummed
$h := 200\ mm$	Assume the height of the slab
$b := 1000\ mm$	Assume the width of the slab
$L := 6\ m$	Length of the slab

Designing loads

$\gamma_C := 25\ \frac{kN}{m^3}$	Density of concrete
$h_{scr} := 0.05\ m$	Screed height
$Fin_{layer} := 1.0\ \frac{kN}{m^2}$	Finnishing layer is assumed
$D_l := \gamma_C \cdot h + h_{scr} \cdot \gamma_C + Fin_{layer} = 7.25\ \frac{kN}{m^2}$	Dead load on the slab per m^2
$L_{load} := 2.5\ \frac{kN}{m^2}$	Live load category A
$A_t := 1\ m$	The tributary area of the slab
$L_L := L_{load} \cdot A_t = 2.5\ \frac{kN}{m}$	Live load on the slab
$D_L := D_l \cdot A_t = 7.25\ \frac{kN}{m}$	Dead load on the slab
$Q_D := \frac{D_l \cdot L}{2} = 21.75\ \frac{kN}{m}$	Shear force due to dead load

$$Q_L := \frac{L_{load} \cdot L}{2} = 7.5 \ \frac{kN}{m}$$

Shear force due to live load

$$M_D := \frac{D_l \cdot L^2}{8} = 32.625 \ kN$$

Bending moment due to dead load

$$M_L := \frac{L_{load} \cdot L^2}{8} = 11.25 \ kN$$

Bending moment due to live load

Load combinations

Consequence class

$$k_{fi} := 1$$

Design load of ULS

$$Q_{ULS} := k_{fi} \cdot 1.35 \cdot Q_D = 29.363 \ \frac{kN}{m}$$

Design load of SLS

$$Q_{ULS} := k_{fi} \cdot 1.15 \cdot Q_D + k_{fi} \cdot 1.5 \cdot Q_L = 36.263 \ \frac{kN}{m}$$

$$M_{ULS} := 1.15 \cdot M_D \cdot k_{fi} + 1.5 \cdot M_L \cdot k_{fi} = 54.394 \ m \cdot \frac{kN}{m}$$

Design moment of ULS

Designing longitudinal reinforcement for ULS

$$f_{cd} := acc \cdot \frac{f_{ck}}{\gamma_c} = 19.833 \ MPa$$

Ccompressive design
strength of concrete

$$f_{yd} := \frac{f_{yk}}{\gamma_s} = 434.783 \ MPa$$

Design yield strength of reinforcement

$$A_s := \frac{\pi \cdot {\phi_s}^2}{4} \cdot \frac{1000 \ mm}{200 \ mm} = \left(1.005 \cdot 10^3\right) \ mm^2$$

Area of steal

$$d := h - c_{nom} - \frac{1.1 \cdot \phi_s}{2} = 166.2 \ mm$$

effective depth of the slab

$\omega := \frac{A_s}{b \cdot d} \cdot \frac{f_{yd}}{f_{cd}} = 0.133$ coefficient

$\beta := min\left(\omega, \beta_{bd}\right) = 0.133$ coefficient

$\mu := \beta \cdot \left(1 - \frac{\beta}{2}\right) = 0.124$ Coefficient

$M_{Rd.ULS} := \mu \cdot f_{cd} \cdot b \cdot d^2 = 67.828\ \mathbf{kN \cdot m}$ Moment resistance design

$UR := \frac{56.981}{67.828} = 0.84$ 84% *ok* Utilization ratio of $M_{ULS} / M_{Rd.ULS}$

Member not required design shear force reinforcement

$\rho_l := min\left(\frac{A_s}{b \cdot d}, 0.02\right) = 0.006$ Reinforcement ratio for longitudinal reinforcement

$k := min\left(1 + \sqrt{\frac{200\ \mathbf{mm}}{166\ \mathbf{mm}}}, 2\right) = 2$

