HARDNESS OF CONCRETE | H

1 Estimation of compressive strength using rebound hammer testing

Rebound hammer testing of concrete is a surface method where the key parameter is surface hardness. The test measures and evaluates the rebound of a hammer from the concrete surface. This is the most commonly used non-destructive method for assessing concrete quality and estimating compressive strength. However, compressive strength is determined based on surface hardness, and no direct physical relationship exists between these two properties. Hardness is a mechanical property, reflecting resistance to surface indentation, but it is not a direct measure of strength of concrete. The compressive strength estimate is based on empirical correlations, which may not always provide accurate results due to various influencing factors. Despite these limitations, when done correctly, rebound hammer testing can be a reliable method, especially when calibrated with standard compressive strength tests.

1.1 The Original Schmidt Hammer

The Original Schmidt Hammer (Fig. 1.1) was invented by Swiss engineer Ernst Schmidt, who introduced the first rebound hammer in 1950. The Original Schmidt, produced since 1965, remains largely unchanged and has yet to be surpassed by any other type of hammer. Rebound testing can be performed with different hammers depending on the strength of concrete and the size of structure. These hammers vary in impact energy, size, and design. Proceq, the manufacturer of the Original Schmidt hammer, offers the largest range of hammers, though many lower-cost imitations are available. Rebound hammers are classified by impact energy:

- Type N (2.25 J),
- Type L (0.75 J),
- Type M (30 J, no longer produced).

The hammer functions by releasing a spring-loaded plunger, which strikes a steel anvil. The rebound distance indicates the hardness of concrete, with results marked as R. In this exercise, the Original Schmidt N hammer will be used. One drawback is that the rebound value is influenced by the test direction, so different relationships between rebound and compressive strength exist for various test angles.

1.2 The SilverSchmidt Hammer

The SilverSchmidt hammer, shown in Fig. 2, is a modern variant of the Original Schmidt N hammer. It is a digital device, and the measured values are displayed on the screen

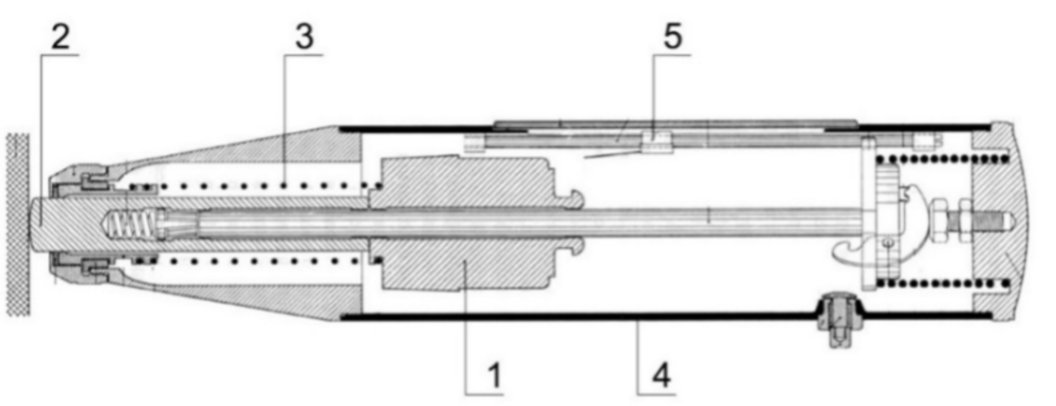

Figure 1: Diagram of the rebound hammer: 1 – Plunger, 2 – Anvil, 3 – Tension spring, 4 – Case, 5 – Scale.

and can automatically be converted into compressive strength (via a selected correlation). The SilverSchmidt no longer measures the rebound value R as the Original Schmidt, but instead uses the value Q, which represents the rebound coefficient, given by the equation:

$$Q = 100 \cdot \frac{\text{restored energy}}{\text{input energy}}$$

Modern SilverSchmidt hammers use optical sensors to measure the velocity of the plunger just before it hits the concrete surface and immediately after the rebound. From the measured velocities, the amount of energy returned is calculated. The value Q is essentially the expression of the returned energy, and the higher the value of Q, the harder the concrete. The value Q is less dependent on factors like friction or gravity compared to the value R, which means there is no need for directional correction depending on the test angle. The compressive strength range that SilverSchmidt can measure is 10 to 100 MPa, according to the manufacturer.

