Concrete knowledge

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...to be enlarged...
Concrete and reinforced concrete

Concrete is a mixture of water, cement, sand, gravel, crushed rocks, or other "aggregates". Hereby the mixture of water and cement turns into "cement lime" and it is filling the space in between the conglomerate of the aggregates. Sometimes one or more admixtures are being added to influence certain characteristics of the concrete like for example the durability, waterresistence, workability or the time of hardening. Hereby the most important factor is the ratio of water and cement (w/c). The cement needs about 35% of its own weight (not volume!) of water to turn into the cement stone. If you add much more water, the space in which the water has filled will be empty (because the water is not being needed by the cement and will evaporate) later on and the concrete will be of a lower quality.
As with most rocklike substances, concrete has a high compressive strength and a very low tensile strength. Reinforced concrete is a combination of concrete and steel wherein the reinforcement steel provides the tensile strength lacking in the concrete. Steel reinforcement is also capable of resisting compression forces and is used in columns to increase their load bearing.

### 0.0 Advantages of reinforced concrete as a structural material

Reinforced concrete may be the most important material available for construction. It is used in one form or another in almost all structures, great or small - buildings, bridges, tunnels, pavement, walls, slabs, beams, water tanks, drainages and roads. The reason, why concrete and reinforced concrete is used that much, can easily be explained by showing up some of its advantages:

1. It has considerable compressive strength as compared to most other materials.

2. Reinforced concrete has great resistance to the actions of fire and water and, in fact, is the best structural material available for situation where water is present. During fires of a average intensity, members with a satisfactory cover of concrete over the reinforcement bars suffer only surface damage without failure.

3. Reinforced concrete is very rigid.

4. It is a low-maintenance material

5. As compared with other materials, it has a very long service life. Under proper conditions, reinforced concrete structures can be used indefinitely without reduction of their load-carrying abilities. This can be explained by the fact that the strength of the concrete does not decrease with time by actually increase over a very long period, measured in years, due to the lengthy process of the solidification of the cement paste.

6. It is usually the only economical material available for footings, basement walls, piers, and similar applications.

7. A special feature of concrete is its ability to be cast into an extraordinary variety of shapes from simple slabs, beams, and columns to great arches and shells.

8. In most areas, concrete takes advantage of inexpensive local materials (sand, gravel and water) and requires relatively small amounts of cement and reinforcing steel.

9. With its’ PH-value of about 12.5 it protects the reinforcement steel from rusting.

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0.1 **Disadvantages of reinforced concrete as a structural material**

To use concrete successfully the designer must be completely familiar with its weak points as well as with its strong ones. Among its disadvantages are the following:

1. Concrete has a very low tensile strength, requires the use of tensile reinforcement.

2. Forms are required to hold the concrete in place until it hardens sufficiently. In addition, falsework or shoring may be necessary to keep the forms in place for roofs, walls, and similar structures until the concrete members gain sufficient strength to support themselves. Formwork is very expensive.

3. The low strength per unit of weight of concrete leads to heavy members. This becomes an increasingly important for long-span structures where concrete's large dead weight has a great effect on bending moments.

4. Similarly, the low strength per unit of volume of concrete means members will be relatively large, an important consideration for tall buildings and long-span structures.

5. The placing and curing of concrete is not as carefully controlled, as is the production of other materials such as structural steel and laminated wood.

Another problem is the problem of shrinkage which will be mentioned later.

0.2 **The main idea of reinforced concrete and its behavior**

In reinforced concrete two materials are combined. Concrete as a formable material with a high compressive strength and on the other side steel, as a material with an enormous high tensile strength.

The designer of a concrete construction has to place the reinforcement steel in such a way, that it can take up the tensile forces, while the concrete takes up the compressing forces. Therefore we have to know in which part of a construction pressure or tensile forces accure. Given this knowledge the reinforcement plans can be drawn.

Another duty of the reinforcement is to protect the concrete from cracking as a result of shrinkage. Shrinkage forces tensile forces, which have to be taken up by the reinforcement steel.
The following sketch shows the typical stresses as a result of bending:

According to these stresses the reinforcement has to be designed:
0.3 **Examples for formwork**

There are great demands to the formwork. It is not only the negative form of the required construction.

1. It has to stand the pressure, while the concrete is being filled in the form and during its compaction.

2. It has to be watertight enough to avoid the cement-lime flowing out.

3. It must not suck the water out of the concrete after the form is filled. So either the form has to be made of non-sucking material as for example metal, or it has to be watered if you for example have a wooden form.

