JCSS-VROU/HOL 99

JCSS PROBABILISTIC MODEL CODE
PART 3: RESISTANCE MODELS

3.10 DIMENSIONS

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3.10 DIMENSIONS

3.10.1 External dimensions of concrete components

In the following the only time independent effects are considered. Dimensional deviations of a dimension X is described by statistical characteristics of its deviations Y from the nominal value X_{nom}:

$$Y = X - X_{nom} \qquad (1)$$

Concerning external (perimeter) dimensions of reinforced concrete cross-section of horizontal members (beams, plates), available data are quite extensive, although not convincing. The following general remarks follow from recent analysis of large samples of measurements [1,2,3,4]. It has been observed that the following aspects do not significantly affect dimensional deviations of reinforced concrete cross-section:
- the type of the elements (reinforced, prestressed),
- the shape of the cross/section (rectangular, I, T, L),
- the class of concrete (strength of concrete),
- dimension orientation (depth, width),
- position of the cross-section (mid-span, support).

It has been found [4] that external dimensions of concrete cross-sections are only slightly dependent on the mode of production (precast, cast in situ).

When precast and cast in situ elements are taken together [2] then for the mean and standard deviation (the normal distribution seems to be satisfactory) of Y may be expected within the limits:

$$0 \leq \mu_y = 0.003 \, X_{nom} \leq 3 \text{ mm} \qquad (2)$$

$$\sigma_y = 4 \text{ mm} + 0.006 \, X_{nom} \leq 10 \text{ mm} \qquad (3)$$

These formulae are valid for the nominal value X_{nom}, up to about 1000 mm (no significant dependence is observed beyond this size). Note that recent European document [6] on execution of concrete structures specifies is in a good agreement with the above mentioned data. The maximum permitted deviation $\pm$ 19 mm (corresponding to about $\sigma_y = 12$ mm is specified given for $X_{nom} = 1000$ mm

3.10.2 Concrete cover

Top Steel

According to the data reported in [1] the average concrete cover to the top steel of beams and slabs in systematically greater than the nominal value (by about 10 mm), the standard deviation is also around 10 mm (within an interval from 5 to 15 mm). Reasonable average formulae (with a great uncertainty) for the cover to beam and plate to steel may be written in an approximate form as:

$$5 \text{ mm} \leq \mu_y \leq 15 \text{ mm} \qquad (4)$$

$$5 \text{ mm} \leq \sigma_y \leq 15 \text{ mm} \tag{5}$$

Bottom steel

Even more scattered and less conclusive are data indicated [1] for cover to bottom steel of beams and slabs. Depending on type of spacers (and perhaps on many other production conditions) data reported in [1] indicate that the mean μ_y may be expected within an extremely broad range from -20 mm to +20 mm, while the standard deviation seems to be relatively small, around 5 mm only, thus

$$-20 \text{ mm} \leq \mu_y \leq 20 \text{ mm} \tag{6}$$

$$\sigma_y \cong 5 \text{ mm} \tag{7}$$

Effective depth

Obviously, the above relations are providing only gross estimates and particular values must be chosen taking into account other specific conditions. Nevertheless, they are in a reasonable agreement with observations concerning effective depth of the cross-section (the depth and concrete cover could be highly correlated). If no further information is available, it is indicated in [2] that the characteristics may be assessed by:

$$\mu_y \cong 10 \text{ mm} \tag{8}$$

$$\sigma_y \cong 10 \text{ mm} \tag{9}$$

Further experimental measurements (related to specified production procedure) with a special emphasis on internal dimensions of horizontal, as well as vertical elements are obviously needed.

3.10.3 Differences between concrete columns, slabs and beams

Concerning external dimensions no significant differences have been found between columns, slabs and beams [4]. There are, however, some differences in concrete cover of these elements. Table 2 shows characteristics of concrete cover based on data reported in [1] collected in UK.

Table 1. Characteristics of concrete cover.

Concrete cover	Mean μ_Y [mm]	Standard deviation σ_Y [mm]
in column - [1] (two samples)	1; 3	0,2; 7
in wall - [1] (one sample-241 obs.)	1	12
of slab bottom steel - [1] and {UK}	−8 to 5 {7 to 23}	6 to 15 {3 to 4}
of slab top steel - [1] and {UK}	− 13 to 11 {5 to 16}	11 to17 {6 to 16}
of beam bottom steel in UK	− 17[*] to 3	2 to 5
of beam top steel in UK	1 to 12	8 to14

[*] Note: The negative mean of deviations was observed when using plastic spacers.

