DETAILING OF BEAMS
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   c. Reinforcement designed for torsion
1. Approximate design of the cross-sectional dimensions

Adopting $b$, capacity conditions for shear and flexure result in $d$ as follows:

$$V_{Rd,\text{max}} = \frac{1}{2}bdv_{cd} \geq V_{Ed} \rightarrow bd \geq 4\frac{V_{Ed}}{f_{cd}} \rightarrow \frac{M_{Ed}}{V_{Ed}} \equiv d$$

$$M_{Rd} \equiv b0,4df_{cd} 0,7d \geq M_{Ed} \rightarrow bd^2 \geq 4\frac{M_{Ed}}{f_{cd}}$$

Value of $\ell / d$ can then be checked for deflection, and adjusted if necessary.
2. Principles of constructing the envelope resistance shear and moment diagrams

The reason of parallel shifting of the diagram of applied moments

The extent of shifting is \( z \), if no shear reinforcement is applied, 0.25\( z \), at bent-up bars

Effect of partial restraint at extreme support:

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Enveloping the moment and shear diagrams of a simple supported beam

\[ m_{R\phi}^- \text{ and } m_{R\phi}^+ \]

capacity moments attributed to a top and bottom bar respectively of diameter \( \phi \)

2 bars are bent-up from 5 on bottom (it is possible)

Design of shear reinforcement (here links) is necessary for the dashed area

Use of minimum links along the Interior part of the beam
Graphical presentation of the capacity moment attributed to each of the longitudinal bars of an rc beam
-Example of the bar id. no. 3, bent-up on left and finished in the span on right:

\[
M_{Rd,3} = \frac{\phi_3^2 \pi}{4} f_{yd} z
\]
Reason of using bent-up bar +,,mustache bar,, at intermediate supports

Detail of the side view of the beam bent-up bar

Detail of the shifted moment diagram and the envelope moment diagram at intermediate support

Detail of the shear force diagrams

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Shear design strategies
- Using bent-up bars

- The "simple grading system," (geom. order) of bent-up bars
- Design of links for \( \max(V_{Ed,1}, 0.5V_{Ed,max}) \) and maintaining its intensity in support direction
- Design of min. links from section of \( V_{Rd,c} \)

- When designing only links, if

\[
\ell_w = \frac{V_{Ed,\text{max}} - V_{Rd,c}}{p_d} \text{ is long}
\]

(greater than \( \approx 1.2 \text{ m} \)), it is more economic to design two link intensities – spacing \( s_1 \) and \( s_2 \) - along \( \ell_w \):

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3. Detailing the reinforcement system of a simple supported beam with cantilever
(example treated numerically in the practical lessons)

Geometrical data and loads

\[ q = 8 \text{ kN/m} \]
\[ g = 24 \text{ kN/m} \]
3.1 The shifted extreme moment diagram and the envelope resistance moment diagram
3.2 The extreme shear diagram and the envelope shear resistance diagram
### 3.3 Bar data and list of bars

**List of bars** for beam G1  Reinforcement quality: B60.50

<table>
<thead>
<tr>
<th>Id. no.</th>
<th>pcs.</th>
<th>Ø</th>
<th>length</th>
<th>Σ length (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>mm</td>
<td>m</td>
<td>Ø8</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>16</td>
<td>8,63</td>
<td>17,26</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>7</td>
<td>62</td>
<td>8</td>
<td>1,26</td>
<td>78,12</td>
</tr>
<tr>
<td>Total length (m)</td>
<td>78,12</td>
<td>64,1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Specific mass (kg/m)</td>
<td>0,395</td>
<td>1,58</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total mass (kg)</td>
<td>30,9</td>
<td>101,3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
4. Choosing the concrete cover and grade (ambiental conditions)

\[ c_{\text{nom}} \geq 10 \text{ mm} + \max \{ c_{\text{min},b}, c_{\text{min},\text{dur}} \} \]

