

**General Design Chart and Design Table to EBCS EN 1992-1-1:2014**

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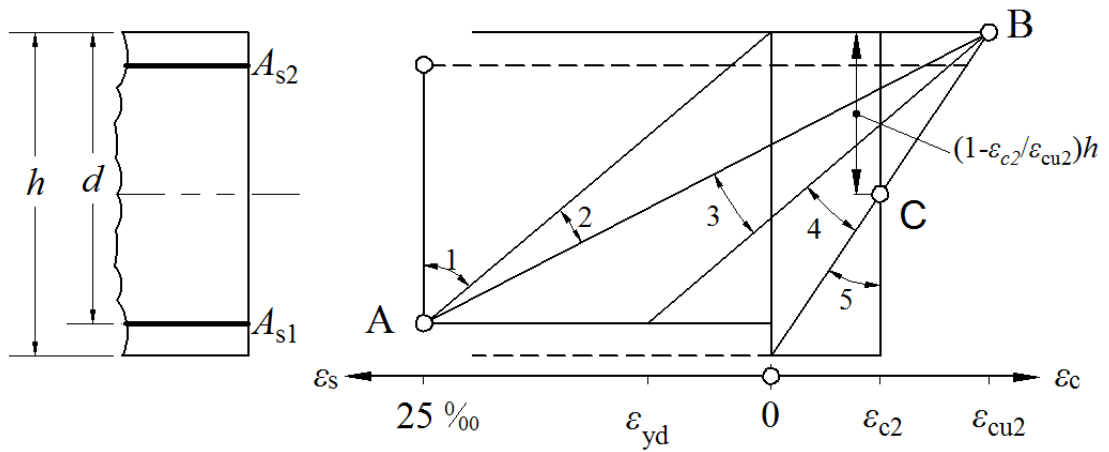
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## 1. Strength and deformation characteristics for concrete

Table 1-1 Strength and deformation characteristics for concrete

| Strength classes for concrete |       |       |       |       |       |       |       |       |       |       |       |       |       |        |
|-------------------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|--------|
| Class                         | 12/15 | 16/20 | 20/25 | 25/30 | 30/37 | 35/45 | 40/50 | 45/55 | 50/60 | 55/67 | 60/75 | 70/85 | 80/95 | 90/105 |
| $f_{ck}$<br>(MPa)             | 12    | 16    | 20    | 25    | 30    | 35    | 40    | 45    | 50    | 55    | 60    | 70    | 80    | 90     |
| $f_{cu}$<br>(MPa)             | 15    | 20    | 25    | 30    | 37    | 45    | 50    | 55    | 60    | 67    | 75    | 85    | 95    | 105    |
| $f_{cm}$<br>(MPa)             | 1.6   | 1.9   | 2.2   | 2.6   | 2.9   | 3.2   | 3.5   | 3.8   | 4.1   | 4.2   | 4.4   | 4.6   | 4.8   | 5.0    |
| $E_{cm}$<br>(GPa)             | 27    | 29    | 30    | 31    | 33    | 34    | 35    | 36    | 37    | 38    | 39    | 41    | 42    | 44     |
| $\varepsilon_{c2}$<br>(‰)     | 2.0   |       |       |       |       |       |       |       |       |       |       |       |       |        |
| $\varepsilon_{cu2}$<br>(‰)    | 3.5   |       |       |       |       |       |       |       |       |       |       |       |       |        |
| $n$                           | 2.0   |       |       |       |       |       |       |       |       |       |       |       |       |        |



**A – Reinforcing steel tension strain limit**

**B – Concrete compression strain limit**

**C – Concrete pure compression strain limit**

**Figure 1-1 Possible strain distribution in the ultimate limit state**

## 2. Design Aids for Reinforced Concrete Beams

### 2.1 Design Table for Reinforced Concrete Beams

Table 2-1 Steps to be taken when using Design Tables

|   |  |
|---|--|
| <ul style="list-style-type: none"> <li>• Calculate <math>\mu_{Sd} = \frac{M_{Sd}}{f_{cd}bd^2}</math></li> <li>• If <math>\mu_{Sd} \leq \mu_{Sd,lim}</math> , then compression reinforcement is not required and</li> </ul> $A_{s1} = \frac{1}{f_{yd}} (\omega \cdot b \cdot d \cdot f_{cd} + N_{Sd})$ <ul style="list-style-type: none"> <li>• If <math>\mu_{Sd} &gt; \mu_{Sd,lim}</math> , then compression reinforcement is required and</li> </ul> $\omega' = \frac{\mu_{sd} - \mu_{sd,lim}}{(1 - d_2/d)}$ $A_{s2} = \omega' bd \frac{f_{cd}}{\sigma_{s2}}$ $A_{s1} = \frac{1}{f_{yd}} ((\omega_{lim} + \omega') \cdot b \cdot d \cdot f_{cd} + N_{Sd})$ |  |
|---|--|

**Table 2-2 Design Table for C 12/15 – C 50/60**

| $\mu_{sd} = \frac{M_{sd}}{f_{cd}bd^2}$ | $\omega = \frac{A_{s1}f_{yd}}{f_{cd}bd}$ | $k_x = \frac{x}{d}$ | $k_z = \frac{z}{d}$ | $\varepsilon_c$<br>(‰) | $\varepsilon_{s1}$<br>(‰) | Percentage<br>Redistributi-<br>on |
|--|--|---------------------|---------------------|------------------------|---------------------------|-----------------------------------|
| 0.000                                  | 0.000                                    | 0.000               | 1.000               | 0.000                  | 25.000                    |                                   |
| 0.010                                  | 0.010                                    | 0.030               | 0.990               | 0.773                  | 25.000                    |                                   |
| 0.020                                  | 0.020                                    | 0.044               | 0.985               | 1.146                  | 25.000                    |                                   |
| 0.030                                  | 0.031                                    | 0.055               | 0.980               | 1.464                  | 25.000                    |                                   |
| 0.040                                  | 0.041                                    | 0.066               | 0.976               | 1.763                  | 25.000                    |                                   |
| 0.050                                  | 0.051                                    | 0.076               | 0.971               | 2.060                  | 25.000                    |                                   |
| 0.060                                  | 0.062                                    | 0.086               | 0.967               | 2.365                  | 25.000                    |                                   |
| 0.070                                  | 0.073                                    | 0.097               | 0.962               | 2.682                  | 25.000                    |                                   |
| 0.080                                  | 0.084                                    | 0.107               | 0.956               | 3.009                  | 25.000                    |                                   |
| 0.090                                  | 0.095                                    | 0.118               | 0.951               | 3.349                  | 25.000                    |                                   |
| 0.100                                  | 0.106                                    | 0.131               | 0.946               | 3.500                  | 23.294                    |                                   |
| 0.110                                  | 0.117                                    | 0.145               | 0.940               | 3.500                  | 20.709                    |                                   |
| 0.120                                  | 0.128                                    | 0.159               | 0.934               | 3.500                  | 18.552                    |                                   |
| 0.130                                  | 0.140                                    | 0.173               | 0.928               | 3.500                  | 16.726                    |                                   |
| 0.140                                  | 0.152                                    | 0.188               | 0.922               | 3.500                  | 15.159                    |                                   |
| 0.150                                  | 0.164                                    | 0.202               | 0.916               | 3.500                  | 13.799                    |                                   |
| 0.160                                  | 0.176                                    | 0.217               | 0.910               | 3.500                  | 12.608                    |                                   |
| 0.170                                  | 0.188                                    | 0.232               | 0.903               | 3.500                  | 11.555                    |                                   |
| 0.180                                  | 0.201                                    | 0.248               | 0.897               | 3.500                  | 10.618                    |                                   |
| 0.190                                  | 0.213                                    | 0.264               | 0.890               | 3.500                  | 9.777                     |                                   |
| 0.200                                  | 0.226                                    | 0.280               | 0.884               | 3.500                  | 9.019                     |                                   |
| 0.205                                  | 0.233                                    | 0.288               | 0.880               | 3.500                  | 8.653                     | 20%                               |
| 0.210                                  | 0.239                                    | 0.296               | 0.877               | 3.500                  | 8.332                     |                                   |
| 0.220                                  | 0.253                                    | 0.312               | 0.870               | 3.500                  | 7.706                     |                                   |
| 0.230                                  | 0.266                                    | 0.329               | 0.863               | 3.500                  | 7.132                     |                                   |
| 0.240                                  | 0.280                                    | 0.346               | 0.856               | 3.500                  | 6.605                     |                                   |
| 0.250                                  | 0.295                                    | 0.364               | 0.849               | 3.500                  | 6.118                     |                                   |
| 0.252                                  | 0.298                                    | 0.368               | 0.847               | 3.500                  | 6.011                     | 10%                               |
| 0.260                                  | 0.309                                    | 0.382               | 0.841               | 3.500                  | 5.667                     |                                   |
| 0.270                                  | 0.324                                    | 0.400               | 0.834               | 3.500                  | 5.247                     |                                   |
| 0.280                                  | 0.339                                    | 0.419               | 0.826               | 3.500                  | 4.856                     |                                   |
| 0.290                                  | 0.355                                    | 0.438               | 0.818               | 3.500                  | 4.490                     |                                   |
| 0.295                                  | 0.363                                    | 0.448               | 0.814               | 3.500                  | 4.313                     | 0%                                |

**Table 2-3 Design Table for C 55/67**

| $\mu_{Sd} = \frac{M_{Sd}}{f_{cd}bd^2}$ | $\omega = \frac{A_{s1}f_{yd}}{f_{cd}bd}$ | $k_x = \frac{x}{d}$ | $k_z = \frac{z}{d}$ | $\varepsilon_c$<br>(‰) | $\varepsilon_{s1}$<br>(‰) | Percentage<br>Redistributi-<br>on |
|--|--|---------------------|---------------------|------------------------|---------------------------|-----------------------------------|
| 0.000                                  | 0.000                                    | 0.000               | 1.000               | 0.000                  | 25.000                    |                                   |
| 0.010                                  | 0.010                                    | 0.033               | 0.989               | 0.855                  | 25.000                    |                                   |
| 0.020                                  | 0.020                                    | 0.048               | 0.983               | 1.256                  | 25.000                    |                                   |
| 0.030                                  | 0.031                                    | 0.060               | 0.979               | 1.592                  | 25.000                    |                                   |
| 0.040                                  | 0.041                                    | 0.071               | 0.975               | 1.901                  | 25.000                    |                                   |
| 0.050                                  | 0.052                                    | 0.081               | 0.970               | 2.202                  | 25.000                    |                                   |
| 0.060                                  | 0.062                                    | 0.091               | 0.966               | 2.509                  | 25.000                    |                                   |
| 0.070                                  | 0.073                                    | 0.102               | 0.961               | 2.827                  | 25.000                    |                                   |
| 0.080                                  | 0.084                                    | 0.113               | 0.956               | 3.100                  | 24.379                    |                                   |
| 0.090                                  | 0.095                                    | 0.128               | 0.950               | 3.100                  | 21.177                    |                                   |
| 0.100                                  | 0.106                                    | 0.143               | 0.944               | 3.100                  | 18.613                    |                                   |
| 0.110                                  | 0.117                                    | 0.158               | 0.938               | 3.100                  | 16.514                    |                                   |
| 0.120                                  | 0.129                                    | 0.174               | 0.932               | 3.100                  | 14.763                    |                                   |
| 0.130                                  | 0.140                                    | 0.189               | 0.926               | 3.100                  | 13.280                    |                                   |
| 0.136                                  | 0.147                                    | 0.198               | 0.922               | 3.100                  | 12.557                    | 20%                               |
| 0.140                                  | 0.152                                    | 0.205               | 0.920               | 3.100                  | 12.007                    |                                   |
| 0.150                                  | 0.164                                    | 0.221               | 0.913               | 3.100                  | 10.903                    |                                   |
| 0.160                                  | 0.176                                    | 0.238               | 0.907               | 3.100                  | 9.935                     |                                   |
| 0.170                                  | 0.189                                    | 0.255               | 0.900               | 3.100                  | 9.080                     |                                   |
| 0.180                                  | 0.201                                    | 0.271               | 0.894               | 3.100                  | 8.318                     |                                   |
| 0.181                                  | 0.203                                    | 0.274               | 0.893               | 3.100                  | 8.214                     | 10%                               |
| 0.190                                  | 0.214                                    | 0.289               | 0.887               | 3.100                  | 7.635                     |                                   |
| 0.200                                  | 0.227                                    | 0.306               | 0.880               | 3.100                  | 7.019                     |                                   |
| 0.210                                  | 0.241                                    | 0.324               | 0.873               | 3.100                  | 6.461                     |                                   |
| 0.220                                  | 0.254                                    | 0.342               | 0.866               | 3.100                  | 5.951                     |                                   |
| 0.224                                  | 0.260                                    | 0.350               | 0.863               | 3.100                  | 5.757                     | 0%                                |

**Table 2-4 Design Table for C 60/75**

| $\mu_{Sd} = \frac{M_{Sd}}{f_{cd}bd^2}$ | $\omega = \frac{A_{s1}f_{yd}}{f_{cd}bd}$ | $k_x = \frac{x}{d}$ | $k_z = \frac{z}{d}$ | $\varepsilon_c$<br>(‰) | $\varepsilon_{s1}$<br>(‰) | Percentage<br>Redistributi-<br>on |
|--|--|---------------------|---------------------|------------------------|---------------------------|-----------------------------------|
| 0.000                                  | 0.000                                    | 0.000               | 1.000               | 0.000                  | 25.000                    |                                   |
| 0.010                                  | 0.010                                    | 0.035               | 0.988               | 0.906                  | 25.000                    |                                   |
| 0.020                                  | 0.020                                    | 0.050               | 0.983               | 1.326                  | 25.000                    |                                   |
| 0.030                                  | 0.031                                    | 0.063               | 0.978               | 1.673                  | 25.000                    |                                   |
| 0.040                                  | 0.041                                    | 0.074               | 0.974               | 1.988                  | 25.000                    |                                   |
| 0.050                                  | 0.052                                    | 0.084               | 0.970               | 2.292                  | 25.000                    |                                   |
| 0.060                                  | 0.062                                    | 0.094               | 0.965               | 2.600                  | 25.000                    |                                   |
| 0.070                                  | 0.073                                    | 0.105               | 0.960               | 2.900                  | 24.752                    |                                   |
| 0.080                                  | 0.084                                    | 0.121               | 0.955               | 2.900                  | 21.146                    |                                   |
| 0.090                                  | 0.095                                    | 0.137               | 0.948               | 2.900                  | 18.340                    |                                   |
| 0.100                                  | 0.106                                    | 0.153               | 0.942               | 2.900                  | 16.093                    |                                   |
| 0.110                                  | 0.117                                    | 0.169               | 0.936               | 2.900                  | 14.253                    |                                   |
| 0.120                                  | 0.129                                    | 0.186               | 0.930               | 2.900                  | 12.719                    |                                   |
| 0.124                                  | 0.133                                    | 0.192               | 0.928               | 2.900                  | 12.204                    | 20%                               |
| 0.130                                  | 0.141                                    | 0.203               | 0.924               | 2.900                  | 11.419                    |                                   |
| 0.140                                  | 0.153                                    | 0.220               | 0.917               | 2.900                  | 10.303                    |                                   |
| 0.150                                  | 0.165                                    | 0.237               | 0.911               | 2.900                  | 9.334                     |                                   |
| 0.160                                  | 0.177                                    | 0.255               | 0.904               | 2.900                  | 8.486                     |                                   |
| 0.166                                  | 0.185                                    | 0.266               | 0.900               | 2.900                  | 8.002                     | 10%                               |
| 0.170                                  | 0.189                                    | 0.273               | 0.897               | 2.900                  | 7.736                     |                                   |
| 0.180                                  | 0.202                                    | 0.291               | 0.890               | 2.900                  | 7.068                     |                                   |
| 0.190                                  | 0.215                                    | 0.310               | 0.883               | 2.900                  | 6.469                     |                                   |
| 0.200                                  | 0.228                                    | 0.328               | 0.876               | 2.900                  | 5.928                     |                                   |
| 0.206                                  | 0.236                                    | 0.340               | 0.872               | 2.900                  | 5.629                     | 0%                                |

**Table 2-5 Design Table for C 70/85**

| $\mu_{Sd} = \frac{M_{Sd}}{f_{cd}bd^2}$ | $\omega = \frac{A_{s1}f_{yd}}{f_{cd}bd}$ | $k_x = \frac{x}{d}$ | $k_z = \frac{z}{d}$ | $\varepsilon_c$<br>(‰) | $\varepsilon_{s1}$<br>(‰) | Percentage<br>Redistributi-<br>on |
|--|--|---------------------|---------------------|------------------------|---------------------------|-----------------------------------|
| 0.000                                  | 0.000                                    | 0.000               | 1.000               | 0.000                  | 25.000                    |                                   |
| 0.010                                  | 0.010                                    | 0.037               | 0.987               | 0.964                  | 25.000                    |                                   |
| 0.020                                  | 0.020                                    | 0.053               | 0.982               | 1.404                  | 25.000                    |                                   |
| 0.030                                  | 0.031                                    | 0.066               | 0.977               | 1.763                  | 25.000                    |                                   |
| 0.040                                  | 0.041                                    | 0.077               | 0.973               | 2.086                  | 25.000                    |                                   |
| 0.050                                  | 0.052                                    | 0.087               | 0.969               | 2.393                  | 25.000                    |                                   |
| 0.060                                  | 0.062                                    | 0.098               | 0.965               | 2.700                  | 24.960                    |                                   |
| 0.070                                  | 0.073                                    | 0.115               | 0.959               | 2.700                  | 20.858                    |                                   |
| 0.080                                  | 0.084                                    | 0.132               | 0.952               | 2.700                  | 17.779                    |                                   |
| 0.090                                  | 0.095                                    | 0.149               | 0.946               | 2.700                  | 15.382                    |                                   |
| 0.100                                  | 0.106                                    | 0.167               | 0.940               | 2.700                  | 13.464                    |                                   |
| 0.110                                  | 0.118                                    | 0.185               | 0.933               | 2.700                  | 11.893                    |                                   |
| 0.111                                  | 0.119                                    | 0.186               | 0.933               | 2.700                  | 11.816                    | 20%                               |
| 0.120                                  | 0.130                                    | 0.203               | 0.926               | 2.700                  | 10.582                    |                                   |
| 0.130                                  | 0.141                                    | 0.222               | 0.920               | 2.700                  | 9.471                     |                                   |
| 0.140                                  | 0.153                                    | 0.241               | 0.913               | 2.700                  | 8.518                     |                                   |
| 0.149                                  | 0.164                                    | 0.257               | 0.907               | 2.700                  | 7.806                     | 10%                               |
| 0.150                                  | 0.166                                    | 0.260               | 0.906               | 2.700                  | 7.690                     |                                   |
| 0.160                                  | 0.178                                    | 0.279               | 0.899               | 2.700                  | 6.965                     |                                   |
| 0.170                                  | 0.191                                    | 0.299               | 0.892               | 2.700                  | 6.324                     |                                   |
| 0.180                                  | 0.204                                    | 0.319               | 0.884               | 2.700                  | 5.753                     |                                   |
| 0.185                                  | 0.210                                    | 0.329               | 0.881               | 2.700                  | 5.507                     | 0%                                |



**Table 2-6 Design Table for C 80/95**

| $\mu_{Sd} = \frac{M_{Sd}}{f_{cd}bd^2}$ | $\omega = \frac{A_{s1}f_{yd}}{f_{cd}bd}$ | $k_x = \frac{x}{d}$ | $k_z = \frac{z}{d}$ | $\varepsilon_c$<br>(‰) | $\varepsilon_{s1}$<br>(‰) | Percentage<br>Redistributi-<br>on |
|--|--|---------------------|---------------------|------------------------|---------------------------|-----------------------------------|
| 0.000                                  | 0.000                                    | 0.000               | 1.000               | 0.000                  | 25.000                    |                                   |
| 0.010                                  | 0.010                                    | 0.038               | 0.987               | 0.999                  | 25.000                    |                                   |
| 0.020                                  | 0.020                                    | 0.055               | 0.981               | 1.451                  | 25.000                    |                                   |
| 0.030                                  | 0.031                                    | 0.068               | 0.977               | 1.820                  | 25.000                    |                                   |
| 0.040                                  | 0.041                                    | 0.079               | 0.972               | 2.149                  | 25.000                    |                                   |
| 0.050                                  | 0.052                                    | 0.090               | 0.968               | 2.459                  | 25.000                    |                                   |
| 0.060                                  | 0.062                                    | 0.104               | 0.963               | 2.600                  | 22.414                    |                                   |
| 0.070                                  | 0.073                                    | 0.122               | 0.957               | 2.600                  | 18.698                    |                                   |
| 0.080                                  | 0.084                                    | 0.140               | 0.950               | 2.600                  | 15.908                    |                                   |
| 0.090                                  | 0.095                                    | 0.159               | 0.944               | 2.600                  | 13.737                    |                                   |
| 0.100                                  | 0.107                                    | 0.178               | 0.937               | 2.600                  | 11.999                    |                                   |
| 0.103                                  | 0.110                                    | 0.183               | 0.935               | 2.600                  | 11.608                    | 20%                               |
| 0.110                                  | 0.118                                    | 0.197               | 0.930               | 2.600                  | 10.575                    |                                   |
| 0.120                                  | 0.130                                    | 0.217               | 0.923               | 2.600                  | 9.387                     |                                   |
| 0.130                                  | 0.142                                    | 0.237               | 0.916               | 2.600                  | 8.380                     |                                   |
| 0.138                                  | 0.152                                    | 0.253               | 0.910               | 2.600                  | 7.677                     | 10%                               |
| 0.140                                  | 0.154                                    | 0.257               | 0.909               | 2.600                  | 7.516                     |                                   |
| 0.150                                  | 0.166                                    | 0.278               | 0.901               | 2.600                  | 6.766                     |                                   |
| 0.160                                  | 0.179                                    | 0.299               | 0.894               | 2.600                  | 6.108                     |                                   |
| 0.170                                  | 0.192                                    | 0.320               | 0.886               | 2.600                  | 5.526                     | 0%                                |