According to the data in Table 1 the following characteristics of concrete cover may be considered as a first approximations (intervals indicated for the mean and standard deviation

represent a reasonable bonds which are dependent on particular conditions and quality of production):

- column and wall:

$$\mu_Y = 0 \text{ to } 5 \text{ mm} \tag{10}$$

$$\sigma_Y = 5 \text{ to } 10 \text{ mm} \tag{11}$$

- slab bottom steel:

$$\mu_Y = 0 \text{ to } 10 \text{ mm} \tag{12}$$

$$\sigma_Y = 5 \text{ to } 10 \text{ mm} \tag{13}$$

- beam bottom steel:

$$\mu_Y = -10 \text{ to } 0 \text{ mm} \tag{14}$$

$$\sigma_Y = 5 \text{ to } 10 \text{ mm} \tag{15}$$

- slab and beams top steel:

$$\mu_Y = 0 \text{ to } 10 \text{ mm} \tag{16}$$

$$\sigma_Y = 10 \text{ to } 15 \text{ mm} \tag{17}$$

Obviously, these values represent only very gross estimates of basic statistical characteristics of concrete cover and particular values should be chosen in accordance with relevant production conditions. Further experimental measurements (related to given production procedure) with a specific emphasis on internal dimensions of horizontal, as well as vertical elements are obviously needed.

Note that recent European document [6] on execution of concrete structures specifies is in a good agreement with the above mentioned data. The minimum permitted deviation of concrete cover is -10 mm (corresponding to $\sigma_y = 6$), the maximum permitted deviation is from 10 mm up to 20 mm (corresponding to about σ_y from 6 to 13 mm).

3.10.4 Cross-section dimensions of hot rolled steel products

In Czech Republic [5] some data on dimensional deviations of cross-sections of rolled products (profile I, L, T) are collected and evaluated at present. Preliminary results obtained for profile I (IPE 80 to 200) indicate that the mean and standard deviation of Y of the basic dimensions (height, width and thickness) is less than 1 mm, while the coefficient of skewness is negligible, thus the indicative values of the deviation characteristics are

$$-1.0 \text{ mm} \leq \mu_Y \leq +1.0 \text{ mm} \tag{18}$$

$$\sigma_Y \leq 1.0 \text{ mm} \tag{19}$$

For cross-section area and modulus it has been found that independently on the profile height the mean of both quantities differ from their nominal values insignificantly (the differences are practically zero) and the coefficients of variations for cross-section area are about 3,2 %, for cross-section modulus about 4,0 %. The normal distribution seems to be fully satisfactory model for all geometrical properties.

3.10.5 Theoretical models

Several theoretical models were considered in previous studies [1] and [2]. It appears that unless further data are available, normal distribution provides a good general model for external dimensions of both reinforced concrete and steel elements and also for effective depth of reinforced concrete cross-section.

However, concrete cover to reinforcement in concrete cross-sections of various concrete elements is a special random variable, which may hardly be described by a normal distribution. In this case different types of one or two side-limited distribution should be considered.

Taking into account various combination of the coefficient of variation $w = \sigma/\mu$, and skewness α (the subscripts are omitted here), the following commonly used distributions could be considered:

- for all w and α beta distribution with general lower and upper bound a and b, denoted Beta($\mu;\sigma,a;b$),
- for all w and $\alpha > 0$ shifted lognormal distribution with lower bound a, denoted sLN($\mu;\sigma, a$),
- for all $\alpha < 2w$ beta distribution with the lower a at zero ($a = 0$), and a general upper bound b, which is denoted Beta($\mu;\sigma;0;b$),
- for $\alpha = 3w+w^3$ lognormal distribution with the lower bound a at zero ($a = 0$),
- for $\alpha = 2w$ gamma distribution (which has the lower bound a at zero ($a = 0$) by definition), denoted Gamma($\mu;\sigma$).

3.10.6 Correlations

It has been found [4] that external dimensions of concrete cross-sections are only slightly dependent on the mode of production (precast, cast in situ). No significant correlation (the correlation coefficients being around 0,12) has been found between vertical and horizontal dimensions. No data are available concerning correlation of internal (concrete cover) and external dimensions even though the depth and concrete cover of some elements could be highly correlated. There may be a strong auto-correlation along the element; correlation distance may be assessed as multiple (say from 3 to 5) of the cross section height or as a part of the span (say 1/4 to 1/2).

3.10.7 References

[1]   Casciati, F., Negri, I, Rackwitz, R. Geometrical Variability in Structural Members and Systems, JCSS Working Document, January 1991.
[2]   Tichý, M. Dimensional Variations. In: Quality Control of Concrete Structures, RILEM, Stockholm, June 1979, pp. 171-180.
[3]   Tichý, M. Variability of Dimensions of Concrete Elements. In: Quality Control of Concrete Structures, RILEM, Stockholm, June 1979, pp. 225-227.
[4]   Bouska, P., Holický, M. Statistical analysis of geometric parameters of concrete cross sections. Research report, Building Research Institute, Prague, 1983 (in Czech - Summary in English is provided).

[5]   Fajkus, M., Holický, M., Rozlívka L., Vorlíček M.: Random Properties of Steel Elements Produced In Czech Republic. Proc. Eurosteel'99, Paper No. 90. Prague 1999.

[6]   ENV 13670-1 Execution of concrete structures - Part 1: Common, Brussels, 2000.