In slabs σ_{cp} is taken zero commonly

$\sigma_{cp} := 0$

$v_{min} := 0.35 \cdot k^{\frac{3}{2}} \cdot \sqrt{f_{ck} \cdot \frac{\mathbf{MPa}}{1}} = 5.857\ \mathbf{MPa}$ EN 1992-1-1:2004, equation (6.3N)

$C_{Rd.c} := \frac{0.18}{\gamma_c} = 0.12$

$v_{Rd.c} = \max\left(C_{Rd.c} \cdot k \cdot \left(100 \cdot \rho_l \cdot f_{ck}\right)^{\frac{1}{3}}, v_{min}\right) + k_1 \cdot \sigma_{cp} + k_1$ EN 1992-1-1:2004, equation (6.2a)

$v_{Rd.c} := \max\left(0.66\ \mathbf{MPa}, 0.58\ \mathbf{MPa}\right) = 0.66\ \mathbf{MPa}$

$V_{Rd.c} := v_{Rd.c} \cdot b \cdot d = 109.692\ \mathbf{kN}$ Shear resistance design

$V_{Ed} := Q_{ULS}$

Design shear

$V_{Ed} := 38\ \mathbf{kN}$

$UR := \frac{V_{Ed}}{V_{Rd.c}} = 0.346$ 35% OK Utilization ratio $V_{Ed} / V_{Rd.c}$

Checking the utilization of characteristic combination of the slab in SLS

$Q_{CH} := Q_D + Q_L = 29.25\ \frac{\mathbf{kN}}{\mathbf{m}}$ characteristic shear design load

$M_{Ed.CH} := M_D + M_L = 43.875\ \mathbf{kN}$ characteristic moment design

$M_{Ed.CH} := 44\ \mathbf{kN} \cdot \mathbf{m}$ characteristic moment design

FINNISH NA

$k_1 := 0.6$

FINNISH NA

$k_3 := 0.6$

$n_{CH} := \frac{E_s}{E_{cm}} = 6.176$

$b_{ch} := n_{CH} \cdot A_s = \left(6.209 \cdot 10^3\right)\ \mathbf{mm}^2$

$a_{ch} := \frac{b}{2} = 0.5\ \mathbf{m}$

$c_{ch} := n_{CH} \cdot A_s \cdot d = \left(1.032 \cdot 10^6\right)\ \mathbf{mm}^3$

$$x_{CH} := \frac{-b_{ch} + \sqrt[2]{{b_{ch}}^{2} + 4 \cdot a_{ch} \cdot (c_{ch})}}{2 \cdot a_{ch}} = 0.04\ \mathbf{m}$$

the distance to the neutral axis

$$C_{ch} := k_1 \cdot f_{ck} \cdot \frac{1}{2} \cdot b \cdot x_{CH} = 416.261\ \mathbf{kN}$$

$$T_{ch} := k_3 \cdot f_{yk} \cdot A_s = 301.593\ \mathbf{kN}$$

$$M_{Rd.ch} := min\left(C_{ch}, T_{ch}\right) \cdot \left(d - \frac{x_{CH}}{3}\right) = 46.139\ \mathbf{kN \cdot m}$$

Moment resistance of charactristic design

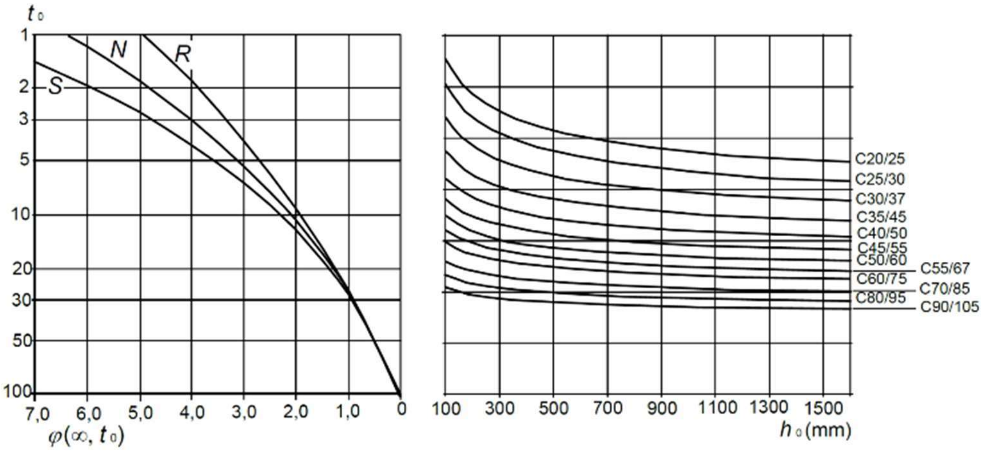
$$UR_{ch} := \frac{M_{Ed.CH}}{M_{Rd.ch}} = 0.954$$