4. The formwork has to be fixed enough to avoid movement during filling it.

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1 Designing concrete - the main influences

Concrete contains aggregates, cement and water (cement-lime). Since the cement-lime is less solid than ordinary aggregates and has negative characteristics such as shrinkage, our mixture should contain as less cement and water as possible!

1.0 The basic idea

The stones and sand fill the space in the form and the cement-lime holds this mixture together such as "glue".

The mixture of sand and gravel has to have as less pores as possible. Meaning: If you fill this mixture into a form, the space (volume) being left in between the aggregates has to be as less as possible. Because: this space has to be filled with cement-lime, which is the "glue" in the mixture. To need as less cement-lime as possible, we have to reduce this space.

Therefore the small “stones” have to fit in between the big “stones”. And the sand has to fill the space in between the small stones as shown:

No concrete can be more solid than the aggregates you use. If (to make it clear) you would use pumice as aggregate, your concrete would never reach up to a high solidity. A great influence on the mixture has the form of the aggregates. The rounder the corn is the better it is. If you choose crushed stones which are much longer than wide, you did choose the worst.

Reason: Crushed and/or flat/small stones have much more surface compared to their volume as round stones. More surface = higher need of glue; cement-lime
Some sorts of natural aggregates and typical mixtures:

The different results:
1.1 The main tests about the aggregates

1.1.0 How to determine character of the aggregates

To find out about the character of our aggregates, some certain qualities have to be checked. To get a representative sample of aggregates we have to split the aggregates in a special way. Either we use a special divider, or we divide our sample by using a hand-divider.

special divider:

To get a good representative sample a certain amount has to be tested

<table>
<thead>
<tr>
<th>Max. size of aggregate in mm</th>
<th>amount in Kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;4</td>
<td>5</td>
</tr>
<tr>
<td>&gt;8</td>
<td>20</td>
</tr>
<tr>
<td>&gt;32</td>
<td>35</td>
</tr>
<tr>
<td>&gt;63</td>
<td>65</td>
</tr>
</tbody>
</table>

dividing "by hand":

the sample:
1.1.1 determining the size (sieve analyses)

A. Character of the test:
The aggregates are being spitted in several groups by size. The share of each group is being expressed in the grading curve measured by mass-%.

B. Required equipment and tools

Set of sieves
- 0.125 mm size of hole
- 0.25 mm size of hole
- 0.5 mm size of hole
- 1 mm size of hole
- 2 mm size of hole
- 4 mm size of square-hole
- 5 mm size of square-hole
- 8 mm size of square-hole
- (11.2 mm size of square-hole)
- 16 mm size of square-hole
- (22.4 mm size of square-hole)
- 31.5 mm size of square-hole
- 63 mm size of square-hole

box or pan
balance, capacity 30 Kg, exactness 10 g
balance, capacity 10 Kg, exactness 1 g
drying-oven
bowls
shovel
sample-splitter
spatula
fine brush

sieving "by hand":

sieving-machine:
C. conducting this sieve analysis:

1. For exact determination two sieving have to be done
2. Take a representative sample
3. Weigh two bowls
4. Split the existing samples into a quantity according to the list on the last page
5. Fill the samples into the bowls and dry it in the drying oven until they are obviously dry. The sand has to run easily through your fingers.
6. Weigh the dried samples
7. Prepare the sieve - set according to the size of the aggregates
8. Pour the sample on the first sieve and move the sieves until obviously no more stones pass the first sieve.
9. Take off the first sieve and test, if maybe some very fine components still pass the sieve. Therefore shake the sieve over some dark paper. Fill the sand from the paper into the next sieve. If stones got stuck in the sieve pull them through. For the smaller sieves use the brush.
10. Fill the material each sieve contains into a bowl. Start with the widest sieve and continue with the smaller sieves. After each sieve determine the weight. The results write down in the following table. This is done with both of the two samples.