Figure 2: The SilverSchmidt N Hammer

1.3 Measurement Procedure

To determine the hardness of the concrete, estimate the compressive strength of the concrete, and determine the concrete strength class, two types of rebound hammers will be used: the Original Schmidt N (the original device based on the patent by Proceq), which is the most commonly used type of hammer, and the modern SilverSchmidt N (also from Proceq).

The hammer is applied to the test surface so that the plunger rests perpendicularly on the concrete surface. Pressure is then applied smoothly without impact until the steel hammer creates a rebound. The rebound value R or possibly Q is recorded.

Depending on the procedure chosen (based on the standard), a minimum of 7 or 8 valid measurements must be taken. It is always preferable to take more measurements. On each location (the side surface of the test cube, clamped in the testing press and loaded at 1/10th of the predicted compressive strength), 10 readings are taken with one hammer. Measurements with the second hammer are applied to the opposite side of the cube. The impact points must be at least 25 mm away from the edge of the cube and from each other (requirement of EN 12504-2; the guidelines of ČSN 73 1373 are ambiguous in this regard). The best approach is to mark a regular grid on the sample. During the test, the hammer will be in a horizontal position. Only results obtained by testing the cement mortar are considered for evaluation. After each impact, visually inspect the spot to ensure that a large aggregate particle or void is not present just below the surface – in such cases, surface destruction would be evident at the test site.

1.4 Test Evaluation

The evaluation procedure will follow the guidelines of the respective standards (ČSN 73 1373 or EN 12504-2). The results will include calculations of compressive strength based on rebound hardness values. Specific procedures and details for these standards are provided in the following sections.

1.5 Evaluation according to ČSN 73 1373

The evaluation is carried out by assigning each rebound value R to the corresponding compressive strength value f_{be} using the equation provided in the standard. For horizontal testing direction, the relationship shown in Table 1 is used. Rebound values $R > 52$ are recommended to be assigned $f_{be} = 63\,\text{MPa}$. The compressive strength values must not differ from the arithmetic mean of all valid measurements at the test site by more than ± 20%. Strength values that do not meet this criterion are considered invalid and must be excluded from further evaluation. If at least 7 valid measurements remain, the full set is considered valid, and the arithmetic mean of the valid compressive strength values is recalculated and rounded to the nearest 1 MPa. If fewer than 7 valid measurements remain, the entire set for the given test site must be discarded. An example of the evaluation of rebound hammer measurements at one testing place according to ČSN 73 1373 is shown in Table 2.

Table 1: Relation for determining compressive strength f_{be} from rebound values R of the Original Schmidt N hammer (horizontal testing direction).

R	f_{be} [MPa]	R	f_{be} [MPa]	R	f_{be} [MPa]	R	f_{be} [MPa]
25	16	32	27	39	39	46	52
26	18	33	28	40	41	47	53
27	19	34	30	41	42	48	55
28	21	35	32	42	44	49	57
29	22	36	33	43	46	50	59
30	24	37	35	44	48	51	61
31	25	38	37	45	50	52	63

Table 2: Example of rebound hammer measurement evaluation according to ČSN 73 1373.

Strike Number	1	2	3	4	5	6	7	8	9	10
Rebound Value R_i	40	41	38	36	40	39	52	30	40	42
Compressive Strength $f_{be,i}$ [MPa]	41	42	37	33	41	39	63	24	41	44

Average Strength f'_{be}	**40.5**
Interval Limits	$0.8 \times f'_{be} = 32.4$, $1.2 \times f'_{be} = 48.6$
Valid Measurements (struck-out values are excluded):	41, 42, 37, 33, 41, 39, ~~63~~, ~~24~~, 41, 44
Evaluation of Test Location	Valid Measurements: 8
New Arithmetic Mean of Strength f'_{be} [MPa]	39.75 => **40**
Set Accepted / Rejected	**Set Accepted**

The result is compressive strength of concrete with uncertain accuracy.

1.6 Evaluation according to EN 12504-2

Compared to the previous method, the calculation according to EN 12504-2 is simpler. The median of the rebound values is determined, and the entire set of 10 measurements (one test site) is evaluated—if more than 20 % of the readings deviate from the median by more than 25 %, the entire set must be discarded. If 80 % or more of the readings are valid, all values are retained (a new median is not calculated).