- \( c_{\text{min},b} \) is the minimum concrete cover conditioned by adequate bound (1 to 3 bar diameter)
- \( c_{\text{min},\text{dur}} \) depends from conditions of the ambiente, as given in the table below
<table>
<thead>
<tr>
<th>Sign</th>
<th>Ambiental conditions</th>
<th>Examples</th>
<th>Min. concrete strength grade</th>
<th>Min. cement-content kg/m³</th>
<th>Max. w/c ratio %</th>
<th>Values of $c_{\text{min, dur}}$ (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>X0</td>
<td>Dry ambient</td>
<td>Dry indoor spaces</td>
<td>C12/15</td>
<td>260</td>
<td>65</td>
<td>10</td>
</tr>
<tr>
<td>XC1</td>
<td>Carbonization in dry or constantly wet ambient</td>
<td>Indoor spaces with medium air humidity content, underwater structures</td>
<td>C20/25</td>
<td>260</td>
<td>65</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>Type of Exposure</td>
<td>Condition</td>
<td>Area of Exposure</td>
<td>Strength Class</td>
<td>Durability</td>
<td>Chloride Concentration</td>
</tr>
<tr>
<td>---</td>
<td>------------------</td>
<td>-----------</td>
<td>------------------</td>
<td>----------------</td>
<td>------------</td>
<td>-----------------------</td>
</tr>
<tr>
<td>XC2, XC3</td>
<td>Carbonization in wet, rarely dry ambient, or by moderate air humidity content</td>
<td>Water reservoirs, foundation structures. Structures of open-air halls, garages, indoor spaces of high humidity</td>
<td>C25/30, C30/37</td>
<td>280</td>
<td>60</td>
<td>25</td>
</tr>
<tr>
<td>XC4</td>
<td>Carbonization in variable dry and humid space</td>
<td>Structures exposed to rain</td>
<td>C30/37</td>
<td>300</td>
<td>50</td>
<td>30</td>
</tr>
<tr>
<td>XD1</td>
<td>Chloride corrosion by limited air humidity content</td>
<td>Structures exposed to atmospheric chloride corrosion</td>
<td>C30/37</td>
<td>300</td>
<td>55</td>
<td>35</td>
</tr>
<tr>
<td>XD2</td>
<td>Chloride corrosion in humid, rarely dry ambient</td>
<td>Water-side surface of non-insulated basins, structures subjected to the effect of industrial water with chloride content</td>
<td>C30/37</td>
<td>300</td>
<td>55</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>Chloride corrosion in variable humid or dry ambient</td>
<td>Structures of bridges, pavements, parking house floors effected by chlorine containing chemicals</td>
<td>C35/45</td>
<td>320</td>
<td>45</td>
<td>45</td>
</tr>
<tr>
<td>---</td>
<td>--------------------------------------------------</td>
<td>---------------------------------------------------------------------------------</td>
<td>--------</td>
<td>-----</td>
<td>----</td>
<td>----</td>
</tr>
<tr>
<td>XD3</td>
<td>Permanent effect of seawater</td>
<td>Basin filled with seawater</td>
<td>C35/45</td>
<td>300</td>
<td>50</td>
<td>40</td>
</tr>
<tr>
<td>XS2</td>
<td>Moderate water saturation without anti-freeze</td>
<td>Vertical surfaces exposed to rain and frost</td>
<td>C30/37</td>
<td>300</td>
<td>55</td>
<td>**</td>
</tr>
<tr>
<td>XF1</td>
<td>High water saturation without anti-freeze</td>
<td>Horizontal surfaces exposed to rain and frost</td>
<td>C30/37</td>
<td>320</td>
<td>50</td>
<td>**</td>
</tr>
<tr>
<td>XF3</td>
<td>Slightly, moderately and strongly aggressive ambient</td>
<td>Structures exposed to sulphate containing soils and groundwater</td>
<td>C30/37</td>
<td>300</td>
<td>55</td>
<td>**</td>
</tr>
<tr>
<td>XA1</td>
<td></td>
<td></td>
<td>C30/37</td>
<td>320</td>
<td>50</td>
<td>**</td>
</tr>
<tr>
<td>XA2</td>
<td></td>
<td></td>
<td>C30/37</td>
<td>360</td>
<td>45</td>
<td>**</td>
</tr>
<tr>
<td>XA3</td>
<td></td>
<td></td>
<td>C35/45</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
5. Some further constructional rules

a) The minimum anchorage length

\[ l_{b,\text{min}} = \max\{10\phi; 100\,\text{mm}, \alpha_{\text{min}} \frac{l_b \sigma_s}{f_{yd}}\} \]

\[ \alpha_{\text{min}} = 0.3 \text{ for bars working in tension} \]
\[ \alpha_{\text{min}} = 0.6 \text{ for bars working in compression} \]
b) Anchorage of links and bent-up bars

Anchorage of links

Anchorage of bent-up bars in the compression and tension zone respectively

Reinforced C

lecture 7/18
c) Reinforcement designed for torsion

For better anchorage, use links of the type indicated below!

Longitudinal bars should be uniformly distributed along all sides of the section: