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Profometer PM-6

Cover Readings Statistical Assessment

The need for statistical Assessment of Cover Readings

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- It is widely recognised that the failure of compliance of the cover depth with the specifications is one of the main causes of premature deterioration of reinforced concrete structures.
- Typically the building codes specify a minimum cover to ensure that there is a low risk of the reinforcement becoming excessively corroded and requiring significant repairs before the end of the intended working life (design service life), on the assumptions that the designer has chosen a practical allowance for deviation, Δc, to add to the minimum value and that the level of workmanship on site is adequate to achieve the minimum cover.
- Examples from the British and German Standards are given on the next two slides.

Durability Recommendations for Concrete Elements according to BS 8500-1

Table A.4 **Durability[A] recommendations for reinforced or prestressed elements with an intended working life of at least 50 years**

Nominal cover[B]	Compressive strength class where recommended, maximum water-cement ratio and minimum cement or combination content for normal-weight concrete[C] with 20 mm maximum aggregate size[D]							Cement/combination types
mm	15 + Δc	20 + Δc	25 + Δc	30 + Δc	35 + Δc	40 + Δc	45 + Δc	50 + Δc	
Corrosion induced by carbonation (XC exposure classes)									
XC1	C20/25 0.70 240	C20/25 0.70 240	C20/25 0.70 240	C20/25 0.70 240	C20/25 0.70 240	C20/25 0.70 240	C20/25 0.70 240	C20/25 0.70 240	All in Table A.6
XC2	—	—	C25/30 0.65 260	C25/30 0.65 260	C25/30 0.65 260	C25/30 0.65 260	C25/30 0.65 260	C25/30 0.65 260	All in Table A.6
XC3/4	—	C40/50 0.45 340	C30/37 0.55 300	C28/35 0.60 280	C25/30 0.65 260	C25/30 0.65 260	C25/30 0.65 260	C25/30 0.65 260	All in Table A.6 except IVB-V
	—	—	C40/50 0.45 340	C30/37 0.55 300	C28/35 0.60 280	C25/30 0.65 260	C25/30 0.65 260	C25/30 0.65 260	IVB-V
Corrosion induced by chlorides (XS from sea water, XD other than sea water) *Also adequate for any associated carbonation induced corrosion (XC)*									
XD1	—	—	C40/50 0.45 360	C32/40 0.55 320	C28/35 0.60 300	C28/35 0.60 300	C28/35 0.60 300	C28/35 0.60 300	All in Table A.6
XS1	—	—	—	C45/55[E] 0.35[F] 380	C35/45[E] 0.45 360	C32/40[E] 0.50 340	C32/40[E] 0.50 340	C32/40[E] 0.50 340	CEM I, IIA, IIB-S, SRPC
	—	—	—	C40/50[E] 0.35[F] 380	C32/40[E] 0.45 360	C28/35 0.50 340	C25/30 0.55 320	C25/30 0.55 320	IIB-V, IIIA
	—	—	—	C32/40[E] 0.40 380	C25/30 0.50 340	C25/30 0.50 340	C25/30 0.55 320	C25/30 0.55 320	IIIB
	—	—	—	C32/40[E] 0.40 380	C28/35 0.50 340	C25/30 0.50 340	C25/30 0.55 320	C25/30 0.55 320	IVB-V
XD2 or XS2	—	—	—	C40/50[E] 0.40 380	C32/40[E] 0.50 340	C28/35 0.55 320	C28/35 0.55 320	C28/35 0.55 320	CEM I, IIA, IIB-S, SRPC
	—	—	—	C35/45[E] 0.40 380	C28/35 0.50 340	C25/30 0.55 320	C25/30 0.55 320	C25/30 0.55 320	IIB-V, IIIA
	—	—	—	C32/40[E] 0.40 380	C25/30 0.50 340	C20/25 0.55 320	C20/25 0.55 320	C20/25 0.55 320	IIIB, IVB-V