**Table 2-7 Design Table for C 90/105**

| $\mu_{Sd} = \frac{M_{Sd}}{f_{cd}bd^2}$ | $\omega = \frac{A_{s1}f_{yd}}{f_{cd}bd}$ | $k_x = \frac{x}{d}$ | $k_z = \frac{z}{d}$ | $\varepsilon_c$<br>(‰) | $\varepsilon_{s1}$<br>(‰) | Percentage<br>Redistributi-<br>on |
|--|--|---------------------|---------------------|------------------------|---------------------------|-----------------------------------|
| 0.000                                  | 0.000                                    | 0.000               | 1.000               | 0.000                  | 25.000                    |                                   |
| 0.010                                  | 0.010                                    | 0.039               | 0.987               | 1.018                  | 25.000                    |                                   |
| 0.020                                  | 0.020                                    | 0.056               | 0.981               | 1.480                  | 25.000                    |                                   |
| 0.030                                  | 0.031                                    | 0.069               | 0.976               | 1.855                  | 25.000                    |                                   |
| 0.040                                  | 0.041                                    | 0.081               | 0.972               | 2.189                  | 25.000                    |                                   |
| 0.050                                  | 0.052                                    | 0.091               | 0.968               | 2.504                  | 25.000                    |                                   |
| 0.060                                  | 0.062                                    | 0.107               | 0.962               | 2.600                  | 21.724                    |                                   |
| 0.070                                  | 0.073                                    | 0.126               | 0.956               | 2.600                  | 18.107                    |                                   |
| 0.080                                  | 0.084                                    | 0.145               | 0.949               | 2.600                  | 15.391                    |                                   |
| 0.090                                  | 0.096                                    | 0.164               | 0.942               | 2.600                  | 13.278                    |                                   |
| 0.099                                  | 0.107                                    | 0.183               | 0.935               | 2.600                  | 11.608                    | 20%                               |
| 0.100                                  | 0.107                                    | 0.183               | 0.935               | 2.600                  | 11.586                    |                                   |
| 0.110                                  | 0.118                                    | 0.203               | 0.928               | 2.600                  | 10.199                    |                                   |
| 0.120                                  | 0.130                                    | 0.223               | 0.921               | 2.600                  | 9.043                     |                                   |
| 0.130                                  | 0.142                                    | 0.244               | 0.914               | 2.600                  | 8.063                     |                                   |
| 0.134                                  | 0.148                                    | 0.253               | 0.911               | 2.600                  | 7.677                     | 10%                               |
| 0.140                                  | 0.154                                    | 0.265               | 0.907               | 2.600                  | 7.221                     |                                   |
| 0.150                                  | 0.167                                    | 0.286               | 0.899               | 2.600                  | 6.490                     |                                   |
| 0.160                                  | 0.179                                    | 0.308               | 0.891               | 2.600                  | 5.850                     |                                   |
| 0.167                                  | 0.188                                    | 0.323               | 0.886               | 2.600                  | 5.450                     | 0%                                |

2.2 General Design Charts

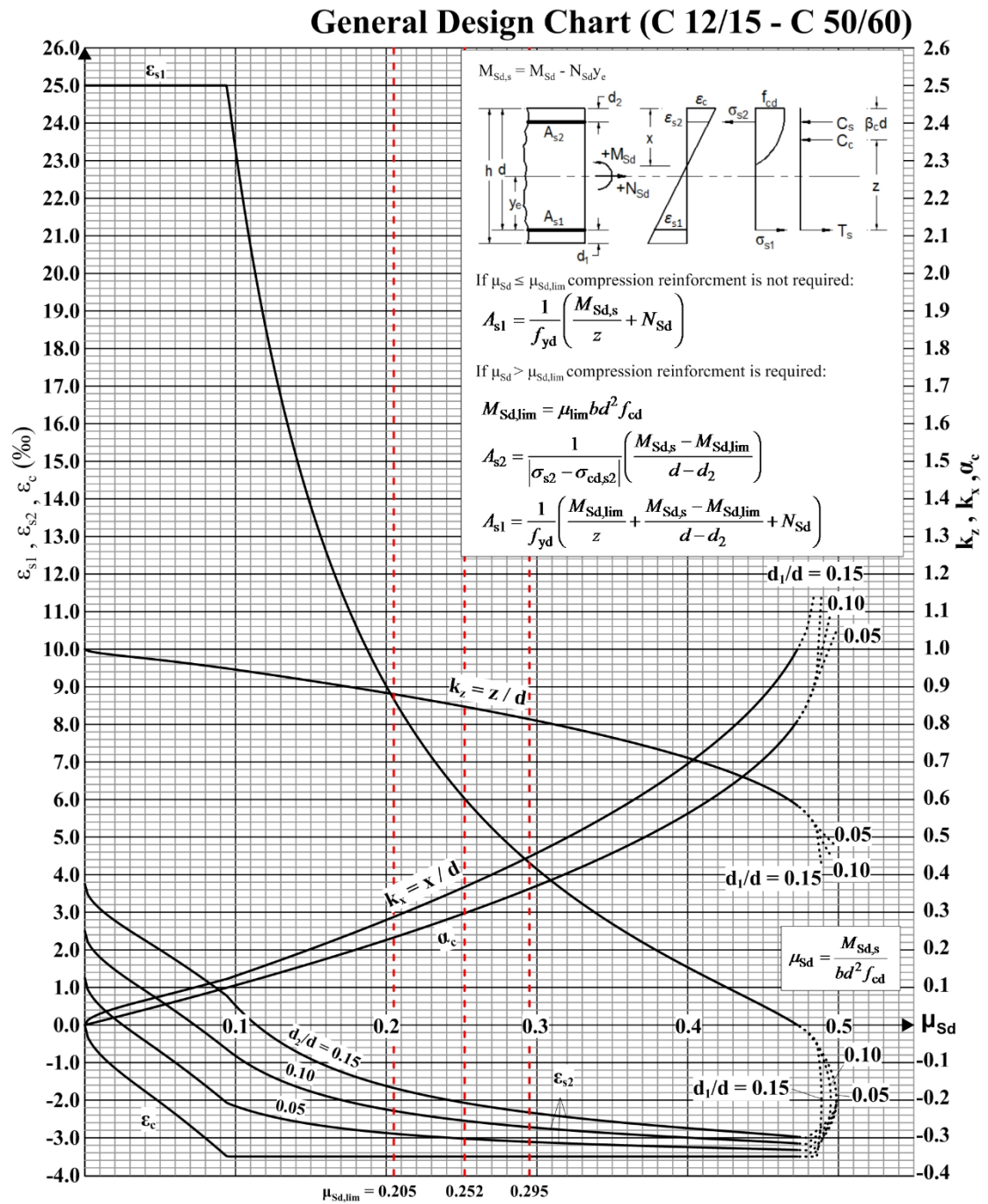


Figure 2-1 General Design Chart for C 12/15 – C 50/60

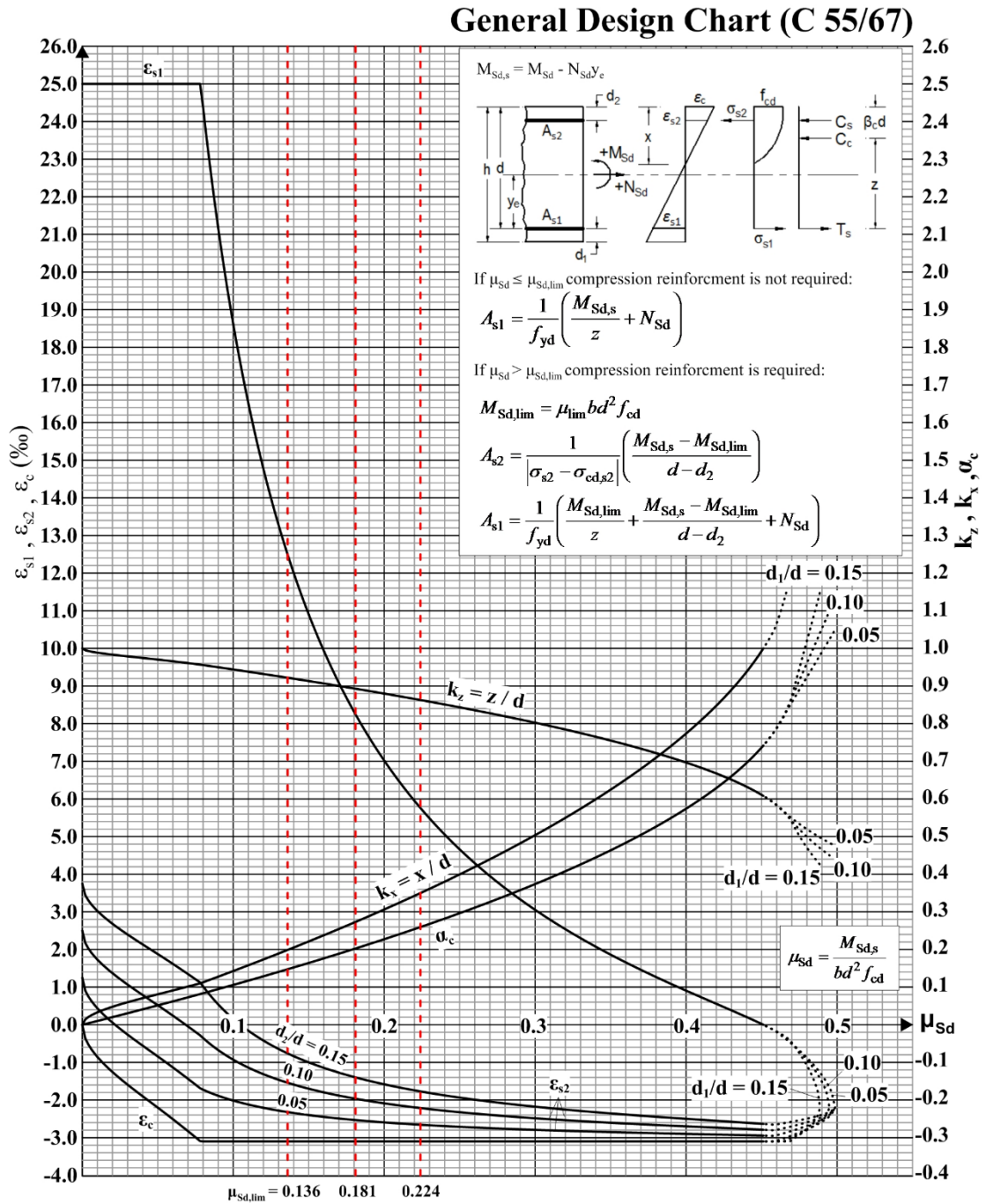


Figure 2-2 General Design Chart for C 55/67

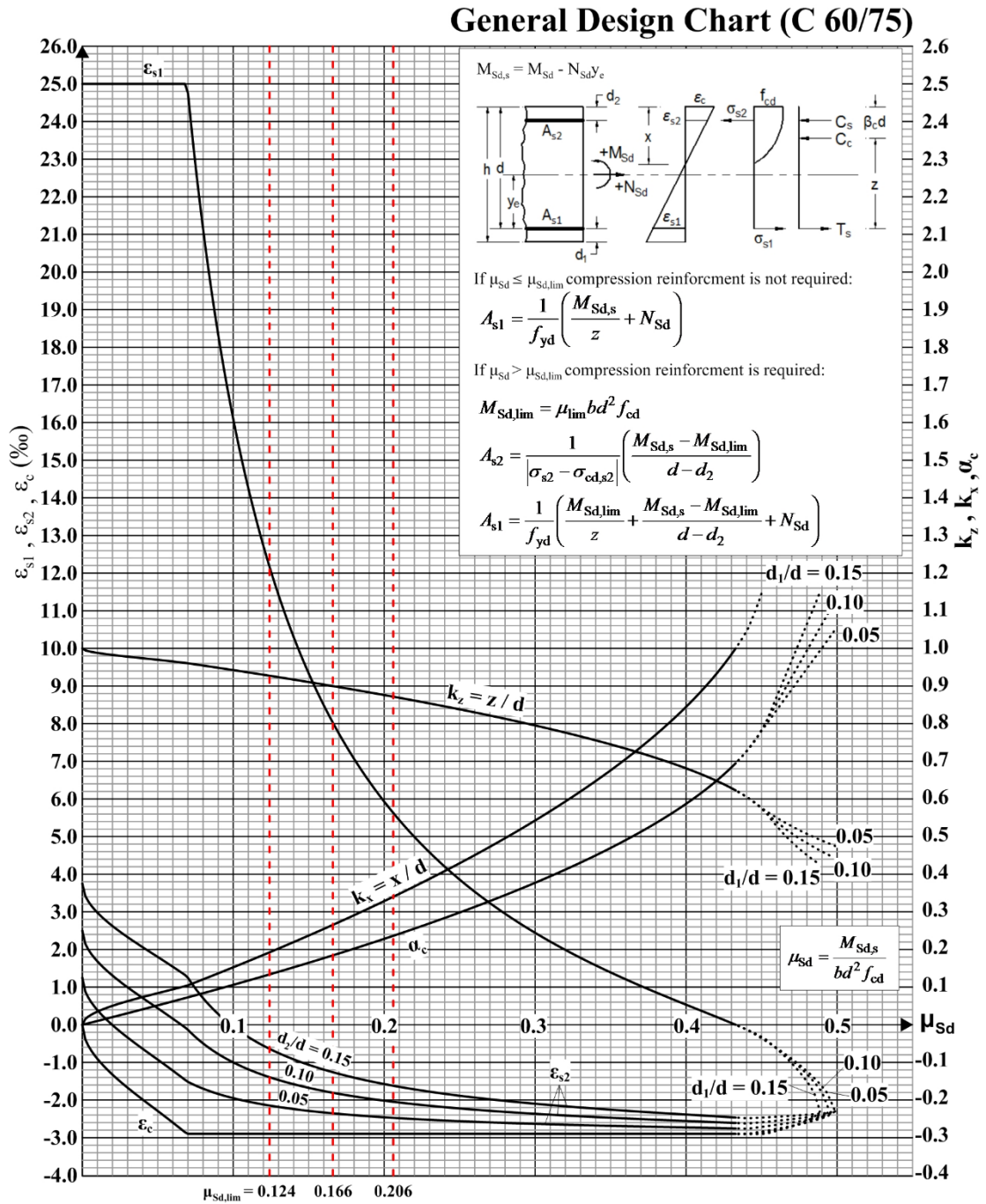


Figure 2-3 General Design Chart for C 60/75

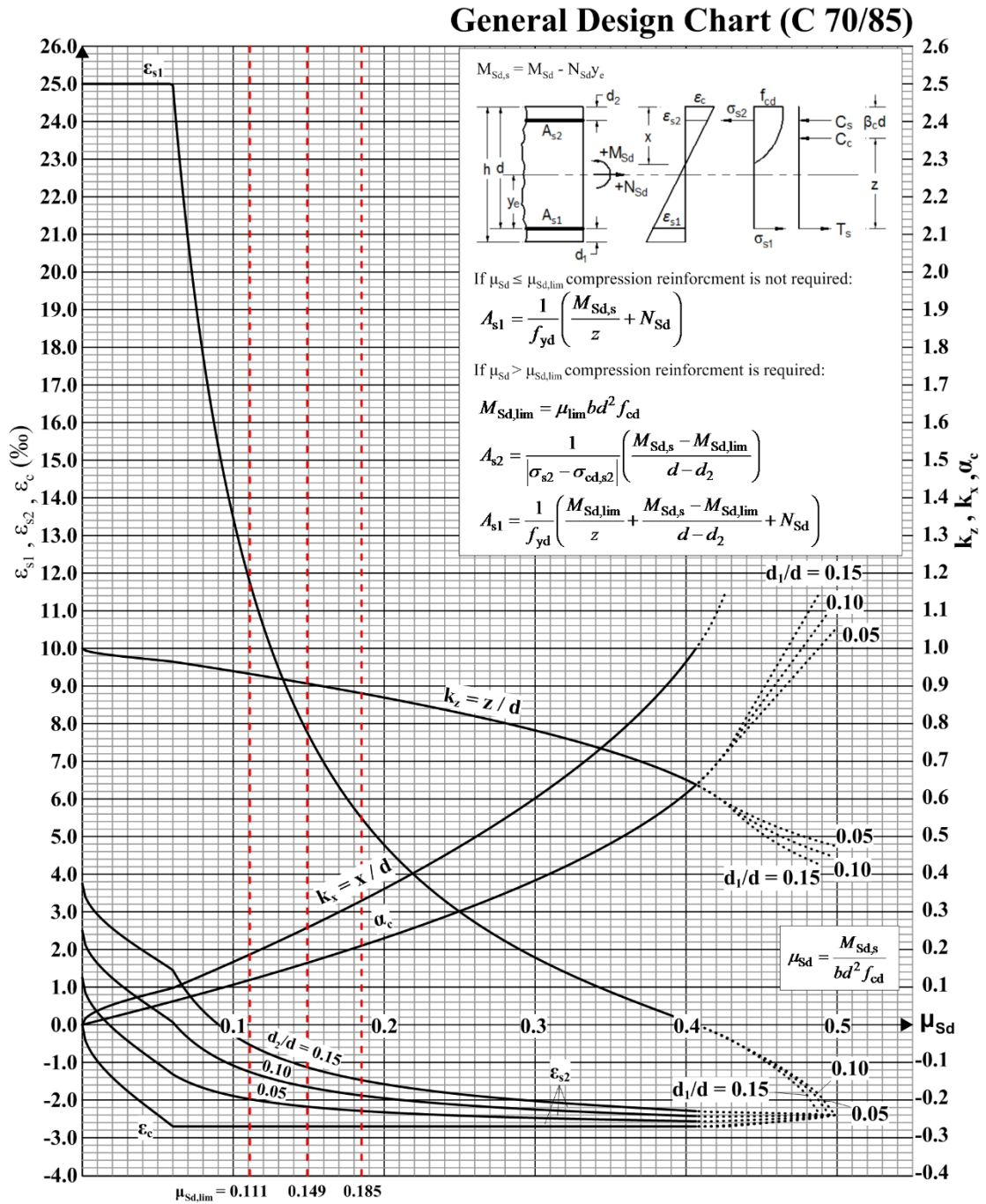


Figure 2-4 General Design Chart for C 70/85

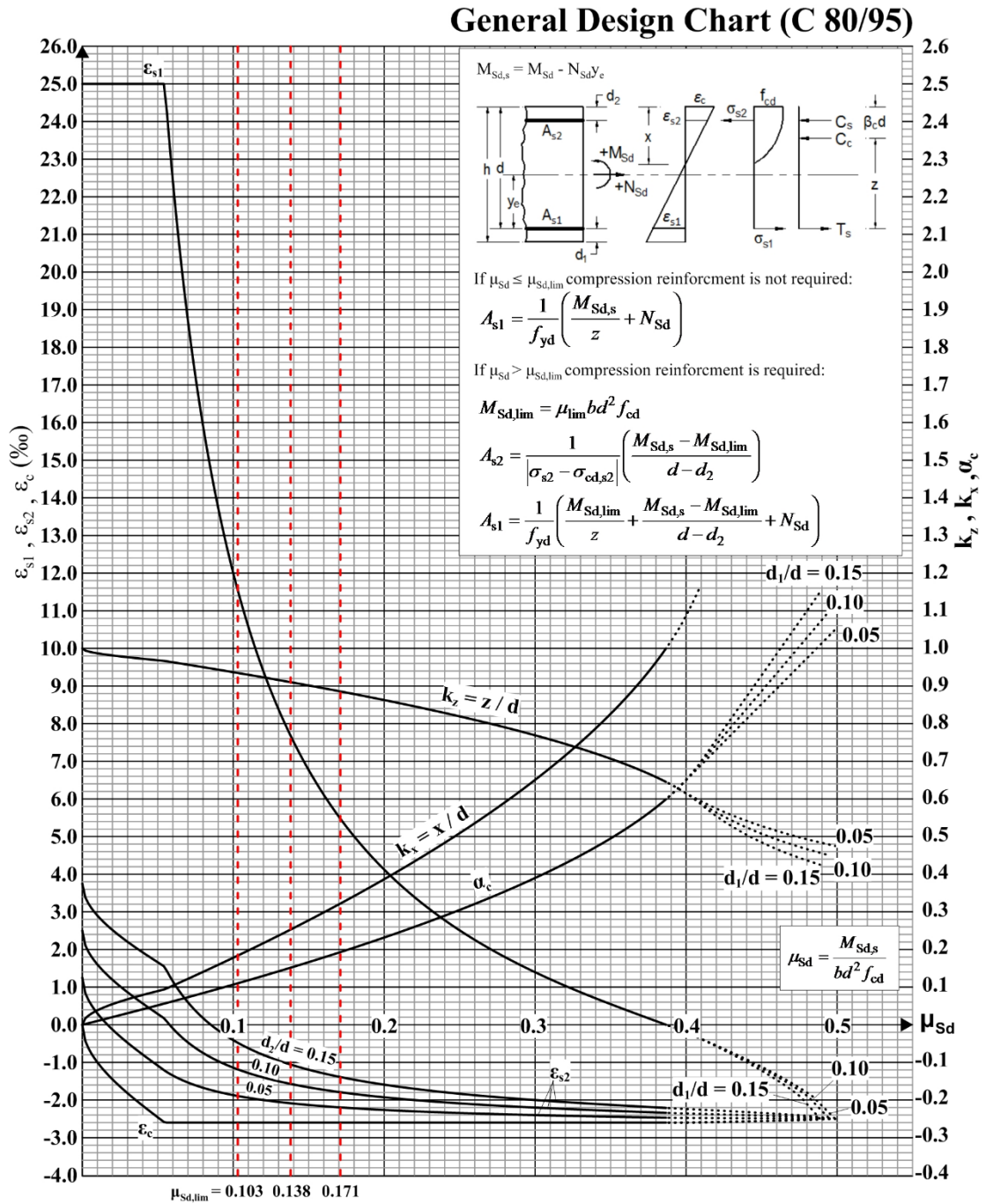


Figure 2-5 General Design Chart for C 80/95

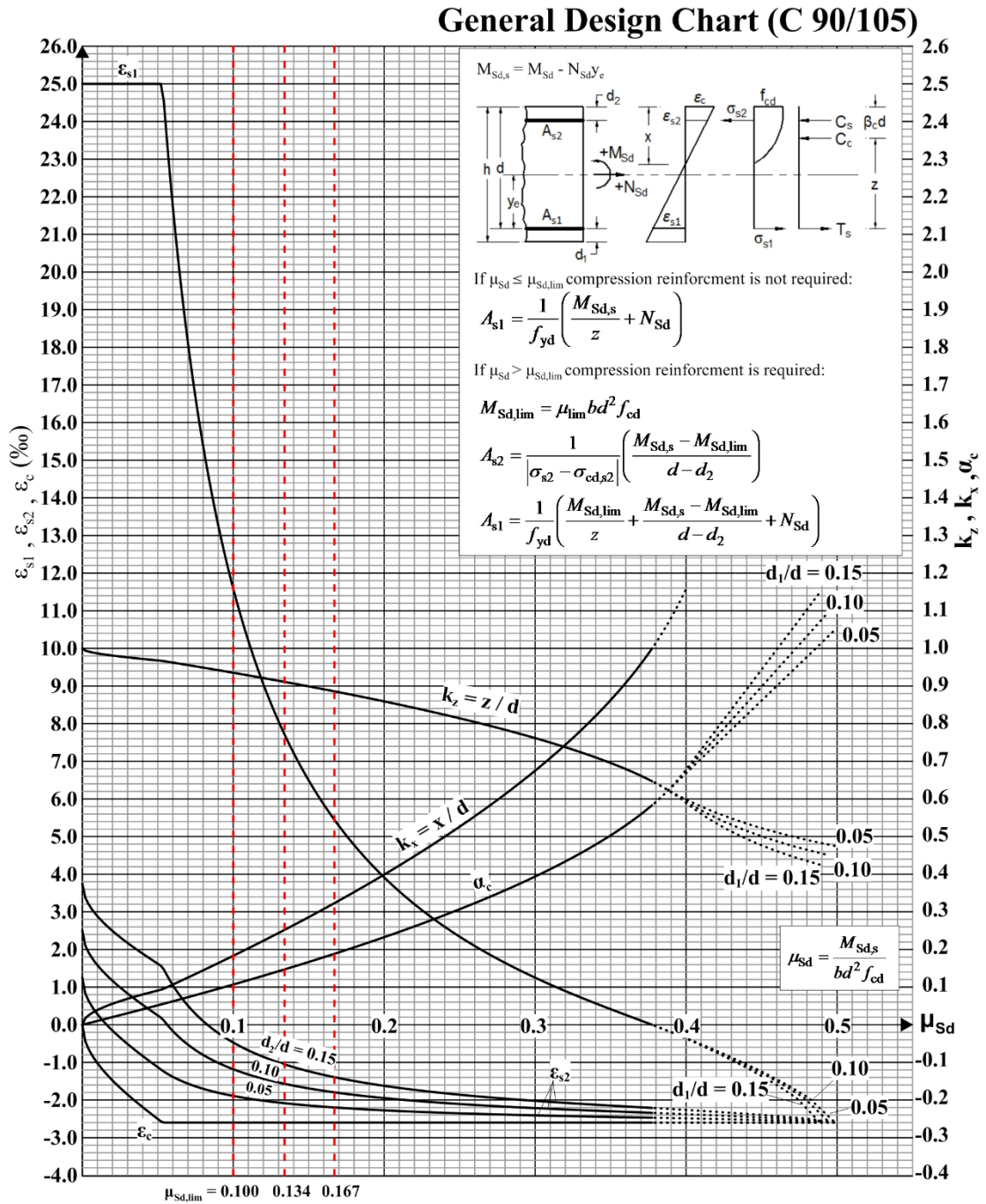


Figure 2-6 General Design Chart for C 90/105



## 2.3 Design Examples

### 2.3.1 Singly Reinforced Section without Normal Load

**Given:** Cross-section:  $b/h/d = 300/600/550$  mm

Action Effects: Design moment = 350 kNm

Material Data: Concrete C 70/85 and Steel S 460