95% *ok* Utilization ratio of $M_{ED.CH}/M_{Rd.CH}$

Checking the utilization of quasi permanent combination of the slab in SLS

$\psi_2 := 0.3$	Live load category is assumed to be A
$k_2 := 0.45$	Finnish NA
$k_3 := 0.6$	Finnish NA
$RH := 80$	Relative humidty
$A_c := b \cdot h = 0.2\ \mathbf{m}^2$	Area of the slab cross section
$u := 1000\ \mathbf{mm}$	Perimeter of the slab
$h_0 := \frac{2 \cdot A_c}{u} = 0.4\ \mathbf{m}$	The notinal size

Shrinkage and creep in Eurocode…



a) inside conditions - RH = 50%

Creep coefficient is close to 2.5 based on table above

$\phi := 2.5$

$$n_{QP} := \frac{E_s}{\dfrac{E_{cm}}{1+\phi}} = 21.618$$

The ratio between the elastic modulus of steel and concrete and creep coefficient

$b_{QP} := n_{QP} \cdot A_s = 0.022\ \mathbf{m}^2$

$a := \frac{b}{2} = 0.5\ \mathbf{m}$

$c := n_{QP} \cdot A_s \cdot d = \left(3.612 \cdot 10^6\right)\ \mathbf{mm}^3$

$$x_{QP} := \frac{-b_{QP} + \sqrt[2]{{b_{QP}}^2 + 4 \cdot a \cdot (c)}}{2 \cdot a} = 0.066\ \mathbf{m}$$

the distance to the neutral axis

$C_{QP} := k_2 \cdot f_{ck} \cdot \frac{1}{2} \cdot b \cdot x_{QP} = 519.713\ \mathbf{kN}$

Compresion force

$T_{QP} := f_{yk} \cdot A_s = 502.655\ \mathbf{kN}$ Tension force

$M_{RdQP} := min\left(C_{QP}, T_{QP}\right) \cdot \left(d - \frac{x_{QP}}{3}\right) = 72.484\ \mathbf{kN \cdot m}$ Moment resistance quasi permenent design

$M_{EdQP} := M_D + \psi_2 \cdot M_L = 36\ \mathbf{kN}$ Moment quasi permanent design

$M_{EdQP} := 36\ \mathbf{kN \cdot m}$

$UR_{QP} := \frac{M_{EdQP}}{M_{RdQP}} = 0.497$ 50% *ok* Utilization ratio of $M_{ED.QP} / M_{Rd.QP}$

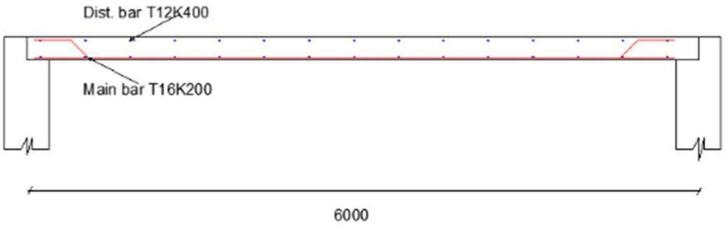
Detailing of the rebar in Ch.9.3 of EC-2

