

Saimaa University of Applied Sciences  
Technology, Lappeenranta  
Double Degree Programme in Civil and Construction Engineering

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# **Early stripping of slab formwork according to Russian standards**

Bachelor's Thesis 2015

## **Abstract**

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Early stripping of slab formwork according to Russian standards, 37 pages, 1 appendix

Saimaa University of Applied Sciences, Lappeenranta Technology, Civil and Construction Engineering

Double Degree Programme in Civil and Construction Engineering Thesis 2015

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The purpose of this work was to make an overview of the modern methods for early stripping of slab formwork. The concrete technology was observed as a basis for every stripping procedure. Methods of concrete strength determination were examined according to Russian standards. The main points and the possibility of implementation of the maturity method were also considered. Doka Concremate was reviewed as an effective and economical solution for a real-time concrete monitoring tool.

The main idea of early stripping was disclosed and the recommendation according to ACI 347.2R-05 was presented.

The work was written subject to the following Russian standards: SP 48.13330.2011 "Organization of construction", SP 70.13330.2012 "Load-bearing and separating constructions", SP 63.13330.2012 "Concrete and won concrete construction. Design requirements", GOST 28570, GOST 22690, GOST 17624, GOST R 53231.

Keywords: slab, formwork, repropping, reshoring, backpropping, concrete maturity, maturity method, formwork stripping, concrete strength.

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## Terminology

Repropping (reshoring)	method of supporting new slabs in order to transfer the construction loads onto the slabs below the one being constructed.
Formwork stripping / striking / dismantling / early stripping	removal of the formwork when the concrete is cured and gained target strength value. The slab is stripped before the concrete reaches its 28-day strength.
Backpropping	method of supporting new slabs that is less widely used and suppose leaving the original shores in place or replacing them individually so as not to allow the slab to deflect and carry its own weight.
Early stripping with activation of the slab	the formwork is removed when the slab can bear its own dead weight. All the props are stress-relieved, deflection of the slab establishes itself and the floor-slab is 'activated' ready to transfer further loads.
Early stripping without activation of the slab	the formwork is removed section by section. The section of the slab temporarily without support must have sufficient strength to bear its dead load.

# **1 Introduction**

## **1.1 The proposition and the actuality of the work**

Nowadays the ever-changing world with its growing population and galloping speed of everyday life requires the construction industry to fulfil all the consequently emerging demands. On the other hand, building companies want to make the construction processes as cheap as possible keeping the quality at the same rate. In the process of constructing a building, one of the most time-consuming processes is making slabs. As the wall formwork can be removed after 24 hours after pouring in most cases slab formwork has to be cured for at least 7 days without being loaded. This makes the construction long and expensive. In Europe and the USA solutions for this issue have already been offered, i.e. reshoring of the slab to provide an opportunity for earlier loading of it and pouring further slabs. However, in Russia such an approach was only mentioned by a few researchers and has not been yet included in any standard. As early stripping can lead to significant cut on the construction time and, thus, on the construction costs it seems reasonable to investigate this subject more detailed.

## **1.2 Russian regulations for concrete works**

Requirements for handling the concrete works on a building site are defined in Russia by SP 48.13330.2011 "Organization of construction". The process of erecting bearing structures and the required times are described in SP 70.13330.2012 "Load-bearing and separating constructions".

# **2 Concrete technology**

Like any other bearing structures, bending concrete elements, e.g. slabs and beams, have to bear the design load without failure and large deflections.

Therefore they are dependent on two main parameters of concrete: compressive strength and elasticity module.

## **2.1 Concrete strength development**

A concrete element is expected to serve many years. In order to last this expected service life in working condition, it must be able to withstand repetitive loadings, fatigue, atmospheric forcing, chemical attack, etc. The duration and model of curing plays a significant role in determining the required concrete mixture necessary to achieve the high level of quality.

Curing occurs after placing of concrete and requires maintenance of sufficient temperature and moisture, both at depth and near the surface. Well-cured concrete has enough moisture for hydration and strength development, resistance to the cycles of freezing and thawing, abrasion and scaling resistance.

The curing time depends on the following factors:

- concrete mixture;
- design strength;
- size and shape of concrete element;
- atmospheric conditions;
- further exposure conditions.

Usually specified 7-day curing generally corresponds to approximately 70 percent of the designed compressive strengths. The 70 percent strength level can be reached faster if concrete cures at higher temperatures or when certain concrete mixtures are used. Similarly, longer curing time may be needed for certain concrete mixtures and/or lower curing temperatures.

Effect of curing duration on compressive strength development is presented in Figure 1.

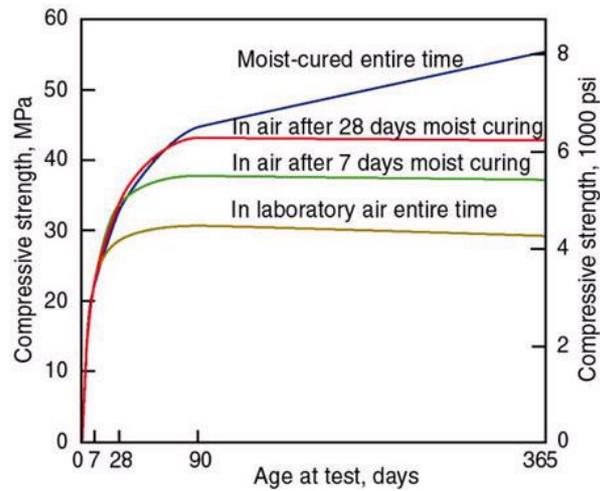


Figure 1. Moist curing time and compressive strength gain

Higher curing temperatures provide an early strength gain of concrete but may decrease its 28-day strength. Effect of curing temperature on compressive strength development is presented in Figure 2.

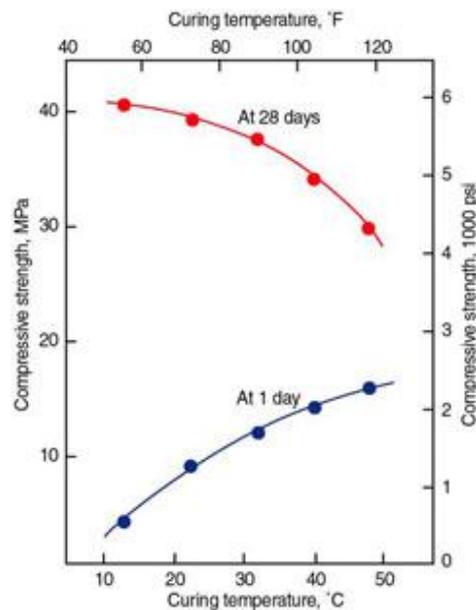


Figure 2. Effect of curing temperature on compressive strength

## 2.2 Deflection

After 3 days of curing, the modulus of elasticity of the concrete reaches more than 90% of the design value, regardless of the concrete mixture. The development of the elastic deformation in the green concrete is therefore insignificant. The creep deformation, which finally ends after several years, is notably

more than the elastic deformation. However, early stripping – e.g. after 4 days instead of 28 – leads to an increase in the overall deformation of less than 5%. The deformation caused by creep deformation, however, may be anything between 50% and 100% of the standard value, depending on such parameters like strength of the aggregates and the atmospheric conditions. This means that the overall deflection of the floor-slab is practically independent of the striking time of the formwork.