DIN Recommendations for Concrete Cover

Requirements for the minimum concrete cover and safety margin

Table 1 Minimum concrete cover and safety margin, extract from DIN 1045-1, 6.3 and table 3 and table 4 [R1]

Exposure Class		Minimum concrete compressive strength class	**Minimum concrete cover c_{min} (mm)** [1) 2)]		**Safety margin Δc (mm)**
			Reinforcing steel	Pre tensioning and post tensioning tendons	
XC1	Dry or permanently wet	C16/20	**10**	20	**10**
XC2	Wet, rarely dry	C16/20	**20**	30	**15**
XC3	Moderate humidity	C20/25	**20**	30	
XC4	Cyclic wet and dry	C25/30	**25**	35	
XD1	Chloride + moderate humidity	C30/37 [3)]	**40**	50	
XD2	Chloride + wet, rarely dry	C35/45 [3)]			
XD3	Chloride + cyclic, wet and dry	C35/45 [3)]			
XS1	Exposed to airborne salt but not in direct contact with sea water	C30/37 [3)]	**40**	50	
XS2	Permanently submerged	C35/45 [3)]			
XS3	Tidal splash and spray zones	C35/45 [3)]			
1)	When more than one exposure class occurs, the higher requirement is to be applied.				
	Furthermore:	For reinforcing steel	→ cmin ≥		

(1) The minimum concrete cover c_{min} specified in DIN 1045-1 [R1] ensures the protection of the reinforcement from corrosion and the bond between the reinforcement and the concrete.

Practical Method for Assessing Cover Readings

- The German Concrete and Construction Association (Deutscher Beton- und Bautechnik-Verein, DBV) have published a practical guideline for assessing concrete cover on real structures.

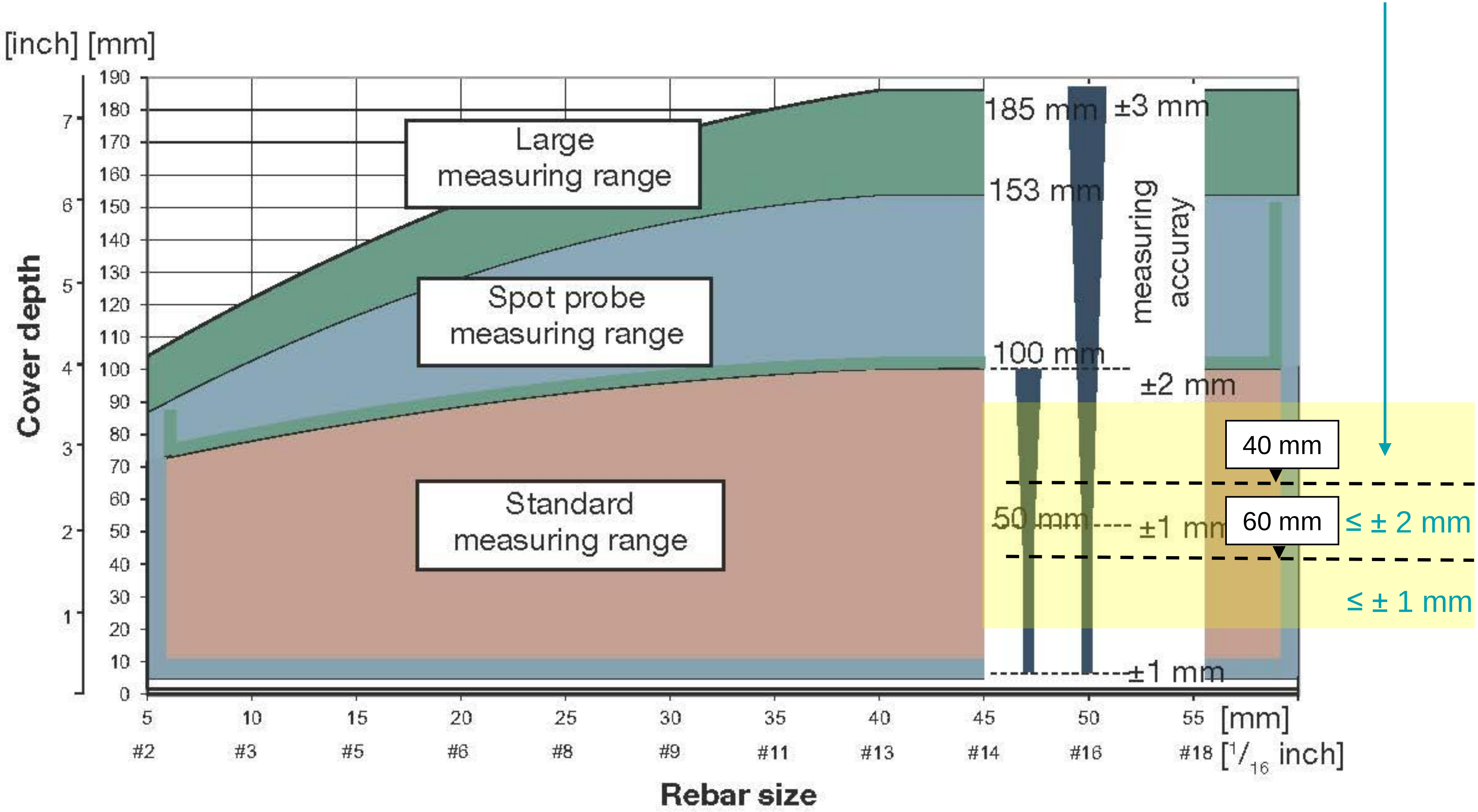
- The minimum concrete cover c_{min} is to be substantiated as:
  - 10%-quantile for elements according to DIN 1045-1, table 4 row 1 [R1] (XC1)
  - 5%-quantile for elements according to DIN 1045-1, table 4, rows 2-4 [R1]. (XC2-XC4)