$A_{s.min} := \max\left(0.26 \cdot \frac{f_{ctm}}{f_{yk}}, 0.0013\right) \cdot b \cdot d = 250.63\ \mathbf{mm^2}$ The minimum area of reinforcing steel within the tensile zone

$A_{s.provided} > A_{s.min}$ $A_{s.min}$ is not limited by Finnish N.A

$n := \frac{4 \cdot A_s}{\pi \cdot \phi_s^{\,2}} = 5$ so T16k200 , $\frac{1\ bar}{m} > A_{s.min}$, $1 \cdot \pi \cdot \frac{\phi_s^{\,2}}{4} = 201.062\ \mathbf{mm^2}$

secondary reinforcement will be used ϕ_s =12mm instead of ϕ_s =16mm
becouse ϕ_s =16 will have larger spacing T16K500, but ϕ_s =12 will be T12k400



Crack width according to EC2

$$A_{s.} := \frac{1000\ mm}{200\ mm} \cdot \frac{\pi \cdot (16\ mm)^2}{4} = 0.001\ m^2$$

$w_{max} := 0.4\ mm$ Crack width Recommended values of wmax (mm)

$\alpha := \frac{E_s}{E_{cm}} = 6.176$ The ratio between the elastic modulus of steel and concrete

$\rho := \frac{A_s}{d \cdot b} = 0.006$ Rreinforcement ratio

$\frac{\varepsilon_c}{\varepsilon_s} = \rho \cdot \alpha + \sqrt{\rho \cdot \alpha \cdot (2 + \rho \cdot \alpha)} = 0.313$ The ratio between steel and concrete strains

$h_{c.ef} := min\left(2.5 \cdot (h - d), \frac{h - x_{QP}}{3}, \frac{h}{2}\right) = 44.668\ mm$ The effective tension height

$A_{c.eff} := h_{c.ef} \cdot b = \left(4.467 \cdot 10^4\right)\ mm^2$ The effective tension area

$\rho_{\rho.eff} := \frac{A_s}{A_{c.eff}} = 0.023$ Effective reinforcement ratio, EN 1992-1-1:2004, equation (7.10)

$k_t := 0.4$ is a factor dependent on the duration of the load, long term loading

$k_1 := 0.8$ Bars are assumed to have good bond characteristics

$k_2 := 0.5$ In case of bending

$k_3 := 3.4$ Recommended value

$k_4 := 0.425$ Recommended value

$$S_{r.max} := k_3 \cdot c_{nom} + k_1 \cdot k_2 \cdot k_4 \cdot \frac{\phi_s}{\rho_{\rho.eff}} = 205.856\ \mathbf{mm}$$

maximum crack spacing,
EN 1992-1-1:2004, equation (7.11)

Steel stress in the bar

$$\sigma_s := \frac{M_{EdQP}}{A_s \cdot \left(d - \frac{x_{QP}}{3}\right)} = 248.332\ \mathbf{MPa}$$

ε_{sm} is the mean strain in the reinforcement under the relevant combination of loads, including the effect of imposed deformations and taking into account the effects of tension stiffening

ε_{cm} is the mean strain in the concrete between cracks

EN 1992-1-1:2004, equation (7.9)

$$\varepsilon_{sm} - \varepsilon_{cm} = max\left(\frac{\sigma_s - k_t \cdot \frac{f_{ctm}}{\rho_{\rho.eff}} \cdot \left(1 + \alpha \cdot \rho_{\rho.eff}\right)}{E_s}, \frac{0.6 \cdot \sigma_s}{E_s}\right) = \left(9.03 \cdot 10^{-4}\right)$$

$$w_k := S_{r.max} \cdot \left(9.03 \cdot 10^{-4}\right) = 0.186\ \mathbf{mm}$$

Crack width, EN 1992-1-1:2004, equation (7.8)