### 3 Determination of concrete strength on site

#### 3.1 Methods of evaluating concrete strength

Further mentioned concrete strength is meant to be the compressive strength of the concrete.

Research of concrete strength has to be held according to GOST 28570, GOST 22690, GOST 17624, GOST R 53231 and STO. Conventionally all the methods in use can be divided into three groups depicted in Figure 3.

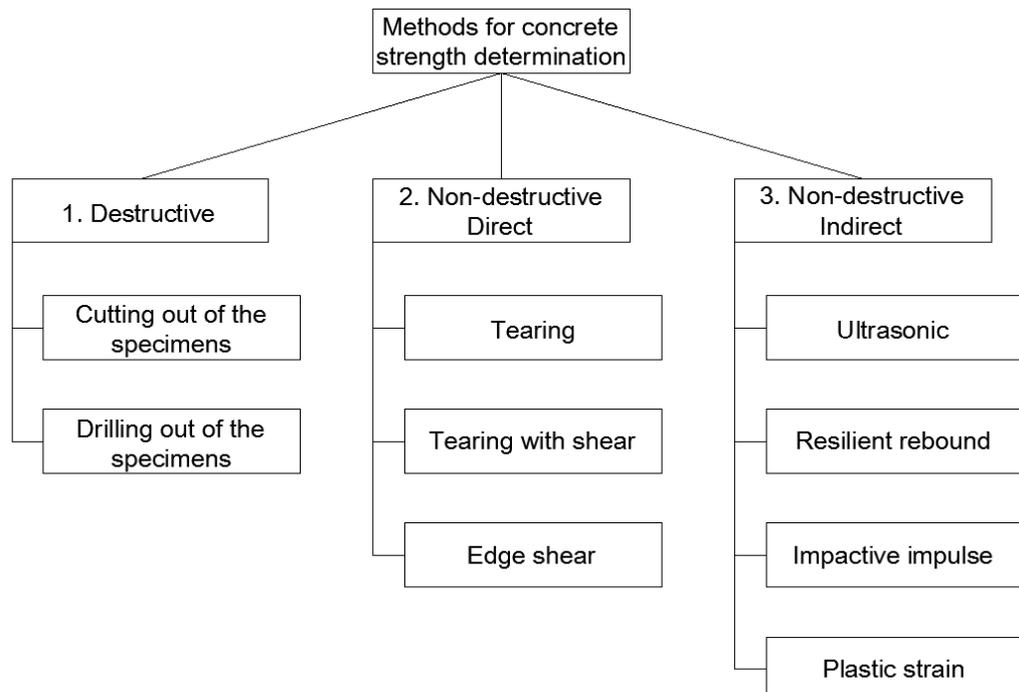


Figure 3. Classification of the methods to determine concrete strength

The results obtained by methods of the first group best correspond to the real material strength value. The reasons are as follows:

- the exact desired parameter is measured – the load when compressive failure occurs;
- the specimen taken from the structure body is examined, not only the surface layer is considered;
- the influence of external conditions (humidity, reinforcement, surface layer defects and others) can be minimized

However, this approach is rarely used for ordinary objects. There are three main reasons for that: high costs of equipment, high labour consumption of measurement and, thus, its prime cost, and local damage of the structure, which in most cases is not allowed.

Generally non-destructive methods are used. Though the most of the tests are made using indirect non-destructive methods. All the indirect non-destructive strength-control methods usually require only the measuring unit. Labour consumption is only determined by measuring the required parameter.

Some studies showed that the methods of the 3<sup>rd</sup> group have significant benefits. They require less time and the cost of each test is lower. Moreover, all the indirect methods are fully non-destructive and cause no damage to structure during the measurements. These factors are the main reason why methods of this group are the most popular among construction companies.

However, the legal usage of those methods is doubtful. According to section 3.14 GOST 22690, the determination of concrete strength requires a calibrating relation between the concrete strength and indirect strength characteristic (as a graph, table of equation). The usage of methods with rebound hammer, shock pulse or plastic deformation is possible only by making the calibrating relation, which means it is necessary to test concrete using methods 1 or 2.

Due to section 3.16 GOST R 53231 the usage of all the indirect control methods is possible only by formulating the calibration relation. According to section 8.3.1 and Appendix B SP 13-102, the determination of concrete strength is performed by non-destructive methods in compliance with GOST 22690 and without forming the calibration relation can only be held by methods of groups 1 and 2.

In other words, the usage of strength control methods from group 3 without forming the calibration relation is forbidden, but the need for this relation leads to unavoidable usage of methods 1 and 2.

The basis for such a coarse approach is as follows:

- high uncertainty of the measurement results. Besides the possible meter error, external factors play a more significant role. They are:
- concrete surface handling;
- occurrence of the reinforcement close to measurement point;
- big aggregate inclusions;
- coating surface damages (defreezing, moistening and other erosion types)
- human element
- other factors

All the listed factors always occur in any combination, and their minimization is either impossible or reduces measurement productivity a lot. Nevertheless, even with minimized influence of external factors by careful preparations, additional studies and statistical processing of measurement results and their screening, the obtained result cannot be used without specific calibration relation for the exact studied concrete.

Establishment of calibration relation, for example, for ultrasonic method according to the requirement of section 3.4 GOST 17624 means testing of 30 cubes (15 series of 2 cubes). In most of the medium-scale projects making so much direct tests negates the necessity of using non-destructive methods. Moreover,

getting customers' agreement for such a huge structure damaging (unavoidable during tests) is hardly possible.

It must be said that even by abiding the minimum number of specimens for forming the calibration relation the relation found can appear to be insufficient for the standards requirements (mean square deviation, constant of variation).

## **3.2 Maturity method**

### **3.2.1 General idea**

The maturity method is based on the principle that concrete strength depends on both age and its temperature. Maturity methods provide a relatively simple approach for determining the early-age compressive strength of concrete during the construction process. The maturity concept claims that specimens of a concrete mixture of the same maturity will have similar strengths, regardless of the combination of time and temperature causing the maturity. The measured maturity index of monolithic concrete is a function of temperature development and age and is used to evaluate its strength development based on a predefined calibration of the time-temperature-strength relationship based on laboratory tests for the exact mixture (Malhotra & Carino 2003).

Maturity method is used as a more trustworthy criterion of the in-place strength of concrete during construction instead of testing field-cured cubes. The conventional approach of measuring the strength of field-cured cubes, cured in the same conditions as the structure, are used to schedule construction activities such as formwork stripping or reshoring, walls backfilling, schedule prestressing and post-tensioning operations. Maturity methods use the fundamental concept that concrete properties develop with time as the cement hydrates and releases heat. The rate of strength development at early ages is related to the rate of hydration of cement. Heat generated from the hydration reaction will be recorded as a temperature rise in the concrete. The main advantage of the maturity method is that it uses the real temperature of the concrete in the structure to es-

timate its in-place strength. The traditional approach of using field-cured cubes does not repeat the same temperature profile of the in-place concrete and likely does not accurately estimate its in-place strength. With the maturity method strength information is provided in real-time since maturity measurements are made on-site at any time. As a result, the construction schedule is optimised, and construction activity timing can be based on more accurate in-place strength information.