Requirements on the Test Instrument

- The following accuracy of cover readings must be met by the measuring instruments to be used for the test.
  - up to 40 mm concrete cover: ≤ ± 1 mm
  - between 40 and 60 mm concrete cover: ≤ ± 2 mm
- As a minimum, the measuring instrument must be checked on site before and after a measurement operation, by means of comparison measurements, for example on a test sample with known concrete cover.

Profometer PM-6
Accuracy of Cover Readings

Profometer PM-6 fulfills the DBV requirements



Measurement Surfaces

- The following concrete structure surfaces are to be differentiated as measurement surfaces:
  - each side of a wall
  - the upper side of a ceiling
  - the under side of a ceiling
  - the sides of rectangular pillars
  - the vertical sides of a beam
  - the under side of a beam
  - the upper side of a beam
- Each measurement surface equates to a basic population.
- As a minimum 20 measurements are required for each surface.

DBV-Evaluation - Requirements

- The Neville-distribution is the basis for the statistical evaluation.
- It’s usability has been proven by carrying out parameter studies on finished structural elements.
- Each measurement surface (see slide no. 8) equates to a basic population.
- As a minimum 20 measurements are required for each surface.
- For the quantitative evaluation, after acquiring all of the measurement values, the first step is to determine the median $X_{M.}$
- Following this, in order to increase the validity, an upper boundary value X_{OG} is calculated from the median X_M and the smallest measured value X_{min} to be used for the evaluation of the measured values X_i.

$$X_{OG} = 2.5 \cdot X_M - 1.5 \cdot X_{min}$$

- Measurement values that exceed this upper boundary value, are to be excluded and the quantitative analysis will be carried out with the reduced measurement series.