$UR_{crack} := \frac{w_k}{w_{max}} = 0.465$ 47% *ok*

Appendix 2: Name of Appendix

Figure 8 shows the bending moment and shear force of the slab due to live load

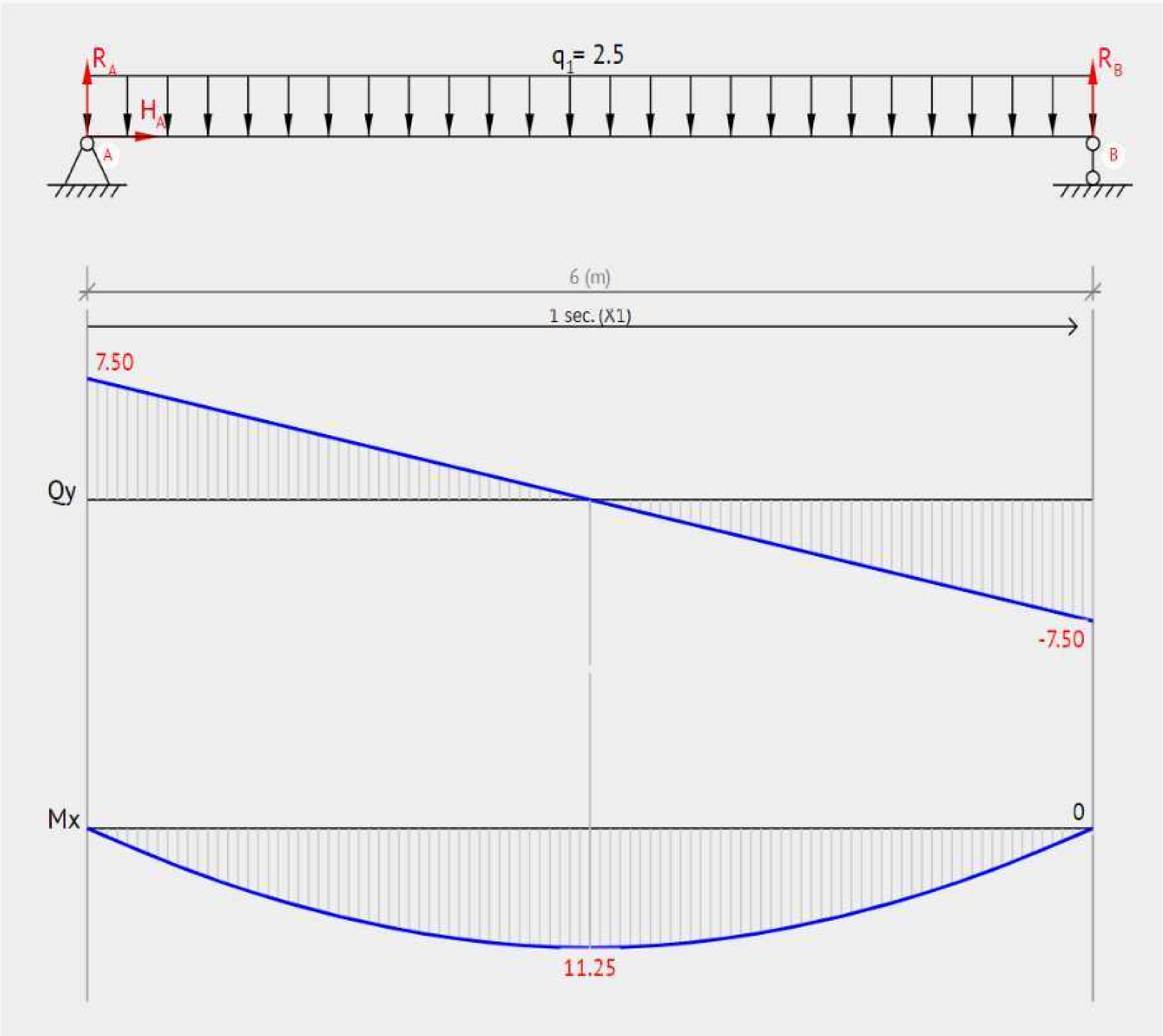


Figure 9 shows the bending moment and shear force of the slab due to dead load

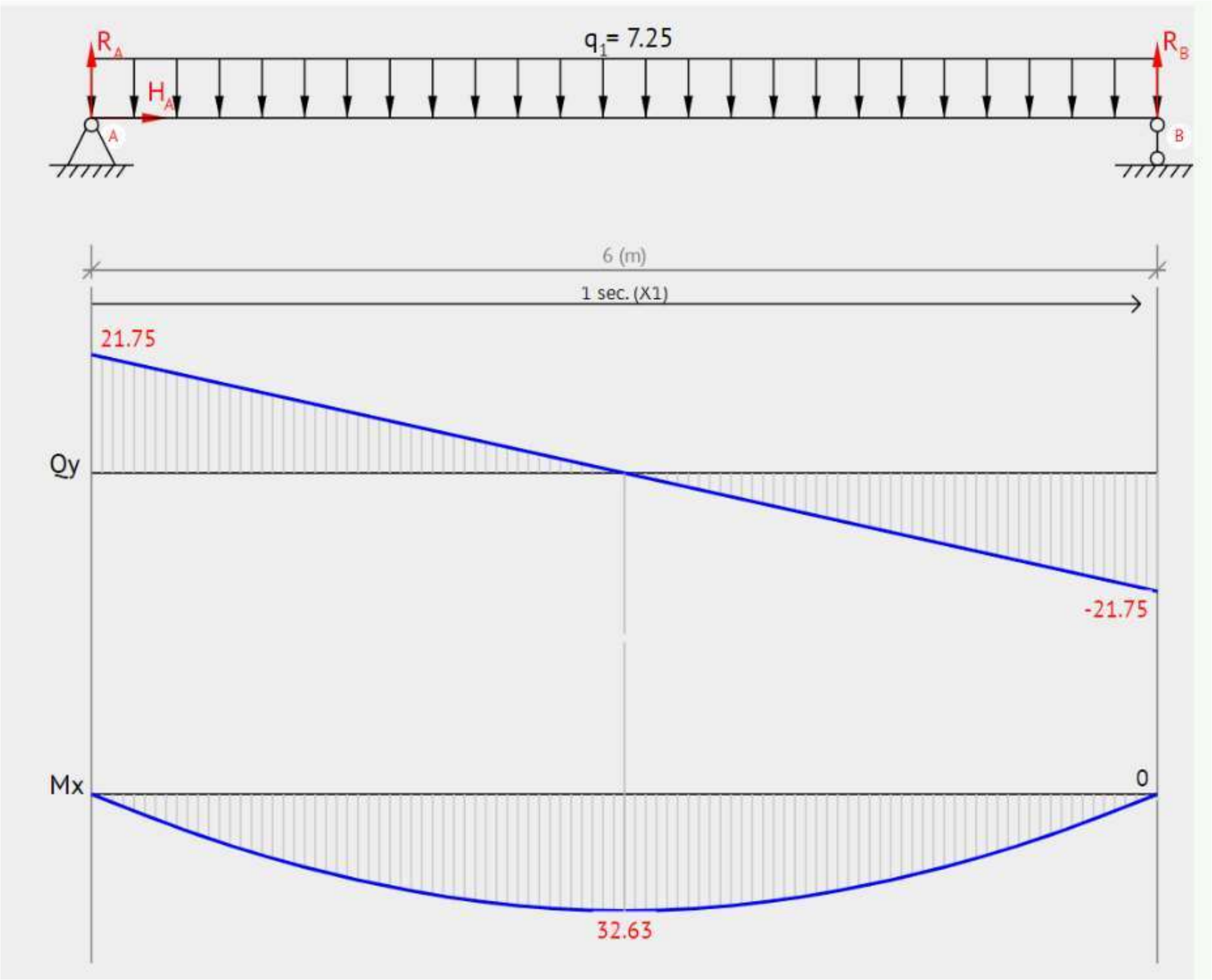