### **3.2.2 Weighed maturity**

The fact that the gain of concrete strength depends on the setting temperature is well known. High temperature lead to higher early strength than low temperatures. In the early 1950s, Saul defined maturity as the result of time and the setting temperature of the concrete (beginning at  $-10\text{ }^{\circ}\text{C}$ ). As Saul had over-eased the relation between temperature and compressive strength, his method had few sense. The effect of various cement types on the gain of compressive strength were disregarded (Newmann & Choo 2003).

In 1973, Bresson and Papadakis presented a maturity method introducing a factor that takes into consideration the sensitivity of the cement to temperatures. According to this method, the higher temperatures are weighed with a higher value than the lower temperatures. This approach is called “weighed maturity“. The disadvantage of this exact approach is that Papadakis and Bresson had considered only temperatures above  $20\text{ }^{\circ}\text{C}$ .

Accordingly, lower temperatures were assumed to have the same effect on all types of cement, which is not the case. De Vree adjusted the method developed by Papadakis and Bresson in such a way that it can also be applied in temperatures below  $20\text{ }^{\circ}\text{C}$ .

### **3.2.3 Method according to de Vree**

Despite the methods according to Papadakis and Bresson and de Vree are similar they are not interchangeable. The maturity calculated with de Vree’s

method differs numerically from that proposed by Papadakis and Bresson. The weighed maturity according to de Vree is calculated as follows:

$$Rg = \frac{10[C^{(0.1T-1.245)} - C^{(-2.245)}]}{\ln C} \quad (1)$$

Accordingly:

Rg - weighed maturity in one hour [°C.h]

T - mean setting temperature of the concrete in this hour [°C]

C - cement-specific parameter

### 3.2.4 Computation of the weighed maturity according to de Vree

The maturity weighed over a period of more than one hour is determined by adding the calculated degrees of maturity per hour. In Table 1, the maturity reached at various setting temperatures and C-values per hour, calculated by the de Vree method, is presented. Accordingly, e.g. a concrete made with cement with at C-value of 1.6, which sets at a temperature of 8 °C, has gained a maturity of 10°C.h after one hour. After 24 hours cured at the same temperature, the concrete will have a weighed maturity of 24x10°C.h=240 °C.h (Egmond & Jacobs 1999).

Temperature [°C]	C-value						
	1.3	1.35	1.4	1.45	1.5	1.55	1.6
6	11	10	10	9	9	9	8
7	12	11	11	10	10	9	9
8	13	12	12	11	11	10	10
9	14	13	12	12	12	11	11
10	15	14	13	13	12	12	12
11	16	15	14	14	13	13	13
12	17	16	15	15	14	14	13
13	18	17	16	16	15	15	14
14	19	18	17	17	16	16	15
15	20	19	18	18	17	17	17
16	21	20	20	19	19	18	18
17	22	21	21	20	20	19	19
18	23	22	22	21	21	21	20
19	24	24	23	23	22	22	22
20	25	25	24	24	24	23	23

21	27	26	26	25	25	25	24
22	28	27	27	27	26	26	26
23	29	29	28	28	28	28	28
24	30	30	30	30	29	29	29
25	32	32	31	31	31	31	31
26	33	33	33	33	33	33	33
27	35	35	35	35	35	35	35
28	36	36	36	36	36	37	37
29	38	38	38	38	38	39	39
30	39	39	40	40	40	41	41
40	57	59	61	63	65	68	70
50	81	86	91	97	103	110	117
60	112	122	133	146	160	175	191
70	151	170	192	217	244	276	311
80	203	236	275	319	372	432	502

Table 1. C-value

Strip	Mean temperature	Weighed maturity to Table 1 maturity	Accumulated weighed maturity
1	13	18	18
2	21	27	45
3	34	46	91
4	48	76	167
5	52	86	253
6	49	78	331
7	43	64	395
8	37	51	446

Table 2. Calculation of the weighed maturity

For a summary calculation of the weighed maturity after, for example, 8 hours of curing with a specific temperature curve, the mean temperature can be determined with the aid of the graphic divided into 8 parts and based on the mean temperature and the C-value for each hour. From example Table 2 the maturity can be calculated. The addition of these 8 values results in the maturity value after 8 hours of curing. For a concrete mixture based on the cement with a value of 1.30 the weighed maturity after 8 hours would then be 446 °Ch. Table 2 shows the computation process. The maturity computer masters this calculation job fast and accurately.

Application of the weighed maturity according to de Vree consequently requires knowledge of the cement-specific parameter (C-value). The C-value takes into account the cement sensitivity to the temperature and depends on the composition of the cement. Thus, the C-value must be determined individually for every type of cement. Determination of the C-value is based on measuring the development of strength of exact concrete mixture (Guidebook on non-destructive testing of concrete structures 2002).

For this purpose, either six prisms or ten 150-mm cubes are produced. Half of the test samples is placed into a water bath at 20°C, the other half at 65°C. The compressive strength is tested at different times. Here, care must be taken that the test results for each series are equally distributed over a specific strength range, which depends on the strength class of the tested cement. Based on experience, or with the aid of Table 3, a C-value is assumed with which the weighed maturity is calculated based on the previously established respective strength. When looking at the results as the points of a graphic, with the Y axis depicting the compressive strength (linear) and the X axis the maturity (logarithmic), then, by way of linear regression, the correlation factor of the line of regression can be calculated. After that, the C-value is changed and the correlation factor determined again (Lang 1997).

<b>Content of Portland cement clinker [M.-%]</b>	<b>C-value</b>
<b>&gt;65</b>	1.3
<b>50...64</b>	1.4
<b>35...49</b>	1.5
<b>20...34</b>	1.6

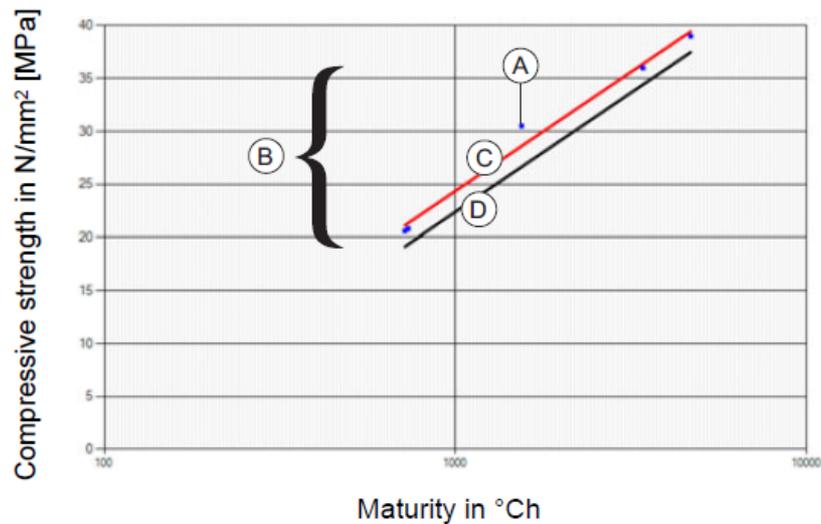
Table 3. C-values related to the content of Portland cement clinker

The C-value for which the highest correlation factor is found is considered to be the right one. Now the points will be lined up as best as possible. The C-value is normally determined by the cement manufacturer and can be obtained from him. It can also be determined in any laboratory equipped to harden specimens at 20°C and 65°C degrees.

### 3.2.5 Creation of a calibration graphic

Applying the weighed maturity for determining the compressive strength of concrete, a known increase of strength at a known curing temperature for particular concrete mixture must be assumed. Based on this information, a graphic can be drawn that shows the ratio between the weighed maturity and the compressive strength of a specific concrete mixture. This graph is called a calibration graphic (Figure 4). The calibration graphic is not only used for converting a calculated maturity into a compressive strength. It can also be used for predicting the point, where the designed compressive strength will be reached based on a previous temperature development and what compressive strength can be expected after a given time. Usually the calibration graphic is created and adjusted for all types of concrete which are used for construction processes on a particular site. For this reason the knowledge of the weighed maturity is required. When the concrete mixture is changed, whether it is a change in the type of cement and strength class or type of aggregate or in the water-cement ratio, a new calibration graphic must be made as the rate of strength gain may thus differ. The calibration graphic is always made for the strength range of interest to the intended concrete application. To ensure that the temperature in all test specimens is known and identical, the specimens are placed in a water bath of 20 °C in a well-insulated form where specimens are stored under defined semi-adiabatic conditions. The compressive strength is determined at various points in time, the respective maturity computed and the value entered in the calibration graphic.

With the weighed maturity according to de Vree, the temperature and the cement type used are taken into account as influencing criteria for the compressive strength. Apart from that, no other factors are considered – such as the water-cement ratio.



- A** Result of the compressive cube test
- B** Calibrated range
- C** Regression curve based on the compressive cube tests
- D** Calibration curve for further measurement

Figure 4. Calibration curve

### 3.2.6 Maturity computer

The maturity computer performs all measuring and computation tasks at a very fast rate. It measures the temperature development basing on maximally four points in the hardened concrete component with the aid of thermocouple measuring wires and calculates the maturity gain at every measuring point. The curing and the results can be read off in the display during or after measuring. The measuring frequency is ten per sensor and measuring interval. The measuring interval is coupled to the adjusted runtime, e.g. ten minutes for a runtime of 75 hours. The maturity is calculated in a temperature range of 1°C to 100°C. The accumulated maturity gain rate per sensor is registered at every measuring interval. The C-value is adjustable from 1.01 to 2.50 and the runtime up to 1,800 hours. The settings cannot be adjusted during measurements. There exist maturity computers that can automatically control the curing process of the setting concrete. This computer controls four production lines simultaneously. The control is based on the following criteria:

- limitation of concrete temperature;
- limitation of the rate of heating;

- limitation of the heating period;
- attainment of the adjusted maturity based on the specified runtime.

The maximum concrete temperature, the rate of heating and the heating period are adjusted by the manufacturer to the specifications of the user. All other set-ups are made by the user himself.

## **4 Doka Concremote**

### **4.1 General information**

Concremote is a tool for providing non-destructive real-time measurement of concrete strength in structure elements on the site. This tool consists of two parts:

- measuring sensors;
- data management and processing.

The sensors placed on the structure member continuously measure the heat development of the concrete, which is mainly influenced by the hydration heat of the cement and by ambient temperatures. The more intense the heat development, the faster the strength development of the concrete.

The measured data (temperature) from the structure member is transmitted to the computing centre via the mobile network as data packages. At the computing centre, they are automatically evaluated by the maturity monitoring method, using calibration measurement. A separate calibration measurement is needed for each different concrete mix to be measured on site. This calibration measurement must be performed either by the customer, by the concrete supplier or by a certified test laboratory. Ideally, the tests are made using the calibration box. For this purpose, six cubes are stored under defined semi-adiabatic conditions. The cubes are tested at different times, depending on the target value (N/mm<sup>2</sup>). Each of these tests results in a value of compressive strength, and the

temperature value associated with it. According to this calibration measurement, the relationship between the compressive strength and the maturity of concrete mix concerned can be computed. The Concremote software continuously provides this data and strengths to its users, enabling them to live monitor the strength development in a specific structure member. As soon as the target value is reached, the next steps (stripping, pre-stressing, etc.) can be taken.

## **4.2 Legal basis**

According to Russian standards and laws, each device has to have the certificate of conformance. This certificate proves the conformity of the tool to certain GOST and allows its use. Yet the maturity method, which lies in the basis on Doka Concremote tool, is not included or described in any of Russian GOST.

On the other hand, the concerned maturity method is included in EN 13670 of 2009 and today Russian standards are considered to get more common with Eurocodes. The corresponding instruction was given a few years ago by the government and the work goes on. Moreover, there is a wide spread practice of setting such goals for the universities. This means that such a research can be ordered in one of the Russian universities to be conducted resulting in a paper proving the accuracy of the method and the device itself. After all, the acceptance of the maturity method by concrete experts and the fact that it is included in many international standards makes it likely to be included in codes soon.

## **4.3 Method statement**

### **4.3.1 Preparation**

During the preparation stage the sensors to be used and their position has to be planned. Concremote is formwork independent and can be used in any kind of structural concrete element. For each structural element and cycle, a minimum of 2 sensors is required. The installation points are determined separately for each project. The structural engineer should be consulted for determining those

points that are critical in terms of static requirements. The sensors must be positioned in such a way that they measure the most critical (maximum stress) or most unfavourable points with regard to the strength development and when necessary, protected from external influences such as sunlight, radiant heaters, etc.

In floor-slabs, the use of slab sensors is recommended (Figure 5). Cable sensors can be used as an alternative. The slab sensors are positioned after leveling the floor-slab. Number of sensors in a floor-slab cycle:

- up to 500 m<sup>2</sup>: at least 2 sensors;
- more than 500 m<sup>2</sup>: more than 2 sensors, as required.

Prior to installing the sensor for the first time, the top lid is opened and the battery is connected by means of the white plug, then the lid is closed again.



Figure 5. Slab sensor

Cable sensors (Figure 6) are recommended for measuring the heat development in mass concrete structures. The measuring points of the cables can be chosen freely (cables are fixed to the reinforcement using cable ties).

Next the target value of concrete compressive strength has to be specified. The recommendations for setting the target value will be given in section 5 of this thesis