**Required:** Amount of tension reinforcement for Class I Works

**Solution:**

**Using Design Table:**

$$\mu_{Sd,lim} = 0.185$$

$$\mu_{Sd,s} = \frac{M_{Sd,s}}{f_{cd}bd^2} = \frac{350 \times 10^6}{46.67 \times 300 \times 550^2} = 0.083 \leq \mu_{Sd,lim}$$

Since  $\mu_{Sd,s} \leq \mu_{Sd,lim}$ , the section is singly reinforced.

Reading  $\omega$  from Table 2-5,

$$\rightarrow \omega = 0.0873$$

$$A_{s1} = \omega bd \frac{f_{cd}}{f_{yd}} = 0.0873 \times 300 \times 550 \times \frac{46.67}{400} = 1680.65 \text{ mm}^2$$

**Using General Design Chart:**

$$\mu_{Sd,lim} = 0.185$$

$$\mu_{Sd,s} = \frac{M_{Sd,s}}{f_{cd}bd^2} = \frac{350 \times 10^6}{46.67 \times 300 \times 550^2} = 0.083 \leq \mu_{Sd,lim}$$

Since  $\mu_{Sd,s} \leq \mu_{Sd,lim}$ , the section is singly reinforced.

Reading  $k_z$  from Figure 2-4,

$$\rightarrow k_z = 0.945$$

$$A_{s1} = \frac{M_{Sd,s}}{z f_{yd}} = \frac{350 \times 10^6}{0.945 \times 550 \times 400} = 1683.51 \text{ mm}^2$$

### 2.3.2 Singly Reinforced Section with Normal Load (Compressive)

**Given:** Cross-section: b/h/d = 300/600/550 mm

Action Effects: Design moment = 350 kNm & Normal Load = 500 kNm

Material Data: Concrete C 70/85 and Steel S 460

**Required:** Amount of tension reinforcement for Class I Works

**Solution:**

**Using Design Table:**

$$M_{Sd,s} = 350 + 500 \times (550 - 300) \times 10^{-3} = 475 \text{ kNm}$$

$$\mu_{Sd,lim} = 0.185$$

$$\mu_{Sd,s} = \frac{M_{Sd,s}}{f_{cd} b d^2} = \frac{475 \times 10^6}{46.67 \times 300 \times 550^2} = 0.112 \leq \mu_{Sd,lim}$$

Since  $\mu_{Sd,s} \leq \mu_{Sd,lim}$ , the section is singly reinforced.

