

## Comparison between compressive strength tests from cores, Capo-Test and Schmidt hammer

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For upgrading of Polish bridges the strength of the in-situ concrete needs to be established. The maximum load has to be increased from 30 tons to 50 tons.

The Department of Civil Engineering at the Technical University in Wroclaw, Poland, has during the past 4 years performed strength testing of 40 such Polish bridges, 20-40 years old.

Testing for strength of 10 of the bridges is reported. The remaining 30 bridges will be reported later.

The methods used have been:

- Drilling out of cores and testing the cores in the laboratory
- Capo-Test pullout testing
- Schmidt hammer

Each core, 100 mm in diameter, was drilled to a depth of 400-500 mm, and cut in slices of 100 mm length – producing 3-4 specimens from each core for compression tests in the laboratory.

After surface planning the Capo-Test was performed according to ASTM C 900-99 on the structure in the vicinity of the coring.

After preparing the surface of the structure by grinding the Schmidt hammer tests were performed close to the core location.

The core specimens were prior to compression tests also tested on the side face with Schmidt hammer after the specimens were slightly loaded in the testing machine to be held in position. The relation between Schmidt hammer results on the cores and on the structure surface is named  $\beta$  in the following. The  $\beta$ -factor illustrates in this manner the influence on the Schmidt hammer results from carbonation and stresses standing in the structure.

## Notations:

All presented data are related to 150 mm cube compressive strength in MPa

$f_{c, cub}$ :	Cube compressive strength (MPa)
$f_{cm, cub}$ :	Mean cube compressive strength (MPa)
P:	Capo-Test pullout force (kN)
L:	Schmidt hammer rebound number (-)

## Relationships used:

### 1. Compression tests of 100 mm diameter cores, 100 mm high, related to 150 mm cube strength in MPa:

Since  $f_{c, cub}(100 \text{ mm}) = 1.12 f_{c, core}(100 \text{ mm})$  and  $f_{c, cub}(150 \text{ mm}) = 0.9 f_{c, cub}(100 \text{ mm})$ , the relationship between 150 mm cube strength and 100 mm core strength, 100 mm high, will be:

$$f_{c, cub}(150 \text{ mm}) \cong f_{c, core}(100 \text{ mm dia., } 100 \text{ mm high}) \quad (1)$$

### 2. CAPO-TEST in kN related to 150 mm cube compressive strength in MPa

The general correlation stated in ref. 1 p.11 is used:

$$f_{c, cub}(150 \text{ mm}) = 1.41 P - 2.82 \text{ for } f_{c, cub} < 50 \text{ MPa} \quad (2.1)$$

$$f_{c, cub}(150 \text{ mm}) = 1.59 P - 9.52 \text{ for } f_{c, cub} > 50 \text{ MPa} \quad (2.2)$$

### 3. Schmidt Hammer rebound number related to 150 mm cube compressive strength in MPa:

The relationship from the Schmidt Hammer manual, ref.2, is used:

$$f_{c, cub}(150 \text{ mm}) = 0.011 L^2 + 0.902 L - 12.87 \quad (3)$$

## Other Notations:

$f_{cm, cub}(cr)$ :	Mean cube compressive strength determined by testing of cores (MPa)
$f_{cm, cub}(CT)$ :	Mean cube compressive strength determined by CAPO-TEST (MPa)
$f_{cm, cub}(L)$ :	Mean cube compressive strength determined by Schmidt Hammer equation by testing the structure after surface grinding (MPa)

- $f_{cm, cub} (LM)$ : Mean cube compressive strength determined by Schmidt Hammer after multiplying by the  $\beta$ -factor
- $\beta$ -factor: Relationship between the mean Schmidt Hammer rebound numbers tested on the circular face of cores held in position in the laboratory compression testing machine and the mean Schmidt Hammer rebound numbers tested on the structure after surface grinding. This  $\beta$ -factor represents the influence on the Schmidt Hammer rebound number of the stresses standing in the structure and the carbonation
- $\alpha(CT)$ : Accuracy of determining the compressive strength by the CAPO-TEST related to core compressive strength:  

$$\alpha(CT) = 100\% (f_{cm, cub} (CT) - f_{cm, cub} (cr)) / f_{cm, cub} (cr)$$
- $\alpha(L)$ : Accuracy of determining the compressive strength by the Schmidt Hammer on the structure, related to core compressive strength:  

$$\alpha(L) = 100\% (f_{cm, cub} (L) - f_{cm, cub} (cr)) / f_{cm, cub} (cr)$$
- $\alpha(LM)$ : Accuracy of determining the compressive strength by the Schmidt Hammer on the cores in the laboratory, related to core compressive Strength:  

$$\alpha(LM) = 100\% (f_{cm, cub} (LM) - f_{cm, cub} (cr)) / f_{cm, cub} (cr)$$

### 1. Bridge: Minsk Mazowiecki

Element tested: Reinforced concrete frame

Time of testing: November, 1999

Carbonation depth	No. of Cores	No. of Capo-Test	No. of Schmidt hammer tests
35 mm	4	6	15 locations, each 6 tests

$$f_{cm, cub}(cr) = 19.6 \text{ MPa}$$

$$f_{cm, cub}(CT) = 20.3 \text{ MPa}, \quad \alpha(CT) = 3.4\%$$

$$f_{cm, cub}(L) = 36.9 \text{ MPa}, \quad \alpha(L) = 88.3\%$$

$$\beta = 0.77$$

$$f_{cm, cub}(LM) = 28.4 \text{ MPa}, \quad \alpha(LM) = 44.3\%$$

### 2. Bridge: Dobrut

Element tested: Reinforced Concrete Beams

Time of testing: May, 2000

Carbonation depth	No. of Cores	No. of Capo-Test	No. of Schmidt hammer tests
4 mm	3	6	12 locations, each 6 tests

$$f_{cm, cub}(cr) = 24.7 \text{ MPa}$$

$$f_{cm, cub}(CT) = 26.9 \text{ MPa}, \quad \alpha(CT) = 8.9\%$$

$$f_{cm, cub}(L) = 37.4 \text{ MPa}, \quad \alpha(L) = 51.4\%$$

$$\beta = 0.76$$

$$f_{cm, cub}(LM) = 28.4 \text{ MPa}, \quad \alpha(LM) = 15.0\%$$

### 3. Bridge: Zyrow

Element tested: Reinforced Concrete Columns

Time of testing: December, 1999

Carbonation depth	No. of Cores	No. of Capo-Test	No. of Schmidt hammer tests
20 mm	4	8	15 locations, each 6 tests

$$f_{cm, cub}(cr) = 29.7 \text{ MPa}$$

$$f_{cm, cub}(CT) = 31.8 \text{ MPa}, \quad \alpha(CT) = 7.1\%$$

$$f_{cm, cub}(L) = 49.5 \text{ MPa}, \quad \alpha(L) = 66.7\%$$

$$\beta = 0.77$$

$$f_{cm, cub}(LM) = 38.2 \text{ MPa}, \quad \alpha(LM) = 28.6\%$$

#### 4. Bridge: Zyrow

Element tested: Reinforced Concrete Post-Tensioned Pre-stressed Beams

Time of testing: December, 1999

Carbonation depth	No. of Cores	No. of Capo-Test	No. of Schmidt hammer tests
0 mm	3	5	12 locations, each 6 tests

$$f_{cm, cub}(cr) = 34.2 \text{ MPa}$$

$$f_{cm, cub}(CT) = 36.8 \text{ MPa}, \quad \alpha(CT) = 10.5\%$$

$$f_{cm, cub}(L) = 56.8 \text{ MPa}, \quad \alpha(L) = 66.1\%$$

$$\beta = 0.76$$

$$f_{cm, cub}(LM) = 43.1 \text{ MPa}, \quad \alpha(LM) = 26.0\%$$

#### 5. Bridge: Wierzbica

Element tested: Reinforced Concrete Beams

Time of testing: April, 2000

Carbonation depth	No. of Cores	No. of Capo-Test	No. of Schmidt hammer tests
19 mm	4	12	12 locations, each 6 tests

$$f_{cm, cub}(cr) = 33.3 \text{ MPa}$$

$$f_{cm, cub}(CT) = 32.3 \text{ MPa}, \quad \alpha(CT) = 3.0\%$$

$$f_{cm, cub}(L) = 61.6 \text{ MPa}, \quad \alpha(L) = 85.0\%$$

$$\beta = 0.80$$

$$f_{cm, cub}(LM) = 49.3 \text{ MPa}, \quad \alpha(LM) = 48.0\%$$

#### 6. Bridge: Jablonica

Element tested: Reinforced Concrete Post-Tensioned Pre-stressed Beams

Time of testing: December, 1999

Carbonation depth	No. of Cores	No. of Capo-Test	No. of Schmidt hammer tests
5 mm	3	5	12 locations, each 6 tests

$$f_{cm, cub}(cr) = 34.2 \text{ MPa}$$

$$f_{cm, cub}(CT) = 37.6 \text{ MPa}, \quad \alpha(CT) = 9.0\%$$

$$f_{cm, cub}(L) = 54.5 \text{ MPa}, \quad \alpha(L) = 59.4\%$$

$$\beta = 0.67$$

$$f_{cm, cub}(LM) = 36.5 \text{ MPa}, \quad \alpha(LM) = 6.7\%$$

### 7. Bridge: Jablonica II

Element tested: Reinforced Concrete Post-Tensioned Pre-stressed Beams

Time of testing: December, 1999

Carbonation depth	No. of Cores	No. of Capo-Test	No. of Schmidt hammer tests
8 mm	3	5	12 locations, each 6 tests

$$f_{cm, cub}(cr) = 35.4 \text{ MPa}$$

$$f_{cm, cub}(CT) = 37.1 \text{ MPa}, \quad \alpha(CT) = 7.1\%$$

$$f_{cm, cub}(L) = 66.3 \text{ MPa}, \quad \alpha(L) = 87.3\%$$

$$\beta = 0.86$$

$$f_{cm, cub}(LM) = 57.00 \text{ MPa}, \quad \alpha(LM) = 61.0\%$$

### 8. Bridge: Kamion

Element tested: Reinforced Concrete Post-Tensioned Pre-stressed Beams

Time of testing: August, 1999

Carbonation depth	No. of Cores	No. of Capo-Test	No. of Schmidt hammer tests
7 mm	3	9	20 locations, each 6 tests

$$f_{cm, cub}(cr) = 37.1 \text{ MPa}$$

$$f_{cm, cub}(CT) = 35.9 \text{ MPa}, \quad \alpha(CT) = 3.2\%$$

$$f_{cm, cub}(L) = 56.9 \text{ MPa}, \quad \alpha(L) = 53.4\%$$

$$\beta = 0.81$$

$$f_{cm, cub}(LM) = 46.1 \text{ MPa}, \quad \alpha(LM) = 24.3\%$$

### 9. Bridge: Modlin

Element tested: Reinforced Concrete Beams

Time of testing: September, 1999

Carbonation depth	No. of Cores	No. of Capo-Test	No. of Schmidt hammer tests
7 mm	4	8	17 locations, each 6 tests

$$f_{cm, cub}(cr) = 37.5 \text{ MPa}$$

$$f_{cm, cub}(CT) = 36.8 \text{ MPa}, \quad \alpha(CT) = 1.9\%$$

$$f_{cm, cub}(L) = 70.9 \text{ MPa}, \quad \alpha(L) = 89.1\%$$

$$\beta = 0.86$$

$$f_{cm, cub}(LM) = 61.0 \text{ MPa}, \quad \alpha(LM) = 62.7\%$$

### 10. Bridge: Modlin

Element tested: Reinforced Concrete Columns

Time of testing: September, 1999

Carbonation depth	No. of Cores	No. of Capo-Test	No. of Schmidt hammer tests
7 mm	3	9	17 locations, each 6 tests

$$f_{cm, cub}(cr) = 42.0 \text{ MPa}$$

$$f_{cm, cub}(CT) = 39.7 \text{ MPa}, \quad \alpha(CT) = 5.5\%$$

$$f_{cm, cub}(L) = 68.4 \text{ MPa}, \quad \alpha(L) = 62.9\%$$

$$\beta = 0.84$$

$$f_{cm, cub}(LM) = 57.4 \text{ MPa}, \quad \alpha(LM) = 36.7\%$$

### Conclusions

Compared to compressive strength testing by cores (100 mm diameter, 100 mm high) drilled out from the structure, the average accuracy on the strength estimates by Capo-Test, Schmidt Hammer on the structure and Schmidt hammer on the cores in the laboratory are the following:

The CAPO-TEST estimate is 6.0% accurate

On the structure the Schmidt Hammer estimate is 71.0% accurate

On cores in the laboratory the Schmidt Hammer estimate is 35.5% accurate

### Summary

Bridge No.	<i>Cores from structure tested in lab transformed to cube strength (1, p.2)</i>		<i>Capo-Test on structure transformed to cube strength (2.1, p.2)</i>		<i>Schmidt Hammer on structure transformed to cube strength (3, p.2)</i>		<i>Schmidt Hammer on cores in lab transformed to cube strength (3, p.2)</i>	
	MPa	Av. of	MPa	$\alpha(CT)$	MPa	$\alpha(L)$	MPa	$\alpha(LM)$
1	19.6	4	20.3	3.4%	36.9	88.3%	28.4	44.3%
2	24.7	3	26.9	8.9%	37.4	51.4%	28.4	15.0%
3	29.7	4	31.8	7.1%	49.5	66.7%	38.2	28.6%
4	34.2	3	36.8	10.5%	56.8	66.1%	43.1	26.0%
5	33.3	4	32.3	3.0%	61.6	85.0%	49.3	48.0%
6	34.2	3	37.6	9.0%	54.5	59.4%	36.5	6.7%
7	35.4	4	37.1	7.1%	66.3	87.3%	57.0	61.0%
8	37.1	3	35.9	3.2%	56.9	53.4%	46.1	24.3%
9	37.5	4	36.8	1.9%	70.9	89.1%	61.0	62.7%
10	42.0	3	39.7	5.5%	68.4	62.9%	57.4	36.7%
<i>Average</i>	<i>32.8</i>		<i>33.5</i>	<i>6.0%</i>	<i>55.9</i>	<i>71.0%</i>	<i>44.5</i>	<i>35.3%</i>

**References:**

- (1) Petersen, C.G.: "LOK-TEST and CAPO-TEST pullout testing, twenty years experience", NDT in Civil Engineering Conference, Liverpool, UK, April 8-11, 1997, The British Institute of Non-Destructive Testing
- (2) Schmidt Hammer Operating Instruction Manual, Proceq, Zürich, Switzerland

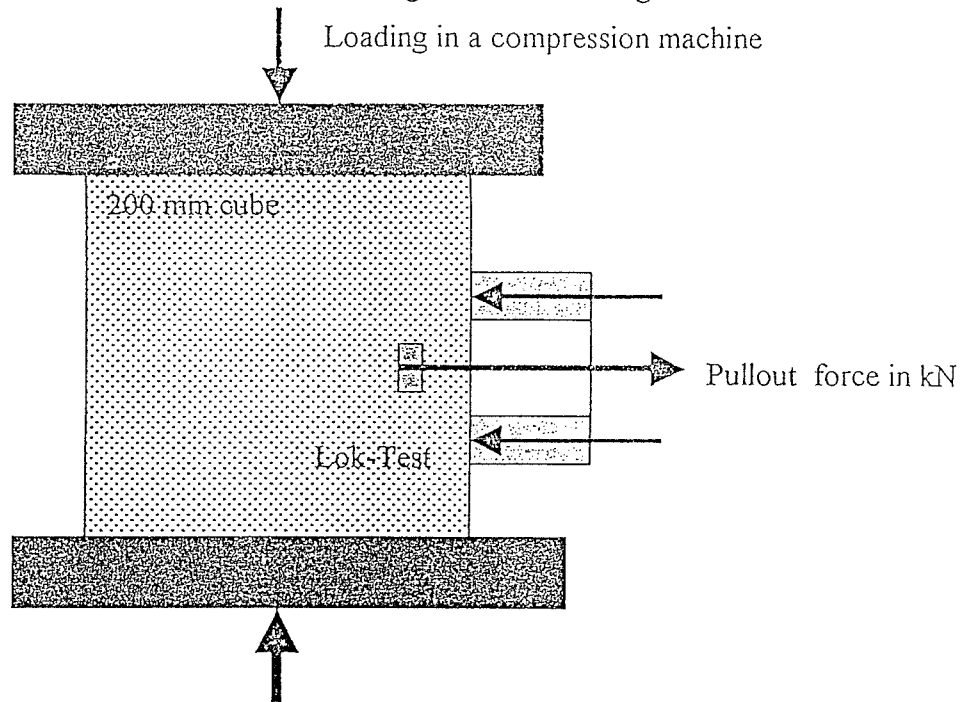


## INFLUENCE OF STRESSES IN A STRUCTURE ON THE LOK-TEST PULLOUT FORCE

The influence of stresses standing in a structure on the pullout force by the Lok-Test system was investigated.

200 mm cubes were prepared in 4 strength classes, ~5 Mpa, ~10 Mpa, ~28 Mpa and ~40 Mpa. Lok-Test inserts were cast-in the vertical faces of 200 mm cubes.

The cubes were loaded in the compression machine of the laboratory at various load levels up to about 60% of the failure load. At the various load levels Lok-Test was performed on a free surface of the cubes perpendicular to the direction of loading as indicated in fig.1.



*Fig1. Test set-up for investigating the influence on the Lok-Test pullout force of the stresses standing in a structure*

The pullout forces measured in relation to the load levels in percentage are illustrated in the enclosed figure 2.

### Conclusion

As will be seen from fig.2, the stresses standing in the cube, are not influencing the pullout force for the investigation made up to about 60% of the failure stresses.

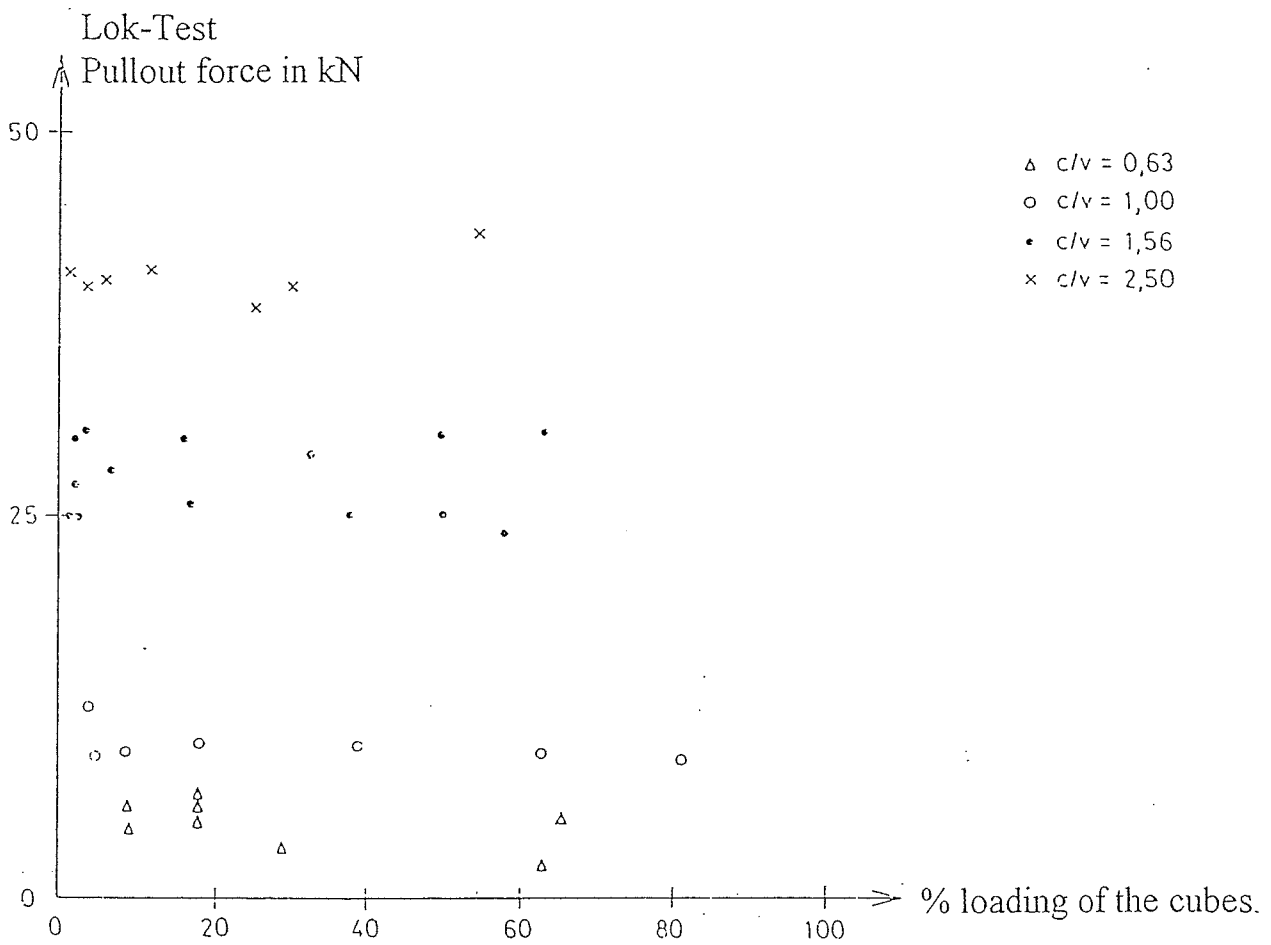


Fig. 2. The Lok-Test pullout force in kN in dependence of the stresses standing in a 200 mm cube