<table>
<thead>
<tr>
<th>sample Nr.: 114</th>
<th>max. size of aggregates</th>
<th>32 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>17472</td>
<td>17721</td>
<td>16368</td>
</tr>
<tr>
<td>18183</td>
<td>17853</td>
<td>16599</td>
</tr>
<tr>
<td>sum</td>
<td>36201</td>
<td>35574</td>
</tr>
<tr>
<td>remained</td>
<td>98,3</td>
<td>91,1</td>
</tr>
<tr>
<td>paste</td>
<td>1,7</td>
<td>8,9</td>
</tr>
</tbody>
</table>

11. The result of the measurement you write down in row 1 and two
12. In row three the sum of rows 1 and 2 are registered.
13. The remaining %-share (row 4) is calculated in mass-%

\[
\text{remained: } \frac{\text{Sum (here 10.970 g)}}{\text{Sum of single groups}} \times 100
\]

14. Row 5: paste = 100 - remained [%]

15. The result is shown in the following grading curve:

![Grading Curve](image)

D. Sources of error:

1. Damaged sieves
2. Sieving for too short period of time (specially sieves 0.5 and 0.25 mm)
3. Sieves are not clean enough
4. Overloaded sieves
1.1.0 **Interpretation of the result**

After the result of the sieve analysis is registered in the grading curve, interpretation of the result takes place. The last picture with the grading-curve shows several lines:

1.1.2 **determining the loose weight of bulk goods**

A. Character of the test:

Under known conditions the aggregates are being filled in a known container. By measuring the weight (mass) of the aggregates, while the volume of the container is known, the loose weight is calculated \([\text{Kg/dm}^3]\).

B. Required equipment and tools

1-l-measuring container
10-l-measuring container
drying oven
balance, capacity 30 Kg, exactness 10 g
small hand-shovel
ruler

C. carrying out

1. Take one representative sample. Dry it for 24 hours in the oven. Temperature \((110 \pm 5) \degree \text{C}\)

2. For max. size of aggregates \(\leq 4 \text{ mm}\) take the 1-l container. For size of aggregates \(> 4 \text{ mm}\) take the 10-l container. Measure the mass (weight) of the container

3. Fill the container by using the hand-shovel. Start filling all around from the rim to the center. Fill the container little over the top.

4. Carefully remove (by using the ruler) all the aggregates being higher than the edge of the container. Do not compact the aggregates!

5. Measure the mass (weight) of the filled container. Exactness = 0.01 Kg \((m_{g, sd})\)

6. Test a second and third sample in the same way.
7. Calculate the "loose weight" \((p_{sg})\)

\[ p_{sg} = \frac{m_{g, sd}}{V} \]

\(p_{sg}\) = loose weight of the sample in kg/dm³

\(m_{g, sd}\) = mass (weight) of the gravel in the container in kg

\(V\) = Volume of the container in dm³

8. Calculate the loose weight of sample 2 and 3 and calculate the mean value

Container with gravel:

D. Calculating a example

A mixture of gravel with maximum size = 32 mm gave us the following values:

\(m_{g, sd} = 17.38\) kg

\(m_{g, sd} = 17.34\) kg

\(m_{g, sd} = 17.30\) kg
The loose weight is calculated by using the formula from Nr. 7

\[ p_{sg1} = \frac{17.38\text{ kg}}{10\text{ liter}} \]

\[ p_{sg1} = 1.738 \text{ kg/dm}^3 \]

\[ p_{sg2} = 1.734 \text{ kg/dm}^3 \]  mean value: \[ \frac{1.738 + 1.734 + 1.730}{3} = 1.734 \frac{kg}{dm^3} \]

\[ p_{sg3} = 1.730 \text{ kg/dm}^3 \]
1.2 **The cement**

1.2.0 **Cement - the material**

Portland cement - characteristics and Production

Compared to hydraulic chalk (limestone) Portland cement hardens much faster and far higher solidity. These characteristics are a result of a Chalk-silica acid, which is not contained in the hydraulic chalk (limestone), the 3-calcium-silica (3CaO*SiO₂), the most chalk-containing conjunction silica acid can have.

This 3-calcium-silica can only be produced at temperatures between 1250 °C and 2100°C. The material (as the powerful reaction with water (H₂O) shows), is very unstable.

Using only the pure components (74% CaO and 26% SiO₂) leads to a very complicated process of "burning" the cement.

Therefore it is necessary, to add some other components, while the cement is "burned". The most suitable material turned out to be ferric oxide and argillaceous earth, material that usually anyways shows up with the silica acid or the chalk (lime).