DBV-Evaluation - Procedure

1.	Arrange the data in order (n ≥ 20) and determine the median	$\overline{X_M} = X_{\left(\frac{n+1}{2}\right)}$ n is odd $\overline{X_M} = \frac{1}{2}\left[X_{\left(\frac{n}{2}\right)} + \left(X_{\left(\frac{n}{2}\right)+1}\right)\right]$ n is even
2.	Determine the mean	$\bar{X} = \frac{1}{n}\sum X_i$
3.	Standard deviation	$s = \sqrt{\frac{1}{n-1}\sum(X_i - \bar{X})^2}$ respectively $s = \sqrt{\frac{1}{n-1}\left(\sum X_i^2 - \frac{1}{n}(\sum X_i)^2\right)}$
4.	Location parameter (Centre value)	$r = \frac{\bar{X} + \overline{X_M}}{2}$
5.	Form parameter	$k = 1.8 \cdot \frac{r}{s}$
6.	Parameter ρ(x) with $x = c_{min}$	$\rho(x) = \frac{x}{r}$
7.	Distribution function with $x = c_{min}$	$F_x(x) = \frac{\rho(x)^k}{(1+\rho(x)^k)}$
8.	**Test decision** Target: 5% quantile for XC2-4, XD1-3, XS1-3 10% quantile for XC-1	Target | 5% quantile | 10% quantile Reject | $F(c_{min}) > 5\%$ | $F(c_{min}) > 10\%$ Accept | $F(c_{min}) \leq 5\%$ | $F(c_{min}) \leq 10\%$
9.	Alternative: Threshold value calculation of the concrete cover x = c(α%), that achieves a probability of α%.	$c(5\%) = \frac{r}{19^{\frac{1}{k}}}$ $c(10\%) = \frac{r}{9^{\frac{1}{k}}}$
10.	Alternative: **Test decision** Target: 5% quantile for XC2-4, XD1-3, XS1-3 10% quantile for XC-1	Target | 5% quantile | 10% quantile Reject | $c_{min} > c(5\%)$ | $c_{min} > c(10\%)$ Accept | $c_{min} \leq c(5\%)$ | $c_{min} \leq c(10\%)$

DBV-Evaluation – Practical Example

- It looks complicated, but it is actually very simple.
- It is only necessary to calculate the median, the mean and the standard deviation and then put these values into the simple formulae for k, r, p(x) and F(x)
- The example is based on measurements made on a concrete slab of a viaduct.
- The specification was for c_{min} = 40 mm (as the lower 5^{th} percentile of the cover depth population);

Span 1								Span 2								Span 3								Span 4								Span 5							
64	56	66	76	52	73	69	71	79	76	79	72	76	79	63	53	80	74	72	65	72	69	72	58	67	80	74	72	69	79	69	79	76	59	58	55	59	58	48	57
61	56	63	69	69	70	74	76	55	72	76	53	57	76	80	28	66	74	62	76	57	63	57	61	49	76	64	69	58	69	49	56	59	51	54	54	63	53	62	53
57	57	37	40	64	56	60	56	56	48	47	57	54	47	56	56	54	72	64	61	56	45	59	63	80	79	74	79	72	79	64	74	59	72	69	51	57	59	57	59
49	51	42	51	57	58	57	54	59	63	64	71	48	72	48	39	58	56	49	63	46	79	76	69	65	76	67	80	69	65	63	59	63	57	69	74	63	67	69	72
58	61	53	49	51	48	55	50	46	49	65	59	63	62	58	47	70	58	58	72	51	62	72	61	72	61	59	63	54	65	64	55	59	57	61	69	69	62	54	59

Figure 9.4 – Cover depth readings obtained in the top reinforcement layer of the slab (mm).

DBV-Evaluation – Practical Example

	c_{min}	40	
Median	X_M	61.5	
	X_{min}	28	
	X_{OG}	111.75	
Mean	X	62.195	
SD	s	9.96763	
Location Parameter	r	61.8475	
Form parameter	k	11.1687	
Parameter p(x)	p(x)	0.64675	
Distribution function	$F(c_{min})$	0.00764	0.76%
Decision:	F(cmin) < 5%	**Accept**	
Threshold value c(5%)	c(5%)	47.5	
Threshold value c(10%)	c(10%)	50.8	
Alternative decision:	c(5%) > c_{min}	**Accept**	