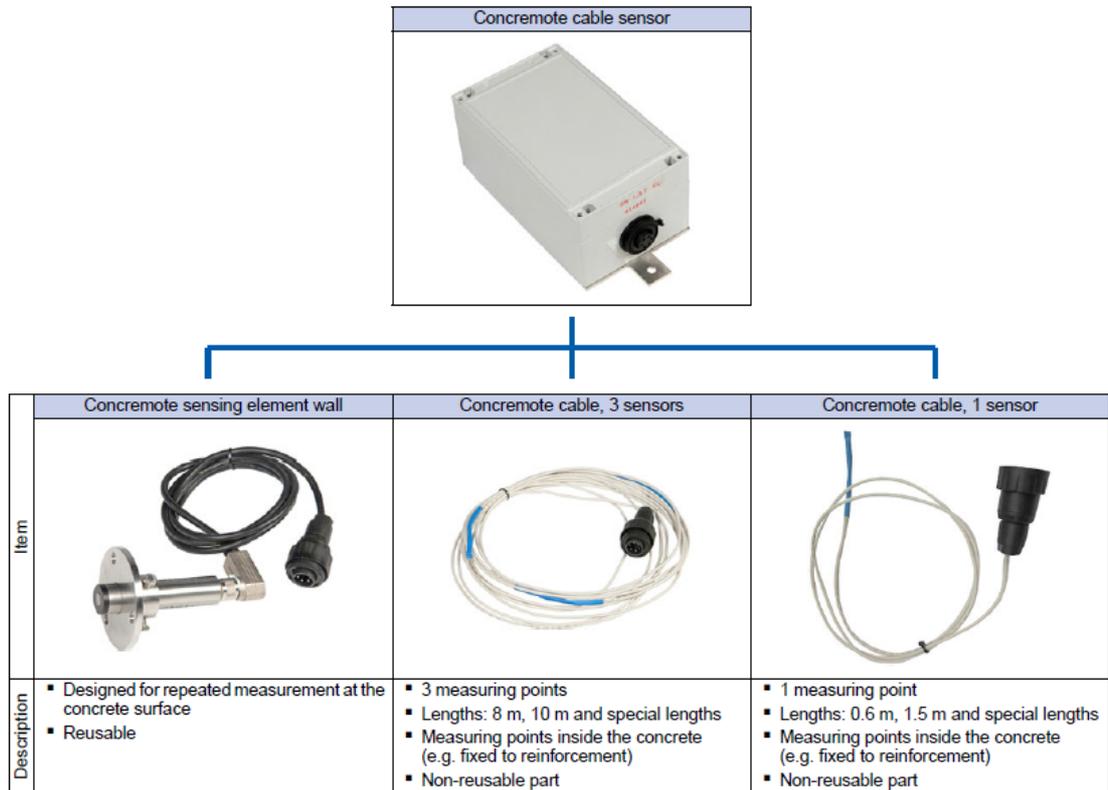


Figure 6. Concremote cable sensor

Then the decision on the calibration measurements has to be made for the concrete mixtures used, and a test laboratory has to be chosen. To ensure the correct work of the sensors and their availability for data transmission a function test has to be performed.

#### 4.3.2 Calibration

Each different concrete mixture needs to be calibrated with the calibration box in order to be able to calculate its strength development, based on the temperature data measured by the sensors. Two calibration boxes (with three concrete cubes each) are necessary for calibration. Before using the sensors for the first time, a calibration measurement has to be made for each concrete mixture to be measured with Concremote.

The calibration measurement is performed with the following steps. The concrete has to be taken out of the mixer. This concrete is filled into the cube

moulds and compacted. After that the filled calibration boxes are transported to the concrete laboratory. Once there, the calibration boxes need to be connected to the power supply. The concrete laboratory technician contacts the support team and tests the cubes according to the test. The specimens from the box are removed in the order laid down in the test protocol by blowing them out of their moulds with compressed air. Pressure test of the samples is conducted with an approved pressure testing device. The date, exact time and the measurement result of the pressure test are then written down. A separate test protocol is completed for each calibration.

After completing all of the six compressive strength tests, the software will automatically generate the calibration curve for the concrete that has been tested. The corresponding data can be accessed via the Concremote software.

### **4.3.3 Implementation**

Performing a measurement consists of two steps:

- positioning the sensor in the structure member;
- adding the measurement in the software.

Position the sensor in the structure member and make sure it does not disrupt any further building processes or subsequent work steps. For the slab sensor immediately after pouring and levelling the concrete, place the sensor on the concrete surface with its tip pointing downwards. The sensor may sink a few centimetres into the concrete, depending on the texture. There is no need to push the sensor down into the concrete. The insertion depth is sufficient when the sensor's tip is immersed in the concrete. For the cable sensors fix the measuring points (blue marks on the cable) at an adequate distance from the reinforcement in order to prevent the temperature of the reinforcement from affecting the concrete measurement. For performing measurements at any desired position in the concrete, an auxiliary, single-use construction may have to be fitted by the user (e.g. reinforced steel).

Next the sensors are assigned to a structure member by means of their serial number and the recorded installation time. When installing the sensors record a name for the structure member in question, the installation time and the sensor's serial number.

#### 4.3.4 Analysis

The measured data is automatically analysed. Users can access various graphs and view data in list form. By means of the graphs one can select the different parameters of the measurement:

- 'Compressive strength' and 'Temperature': for illustrating results
- 'Maturity', 'Calibration curve' and 'Data': for illustrating data

In compressive strength graph (Figure 7) the user can monitor the compressive strength development. The thin, orange line inside the compressive strength development curve represents the non-calibrated range. The measurement result is considered calibrated only from where the orange line ends.

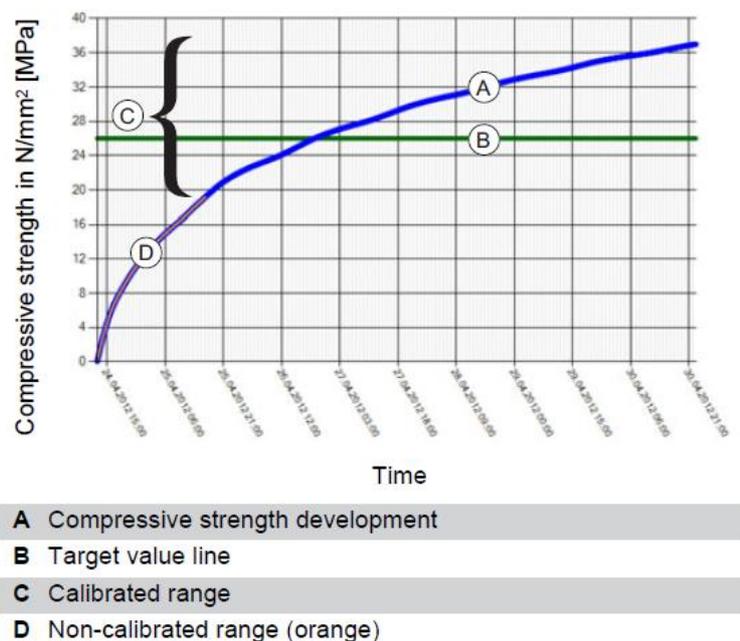
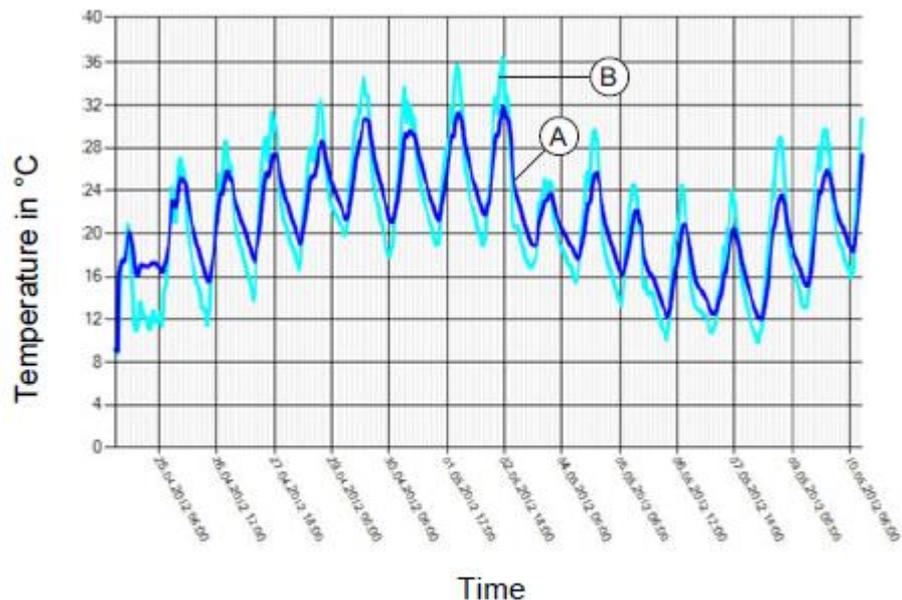


Figure 7. Compressive strength graph

The temperature graph (Figure 8) illustrates the temperature profile of the measurement as a function of time. The concrete temperature and the ambient

temperature recorded by the sensor are both displayed in one graph in different colours.