While these components are burned in the rotary kill, sintering temperature has to be reached. Now the components turn into a mushy mass. After cooling down again, the material turns into dark, stone-hard pieces, the cement clinker. The most important factor in this process is to find the perfect mixture of the components. If for example too much chalk, this chalk will not be turned into 3CaO*SiO₂. It will remain in the final product, covered by the Portland cement. Later, after adding water and the process of hybridization is almost finished, the chalk will react with the remaining water will increase its volume, as a consequence the concretes quality will be harmed.

In a modern production process, the single components are measured with a exactness of 0.1 %
Later on the ingredients can easily be controlled since we know about the main ingredients:

<table>
<thead>
<tr>
<th>Short writing</th>
<th>Formula</th>
<th>CaO (%)</th>
<th>SiO2 (%)</th>
<th>Al2O3 (%)</th>
<th>Fe2O3 (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C3S</td>
<td>3 CaO*SiO2</td>
<td>73.7</td>
<td>26.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C2S</td>
<td>2 CaO*SiO2</td>
<td>65.1</td>
<td>34.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C3A</td>
<td>3 CaO*Al2O3</td>
<td>62.3</td>
<td></td>
<td>37.7</td>
<td></td>
</tr>
<tr>
<td>C4AF</td>
<td>2 CaO<em>Al2O3</em>Fe2O3</td>
<td>46.1</td>
<td>21</td>
<td>32.9</td>
<td></td>
</tr>
</tbody>
</table>

### 1.2.1 Cement - its production

This process of production needs a real high tech production unit (if a perfect result is requested).

The material, after being dig out of the ground or wall, is stored on big dumps, containing about 50,000 t. This is about a week's capacity. In order to mix (Homogenization) the raw material, it is being dig from this dump into the first crusher. This homogenization takes place 4 times during the production process and guarantees the homogeneous quality of the final product.

**Sketch of a production unit:**

![Sketch of a production unit]
1.2.2 Cement - the different kinds of

The main cement is the pure Portland Cement, which is named after the peninsula PORTLAND in England, where stone is found similar to cement stone. In countries with high-developed concrete techniques, several kinds of cement are used. Nowadays for instance, complete Europe developed standardization for cement. In addition to the pure Portland cement, several materials such as foundry sand, argillaceous earth (Puzzuoli), fly ash containing silica acid, burned slate or limestone are added.

The old (valid until 2002) list of cements (just to show the number and possible characters of different cements):

<table>
<thead>
<tr>
<th>kind of Cem</th>
<th>naming</th>
<th>short sign</th>
<th>main components [%]</th>
<th>Rest [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>CEM I</td>
<td>Portland Cement</td>
<td>CEM I</td>
<td>Portland Cem Clinker</td>
<td>-</td>
</tr>
<tr>
<td>CEM II</td>
<td>Portland foundry C.</td>
<td>CEM II/A-S</td>
<td>80-94</td>
<td>6-20</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CEM II/B-S</td>
<td>65-79</td>
<td>21-35</td>
</tr>
<tr>
<td>Portland Puzzuoli C.</td>
<td>CEM II/A-P</td>
<td>80-94</td>
<td>-</td>
<td>6-20</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CEM II/B-P</td>
<td>65-79</td>
<td>-</td>
</tr>
<tr>
<td>Portland fly ash C.</td>
<td>CEM II/A-V</td>
<td>80-94</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Portland oil slate C.</td>
<td>CEM II/A-T</td>
<td>80-94</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CEM II/B-T</td>
<td>65-79</td>
<td>-</td>
</tr>
<tr>
<td>Portland limestone C.</td>
<td>CEM II/A-L</td>
<td>80-94</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Portl. fly ash foundry C.</td>
<td>CEM II/B-SV</td>
<td>65-79</td>
<td>10-20</td>
<td>-</td>
</tr>
<tr>
<td>CEM III</td>
<td>furnace C.</td>
<td>CEM III/A</td>
<td>35-64</td>
<td>36-65</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CEM III/B</td>
<td>20-34</td>
<td>66-80</td>
</tr>
</tbody>
</table>

Almost each Cement, being listed in this table, is produced and available different solidity classes (being influenced by the finesse of the cement (3000 cm²/g or more)) and this with different characters:

<table>
<thead>
<tr>
<th>Class of sol.</th>
<th>compressive strength [N/mm²]</th>
<th>heat release</th>
<th>late developed solidity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>initial strength</td>
<td>standard strength</td>
<td>2 days</td>
</tr>
<tr>
<td>32,5</td>
<td>≥ 16</td>
<td>≥ 16</td>
<td>-</td>
</tr>
<tr>
<td>32,5 R</td>
<td>≥ 10</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>42,5</td>
<td>≥ 10</td>
<td>≥ 16</td>
<td>-</td>
</tr>
<tr>
<td>42,5 R</td>
<td>≥ 20</td>
<td>≥ 16</td>
<td>-</td>
</tr>
<tr>
<td>52,5</td>
<td>≥ 20</td>
<td>≥ 16</td>
<td>-</td>
</tr>
<tr>
<td>52,5 R</td>
<td>≥ 30</td>
<td>≥ 16</td>
<td>-</td>
</tr>
</tbody>
</table>

All together some dozens of cements for different purposes.
1.2.3 **Characteristics of cement lime**

Cement lime, a mixture of cement and water, has two extreme negative characteristics:

- the cement lime is less solid than most of the common aggregates. It is the weakest component in our mixture

- during hydratisation the cement stone (the former cement lime) reduces its' volume. This effect is called shrinkage. As a result of shrinkage our concrete construction might show cracks.

Therefore and for some other reasons (cement also is much more expensive than gravel (profitability)), we always try to reduce the quantity of cement lime in our designed mixture.

1.3 **Cement and water - the ideal proportion**

The chemical reaction of cement and water has - as each chemical reaction - certain irrefutable rules. One - the most important rule for us - is, that the cement needs 40 % of its' own weight of water to reach to a perfect (100 %) hydratisation.

This means:
If we mix 10 Kg of cement with 4 Kg of water, we will have a perfect cement stone. If we add less water, no complete hydratisation will take place.
If we add more water, we will have cement stone with water lenses in between, which will turn into simply air-filled bubbles, after the stone has dried.
1.3.0 **Some rules and hints**

- The higher the w/c ratio is, the lower is the solidity of the concrete.

- Concrete with a higher w/c ratio is sucking water faster and more than as if it had a low w/c ratio. The danger of corrosion of the reinforcement bars is increasing.

- Concrete with a high w/z ratio is drying faster and shrinkage is increasing. As a result of fast drying up the concrete cracks and high tensions is the result.

But the most important thing we have to understand is:

**Each liter of "not by the cement needed water" causes one liter of "air" in our concrete.**

And this has negative results:
1.4 **Dosage of cement lime v/s w/c-ratio**

The more cement lime we add to our mixture the higher the workability of our concrete will be and the higher the danger of shrinkage will be. But the lower the w/c ratio is, the higher will be the solidity of the cement stone and this with of the concrete we design.

1.4.0 **Two examples of different mixtures**

**Example Nr. 1:**
Two concretes with the same volume of cement and aggregates, but different w/c ratios shall be inspected concerning solidity and workability. These concretes are mixed from:

100 Kg Cement
+ 600 Kg dry Aggregates

\[ \omega = \frac{50\text{Kg Water}}{100\text{KgCement}} = 0.50 \]

Concrete 1

\[ \omega = \frac{80\text{Kg Water}}{100\text{KgCement}} = 0.80 \]

Concrete 2

**Assessment:**

a) Solidity: Concrete 1 with w/c = 0.50 is about twice as solid as Concrete 2

b) Workability: Since Concrete 2 contains more water, the workability is higher.

**Conclusion:** Concretes containing the same quantity of cement, but having a higher workability, do contain more water.

**Example Nr. 2:**

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Two concretes with the same w/c ratio and aggregates, but different volumes of cement lime shall be inspected concerning solidity and workability. These concretes are mixed from:

- Concrete 3: 600 Kg dry Aggregates
  - 100 Kg Cement
  - 50 liter = 50 Kg water

\[ \omega = \frac{50 \text{Kg Water}}{100 \text{Kg Cement}} = 0.50 \]

- Concrete 4: 50 liter = 50 Kg water
  - 150 Kg Cement
  - 75 liter = 75 Kg water

\[ \omega = \frac{75 \text{Kg Water}}{150 \text{Kg Cement}} = 0.50 \]

**Assessment:**

a) Solidity: Concrete 3 and concrete 4 have, because of the same w/c = 0.50, the same solidity.

b) Workability: Since Concrete 4 contains more cement lime, its' workability is higher.

**Conclusion:** Without affecting the solidity, the workability of a concrete can be influenced by adding more cement lime of the same w/c ratio.