Reading  $\omega$  from Table 2-5,

$$\rightarrow \omega = 0.1204$$

$$A_{s1} = \omega b d \frac{f_{cd}}{f_{yd}} + \frac{N_{Sd}}{f_{yd}} = 0.1204 \times 300 \times 550 \times \frac{46.67}{400} - \frac{500 \times 10^3}{400} = 1067.87 \text{ mm}^2$$

**Using General Design Chart:**

$$M_{Sd,s} = 350 + 500 \times (550 - 300) \times 10^{-3} = 475 \text{ kNm}$$

$$\mu_{Sd,lim} = 0.185$$

$$\mu_{Sd,s} = \frac{M_{Sd,s}}{f_{cd} b d^2} = \frac{475 \times 10^6}{46.67 \times 300 \times 550^2} = 0.112 \leq \mu_{Sd,lim}$$

Since  $\mu_{Sd,s} \leq \mu_{Sd,lim}$ , the section is singly reinforced.

Reading  $k_z$  from Figure 2-4,

$$\rightarrow k_z = 0.925$$

$$A_{s1} = \frac{M_{Sd,s}}{z f_{yd}} + \frac{N_{Sd}}{f_{yd}} = \frac{475 \times 10^6}{0.925 \times 550 \times 400} - \frac{500 \times 10^3}{400} = 1084.15 \text{ mm}^2$$

### 2.3.3 Doubly Reinforced Section with Moment Redistribution

**Given:** Cross-section:  $b/h/d/d_2 = 300/600/550/55$  mm

Action Effects: Design moment = 600 kNm after moment redistribution

Material Data: Concrete C 70/85 and Steel S 460

Percent Moment Redistribution: 20%

**Required:** Amount of tension and compression reinforcement for Class I Works

**Solution:**

**Using Design Table:**

$$\mu_{Sd,lim} = 0.111 \text{ for 20\% moment redistribution}$$

$$\mu_{Sd,s} = \frac{M_{Sd,s}}{f_{cd} b d^2} = \frac{600 \times 10^6}{46.67 \times 300 \times 550^2} = 0.142 > \mu_{Sd,lim}$$

Since  $\mu_{Sd,s} > \mu_{Sd,lim}$ , the section is doubly reinforced.

Reading  $\omega_{lim}$  from Table 2-5,

$$\rightarrow \omega_{lim} = 0.119$$

$$\omega' = \frac{\mu_{Sd,s} - \mu_{Sd,lim}}{(1 - d_2/d)} = \frac{0.142 - 0.111}{(1 - 55/550)} = 0.0344$$

Area of tension reinforcement,

$$A_{s1} = (\omega_{\text{lim}} + \omega') bd \frac{f_{cd}}{f_{yd}} = (0.119 + 0.0344) \times 300 \times 550 \times \frac{46.67}{400} = 2953.16 \text{ mm}^2$$

Check whether the compression reinforcement has yielded,

$$\varepsilon_{s2} = \left(1 - \frac{d_2/d}{k_x}\right) \varepsilon_c = \left(1 - \frac{0.10}{0.186}\right) \times 2.7 = 1.23\%$$

$$\rightarrow \varepsilon_{s2} = 1.23\% \leq \varepsilon_{yd} = 2.0\% \rightarrow \sigma_{s2} = \varepsilon_{s2} E_s = 1.23 \times 200 = 246 \text{ MPa}$$

Calculate the stress in concrete at the level of compression reinforcement to avoid double counting of area,

$$\rightarrow \varepsilon_{cs2} = 1.23\% \leq \varepsilon_{c2} = 2.4\%$$

$$\sigma_{cd,s2} = f_{cd} \left[1 - \left(1 - \frac{\varepsilon_{cs2}}{\varepsilon_{c2}}\right)^n\right] = 46.67 \times \left[1 - \left(1 - \frac{1.23}{2.4}\right)^{1.45}\right] = 30.20 \text{ MPa}$$

Area of compression reinforcement,

$$A_{s2} = \omega' bd \frac{f_{cd}}{|\sigma_{s2} - \sigma_{cd,s2}|} = 0.0344 \times 300 \times 550 \times \frac{46.67}{|246 - 30.20|} = 1227.52 \text{ mm}^2$$

**Using General Design Chart:**

$$\mu_{Sd,lim} = 0.111 \text{ for 20\% moment redistribution}$$

$$\mu_{Sd,s} = \frac{M_{Sd,s}}{f_{cd} b d^2} = \frac{600 \times 10^6}{46.67 \times 300 \times 550^2} = 0.142 > \mu_{Sd,lim}$$

Since  $\mu_{Sd,s} > \mu_{Sd,lim}$ , the section is doubly reinforced.

$$M_{Sd,lim} = \mu_{Sd,lim} b d^2 f_{cd} = 0.111 \times 300 \times 550^2 \times 46.67 \times 10^{-6} = 470.12 \text{ kNm}$$

Reading  $k_{z,lim}$  from Figure 2-4,

$$\rightarrow k_{z,\text{lim}} = 0.933$$

Area of tension reinforcement,

$$A_{s1} = \frac{M_{Sd,\text{lim}}}{z_{\text{lim}} f_{yd}} + \frac{(M_{Sd} - M_{Sd,\text{lim}})}{(d - d_2) f_{yd}} = \frac{470.12 \times 10^6}{0.933 \times 550 \times 400} + \frac{(600 - 470.12) \times 10^6}{(550 - 50) \times 400}$$

$$A_{s1} = 2939.76 \text{ mm}^2$$

Check whether the compression reinforcement has yielded,

Reading  $\varepsilon_{s2}$  from Figure 2-4,

$$\frac{d_2}{d} = \frac{55}{550} = 0.10$$

$$\rightarrow \varepsilon_{s2} = -1.25\% \leq \varepsilon_{yd} = -2.0\% \rightarrow \sigma_{s2} = \varepsilon_{s2} E_s = 1.25 \times 200 = 250 \text{ MPa}$$

Calculate the stress in concrete at the level of compression reinforcement to avoid double counting of area,

$$\rightarrow \varepsilon_{cs2} = 1.25\% \leq \varepsilon_{c2} = 2.4\%$$

$$\sigma_{cd,s2} = f_{cd} \left[ 1 - \left( 1 - \frac{\varepsilon_{cs2}}{\varepsilon_{c2}} \right)^n \right] = 46.67 \times \left[ 1 - \left( 1 - \frac{1.25}{2.4} \right)^{1.45} \right] = 30.61 \text{ MPa}$$

Area of compression reinforcement,

$$A_{s2} = \frac{1}{|\sigma_{s2} - \sigma_{c2}|} \frac{(M_{Sd} - M_{Sd,\text{lim}})}{(d - d_2) \sigma_{s2}} = \frac{1}{|250 - 30.61|} \frac{(600 - 470.12) \times 10^6}{(550 - 50)}$$

$$A_{s2} = 1184.01 \text{ mm}^2$$