- A** Concrete temperature measured by the sensor
- B** Ambient temperature measured by the sensor

Figure 8. Temperature graph

The maturity curve (Figure 9) is generated on the basis of the measured temperature, the time, as well as the concrete data on which the measurement is based.

The calibration curve (Figure 4) depicts the result of the calibration, expressed as a relationship between the compressive strength and the maturity. The results of the compressive cube tests are indicated as blue dots. The red regression curve is automatically computed by the software, based on the compressive cube tests. The black calibration/reference line running parallel below the red line (mean value), forms the basis for calculating further strength values. The spread of the measured values ensures certainty and reliability in the process.

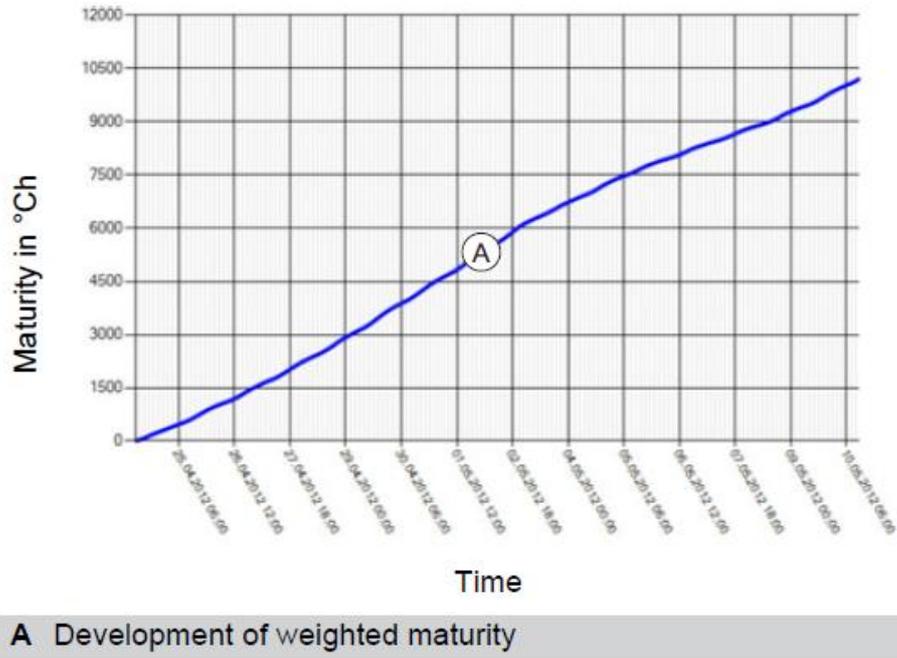


Figure 9. Maturity curve

#### 4.3.5 Further steps

As the required concrete strength is reached the constructor can decide on striking the formwork. If the strength development takes too much time, the constructor can consider optimizing the target value. This can be performed by consulting the structural engineer for reducing service load after stripping the formwork or additional calculation of the bearing element with repropping (see section 5). The other way to improve concrete strength development is to optimize the concrete mixture and prevent heat loss of the structure member.

The concrete mixture can be adjusted by increasing of the fresh concrete temperature with the heated aggregates and/or mixing water. Moreover, strength development can be graded up by modifying binder or cement, or by using chemical and mineral admixtures. In case of significant heat loss, which can also cause structure cracking, the element has to be covered with insulation or additionally heated.

## **5 Stripping slab formwork**

### **5.1 Minimum stripping parameters according to Russian law**

According to SP 70.13330.2012 “Load-bearing and separating constructions” the minimum concrete bearing capacity at stripping for the unloaded horizontal structures with a span less than 6 m is required to be no less than 70% of designed capacity, for spans more than 6 m – 80% of designed capacity. The minimum bearing capacity for the loaded horizontal structures, including the superposed concrete, is defined by the Method Statement and has to be approved by the designing agency.

Moreover, SP 48.13330.2011 “Organization of construction” claims that Method Statement has to include arrangements for proving the strength and stability of existing buildings and those under construction. Thus, the stability calculation of the building is required.

### **5.2 General idea of early stripping**

When the slab formwork is stripped before reaching its 28-day design strength the term ‘early stripping’ is used. By the time of striking the formwork the slab has to have sufficient strength to bear its dead weight.

There are two general types of early striking:

- striking the formwork with slab activation;
- striking the formwork without slab activation.

The activation of the slab means that after the floor props are removed (backed-off) and the deflection of the slab establishes itself and the floor-slab is 'activated' ready to transfer further loads. Striking with activation of the slab is performed by removing all the formwork and props. When the formwork is stroked without slab activation the formwork is removed section by section and the floor

props are immediately reinstalled. The section of the slab temporarily without support must have sufficient strength to bear its dead load.

Setting the formwork for the next floor slab and its pouring requires additional strength (as the load exceeds the dead load of the slab) by the activated slab. In this case repropping is used. The temporary reshoring supports the already poured slabs so as to sustain the loads from the ongoing working and pouring operations on subsequent floor-slabs. The using of repropping for unloading cast-in-situ slab before it reaches essential strength has not yet been regulated by Russian standards.

### **5.3 Required concrete strength for striking**

To cast the new slab, the supporting slab immediately below should have sufficient capacity to carry the loads imposed on it during construction. The loads on the supporting slab are:

- self-weight of supporting slab;
- any construction load on the supporting slab;
- total construction load of the new slab, i.e.
  - weight of concrete in new slab plus,
  - the self-weight of the temporary works plus,
  - construction live load on new slab.

If the supporting slab has sufficient capacity to carry the loads imposed, reshoring is not required. If it does not then reshoring is required. Before they are loaded, the concrete strength required in reshored supporting slabs should be calculated. The required strength of a concrete slab for striking depends on:

- characteristic design service load;
- construction load;
- characteristic concrete design strength;
- actual concrete characteristic strength at the time of striking.

The formula for calculating the required early striking strength is given by Equation 2. This gives the characteristic strength of concrete  $f_c$  required for early

striking. It is recommended that a minimum live construction load of 0.75 kN/m<sup>2</sup> be used for the slab. This load should be added to the slab self-weight to calculate  $w$ . The main idea of this assumption is that imposed load is proportional to concrete strength. Accordingly the slab can be activated with less concrete strength when the smaller service load on the slab is provided (Palett 2001).

$$f_c \geq f_{cu} \left( \frac{w}{w_{ser}} \right), \quad (2)$$

where  $f_c$  – required concrete strength for early striking, kN/m<sup>2</sup>

$f_{cu}$  – designed concrete strength, kN/m<sup>2</sup>

$w$  – construction load considered on slab, kN/m<sup>2</sup>

$w_{ser}$  – designed service load, kN/m<sup>2</sup>.

Some authors suggest a more economical approach with the equation:

$$f_c \geq f_{cu} \left( \frac{w}{w_{ser}} \right)^{1.67} \quad (3)$$

This equation allows to strike at smaller concrete strength (as  $\frac{w}{w_{ser}} < 1$ ). However, Equation 3 is only applicable to slab thicknesses less than 300 mm.

## 5.4 Repropping design

### 5.4.1 Repropping necessity and preconditions

If the subjacent slab has enough capacity to bear the loads, no reshoring is required, but if not then reshoring is necessary. Figure 10 gives a presentation of typical reshores over different numbers of floors. The number of floors to be re-propped depends on the service load on the slab after casting, which must not exceed the design service load. In fact, during construction this requirement may not always be fulfilled. This could occur when the self-weight is a high proportion of the design load. In these circumstances, the permanent and temporary works designers should agree on the procedure to enable a safe and economical structure to be built.

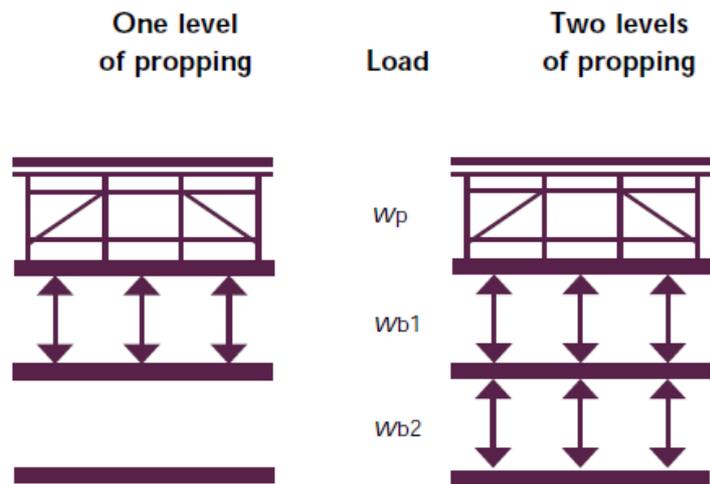


Figure 10. Diagrammatic presentation of reshoring

The use of repropping has several preconditions:

- the slabs behave elastically;
- foundation slabs are deemed to be infinitely rigid: this means when support is left in place all the way down to the foundation slab, 100 % of the new concreting load goes into the temporary reshores, as the floor-slabs cannot be 'activated';
- the reshores between the floor slabs and the falsework shoring supporting the slab formwork are not rigid, i.e. they change in length with load;
- the load applied onto the supporting slab from the falsework is uniformly distributed and, further, the reshoring generates a uniformly distributed support system from underneath the slab;
- the loads from the slab to be poured are distributed proportionately onto the previously cast floor-slabs below, provided that these have identical rigidity, e.g. are of equal thickness. This, and compatibility conditions, mean that the deformation rise is the same for each floor-slab;
- all finished floor-slabs must be 'activated', to allow the deadweight-related deformations occur before any loads are transferred from the floor above. The floor props must be completely stress-relieved (zero pre-load);
- the effects of temperature change are ignored.

## 5.4.2 Typical phases of construction

In a typical construction of a multi-storey monolithic concrete building where both props and repping are used, there are four construction phases (Figure 11):

1. Installation of the props and formwork before the casting of the floor slab.
2. Removal of the shores and formwork allowing the 'activation' of the slab.
3. Removal of reshores at the lowest interconnected level.
4. Placement of reshores in the storey from which the shores and forms were removed. The reshores are placed aflush without initially carrying any load.

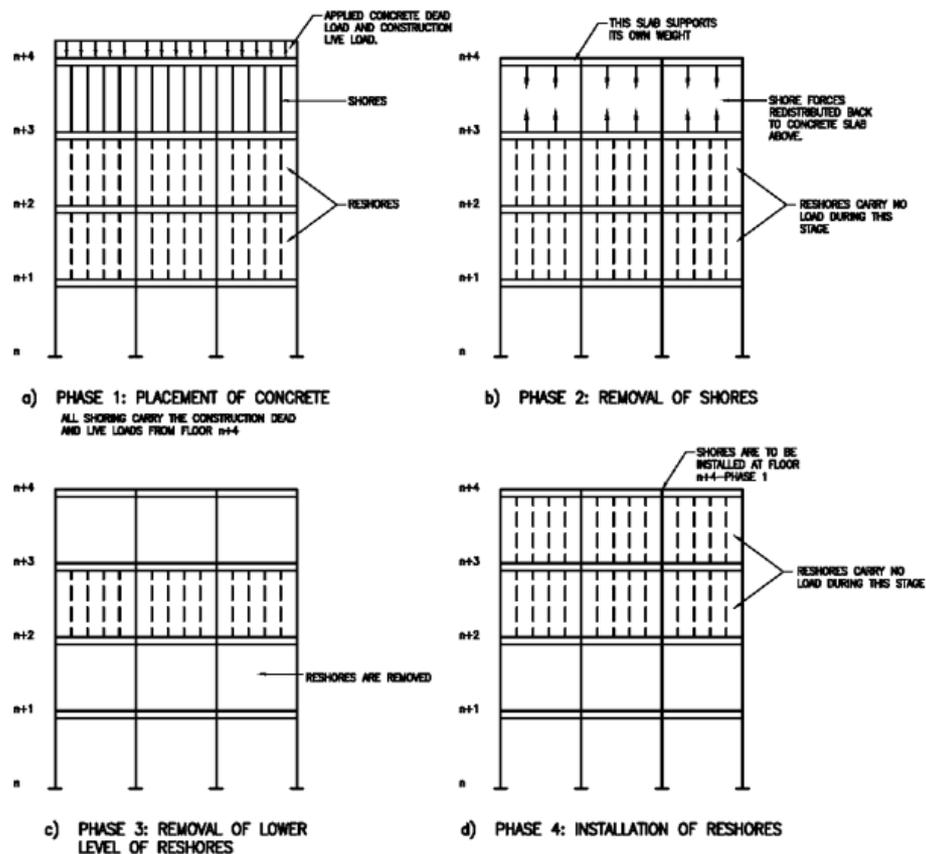


Figure 11. Typical construction phases

### 5.4.3 Load distribution

The reshoring load and hence the load in the supporting slabs can be determined by various methods using both two- and three-dimensional analysis. The simplest method, to be used for basic repetitive structures, is an empirically-analytical method based on the percentage of load transferred in two-dimensional analysis. This method serves a basis for recommendations by ACI 347.2R-05 and BS 5975:1996.

Obviously, the assumptions of the simplified method are not precisely true. Analytical studies by other researchers based on the simplified method verified its validity by comparing the predicted values with field measurements. Field measurements have consisted of measured loads on shores and reshores during the construction process. Most of the available field observations were found to be in fair agreement with the predicted values. The assumptions and limitations of the method have been investigated and the simplified method has been refined in various ways: in construction methods and schedules, introduction of reshores, analysis of short-and long-term deflections, and in structural reliability.

Figure 12 (see appendix) demonstrates the application of the simplified method. The example uses one level of shores and two levels of reshores. The construction live loads and weight of forms and shores are included in the load analysis. The slabs are assumed to have equal thickness and stiffness and, therefore, the construction loads are distributed equally among the slabs. The shores and reshores are assumed to be infinitely stiff relative to the supported slabs. Following the four phases of construction, each floor level is subjected to construction loads that vary in magnitude as the construction advances.

In Step 1, the first elevated floor slab is placed, and the full load is transferred to the ground by the shores. In Step 2, the shores are removed and the slab is now carrying its own weight. The reshores are placed snugly under the slab, carrying no load. In Step 3, the second elevated floor slab is shored and placed.

The first floor slab cannot deflect and all added load goes through the reshores to the ground. In Step 4, the shores are removed, and the second elevated floor slab carries its own weight. The reshores are placed under the second floor, but do not carry load. In Step 5, the third elevated floor slab is shored and placed. All added load goes through the shores and reshores to the ground. In Step 6, the shores are removed, and the third elevated floor slab carries its own weight. The reshores are removed from beneath Level 1 and are placed under the third floor without carrying any load. During this step, the support conditions have changed because there is no longer a continuous support to the ground. When the fourth floor slab is shored and placed during Step 7, the added load is equally shared between the supporting slabs below. The removal and relocation of shores and reshores, and the placement of a new slab at the top active floor, continues in a similar manner for the remaining steps. After Step 6, the cycles repeat throughout the full height of the building.

The load in shores at the end of each step is calculated on the basis of a summation of vertical forces. The total weight of slabs and construction loads above the shore level being considered, less the loads carried by slabs above, gives the load transmitted by the shores (ACI 347.2R-05 Guide for Shoring/Reshoring of Concrete Multistory Buildings 2005).

While the simplified method assumes distribution of the construction loads between the supported floors in proportion to their relative stiffness, some project-specific circumstances may necessitate altering the distribution slightly.

## **6 Conclusions**

This thesis dealt with examining the Russian standards whether they allow the worldwide used approaches for early stripping to be used. Despite the fact that maturity method is not yet included in any Russian code it seems that it does not represent a significant issue since this method can either be developed by one of the Russian institutions itself or by some company's order.

Even though single researches have already been conducted, the concrete strength determination based on maturity method is not yet used in Russia. Here Concremate can serve as a modern, effective and reliable tool for the determination of concrete strength in real time. This tool has several benefits for the construction companies as it increases speed and quality, saves costs in the construction process by:

- opportunity for earlier striking formwork, depending on real measurements instead of estimations;
- saving construction time is saving costs;
- modern quality management instrument by using real-time data and, which can be used for documentation – another step forward to “Integral Building”

Early stripping is also missing in Russian codes. But through this work it was found that it is allowed to use repropping when it is taken into consideration by a structural engineer during the design stage.

Fast reuse of formwork material and props is desired to allow other operations to follow concrete works as soon as possible. The props that support the freshly placed concrete transfer that weight to the floor slab below, which can exceed that floor slab’s design load capacity. For this reason, repropping is provided for a number of floors to distribute the construction load to several floor levels below. Stripping formwork is generally more economical if all the formwork material is removed at the same time before placing repropping. In this case, the structure element is required to bear its own weight, thus reducing the load in the reshores. A combination of props and repropping usually requires fewer levels of interconnected slabs, thus providing more free areas for other operations. Backpropping is the other method of supporting new slabs that is less widely used and suppose leaving the original shores in place or replacing them individually so as not to allow the slab to deflect and carry its own weight. These methods require careful consideration by the contractor and review by the engineer to ensure that excessive slab and prop loads do not develop.

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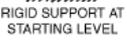
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## **APPENDIX A**

**Table 3.1—Simplified analysis of loads on shores and slabs using one level of shoring, two levels of reshoring**

D = weight of slab  
 Assumed construction live load = 0.4 D  
 Assumed shore and form weight = 0.1 D  
 Reshore weight is neglected

 RIGID SUPPORT AT STARTING LEVEL  
 FRESHLY PLACED SLAB  
 HARDENED SLAB  
 STORY OF RESHORES  
 STORY OF SHORES AND FORMWORK

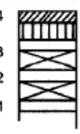
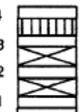
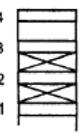
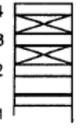
STEP	OPERATION AND REMARKS	STRUCTURE STATUS	Load on slab in multiples of D			Shore/reshore load at end of operation
			At beginning	Change during operation	Total at end of operation	
1	Place Level 1 concrete. Full load is transmitted to ground by shores		0	0	0	1.5 D
2	Construction live load is gone. Remove Level 1 shores, allowing Slab 1 to carry its own weight. Then place reshores beneath it, snug but not loaded.		0	+1 D	1 D	0
3	Form, shore, and place Level 2 concrete. Slab 1 cannot deflect and all added load goes through reshores to ground.		0 1 D	0	0 1 D	1.5 D 1.5 D
4	Slab 2 hardens and construction live load is gone. Remove the Level 2 forms and shores, allowing Slab 2 to carry its own weight. Then place reshores beneath it, snug but not loaded.		0 1 D	+1 D 0	1 D 1 D	0 0
5	Form, shore, and place Level 3 concrete, including the 0.5 D construction live load and shore load. All added load goes through shores to the ground since slabs can't deflect further.		0 1 D 1 D	0	0 1 D 1 D	1.5 D 1.5 D 1.5 D
6	Construction live load is assumed removed as Slab 3 hardens. Remove shores beneath Level 3, allowing it to carry its own weight. This leaves no net load in reshores beneath Level 1, and they are removed and installed snugly beneath Level 3. They carry no load.		0 1 D 1 D	+1 D 0	1 D 1 D 1 D	0 0 0
7	Form, shore, and place Level 4 concrete with the assumed 0.5 D construction live load and shore load. The total new applied load, 1.5 D, is distributed equally to the three interconnected slabs.		0 1 D 1 D 1 D	0 +0.5 D +0.5 D +0.5 D	0 1.5 D 1.5 D 1.5 D	1.5 D 1 D 0.5 D 0
8	Level 4 concrete hardens and the construction live load of 0.4 D is removed in equal parts from the slabs to which it was distributed.		0 1.5 D 1.5 D 1.5 D	0 -0.13 D -0.13 D -0.14 D	0 1.37 D 1.37 D 1.36 D	1.1 D 0.73 D 0.36 D
9	Remove shores beneath Level 4, causing that slab to carry its own weight. The load in those shores including their own weight is removed from the slabs to which it had been distributed		0 1.37 D 1.37 D 1.36 D	+1 D -0.37 D -0.37 D -0.36 D	1 D 1 D 1 D	0 0 0
10	Move reshores beneath Level 2 up, placing them snugly beneath Level 4, where they carry no load. There is no change in system loads.  SYSTEM CONDITIONS ARE NOW THE SAME AS AT THE END OF STEP 6, AND WHEN THE LEVEL 5 SLAB IS PLACED, THE CYCLE REPEATS.		1 D 1 D 1 D	0 0 0	1 D 1 D 1 D	0 0 0

Figure 12. ACI Table for simplified analysis of load on shores