Figure 10 shows poured slab

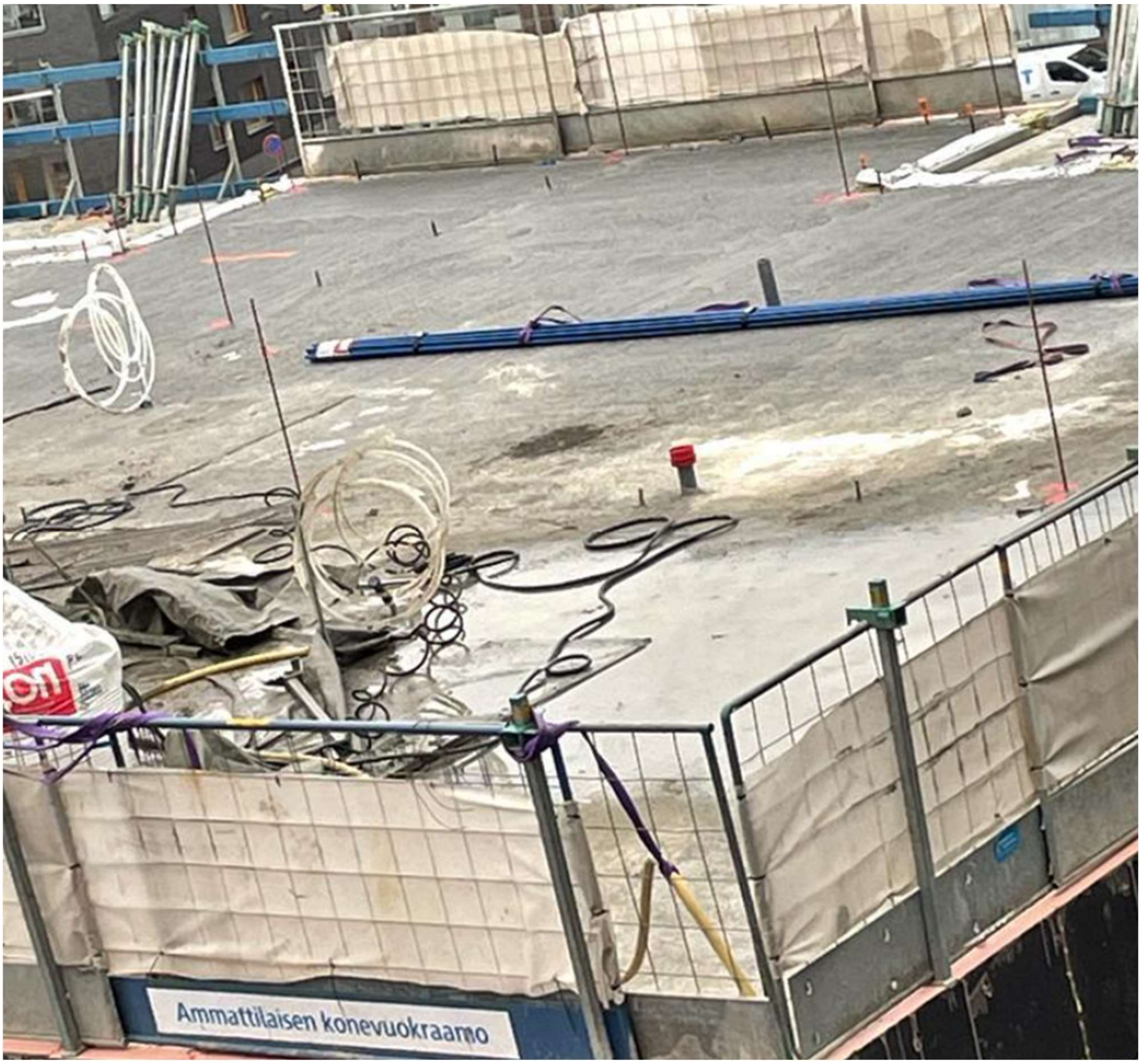


Figure 11 shows a cracked slab

Figure 12 shows injected slab