The result of the test is the median of all readings, which represents the hardness of the concrete and is rounded to the nearest whole number. An example of rebound hammer measurement evaluation at a test site using EN 12504-2 is shown in Table 3.

Further steps are no longer covered by EN 12504-2, and the compressive strength is

Table 3: Example of rebound hammer measurement evaluation according to EN 12504-2.

Strike Number	1	2	3	4	5	6	7	8	9	10
Rebound Value R_i	40	41	38	36	40	39	52	30	40	42

Median R	**40.0**
Interval Limits	$0.75 \times R = 30.0$, $1.25 \times R = 50.0$
Number of Deviant Measurements	$1 \rightarrow 10\% < 20\%$ (from all 10 measurements)
Evaluation of the Set	**Set Accepted**
Hardness Value R	40.0 => **40**

determined according to EN 13791 using conversion relationships.

1.7 Evaluation according to EN 13791

The updated version of EN 13791 strictly separates the determination of compressive strength of concrete in unknown structures (in the sense of existing, old structures) from the determination of compressive strength of concrete in new structures, if during construction there were doubts about the quality of the concrete. In the case of doubts about new structures, non-destructive methods are preferred to verify compressive strength. The standard contains a rather interesting annex B, which states:

- Tests must be performed by a person properly trained in the use of rebound hammers,
- Rebound values for all test sites in the tested area are used to determine the median value for the tested area,
- If all the following conditions are met:
  - It is ordinary dense concrete (not lightweight or heavy concrete),
  - There was no special formwork used that influences permeability or surface hardness of the concrete,
  - For rebound measurement (either rebound R or value Q, describing the returned energy), a type N hammer with an impact energy of 2.25 J was used,
  - Carbonation depth does not exceed 5 mm,
  - The rebound values meet the criteria in column 1, or column 2 of Tables B.1 (rebound R), or both criteria in column 1 and column 2 of Table B.2 (value Q),
- The compressive strength class of the concrete can be estimated from the values in column 3 of the relevant tables.

Tables B.1 and B.2 from EN 13791 are transcribed into Table 4 and Table 5.

Table 4: Rebound value R and the assigned compressive strength class of ordinary dense concrete according to EN 206+A2 (Table B.1 from EN 13791).

Minimum value from all test areas	**Median value from all test areas**	**Compressive strength class according to EN 206+A2**
≥ 26	≥ 30	C 8/10
≥ 30	≥ 33	C 12/15
≥ 32	≥ 35	C 16/20
≥ 35	≥ 38	C 20/25
≥ 37	≥ 40	C 25/30
≥ 40	≥ 43	C 30/37
≥ 44	≥ 47	C 35/45
≥ 46	≥ 49	C 40/50
≥ 48	≥ 51	C 45/55
≥ 50	≥ 53	C 50/60
≥ 53	≥ 57	C 55/67
≥ 57	≥ 60	C 60/75
≥ 62	≥ 65	C 70/85
≥ 66	≥ 69	C 80/95

Table 5: Value Q and the assigned compressive strength class of ordinary dense concrete according to EN 206+A2 (Table B.2 from EN 13791).

Minimum value from all test areas	**Median value from all test areas**	**Compressive strength class according to EN 206+A2**
≥ 25	≥ 34	C 8/10
≥ 29	≥ 40	C 12/15
≥ 36	≥ 45	C 16/20
≥ 42	≥ 49	C 20/25
≥ 46	≥ 52	C 25/30
≥ 51	≥ 56	C 30/37
≥ 56	≥ 60	C 35/45
≥ 58	≥ 62	C 40/50
≥ 60	≥ 64	C 45/55
≥ 62	≥ 66	C 50/60
≥ 64	≥ 68	C 55/67
≥ 66	≥ 71	C 60/75
≥ 69	≥ 73	C 70/85
≥ 71	≥ 75	C 80/95

2 Determination of Compressive Strength of Concrete

The compressive strength f_c of the concrete cube in N/mm^2 (MPa) will be determined after rebound hammer testing using the Original Schmidt N and SilverSchmidt N. The compressive strength is given by the equation

$$f_c = \frac{F}{A_c}.$$

where F is the maximum load at failure in N, and A_c is the cross-sectional area of the test specimen on which the load acts, in mm^2. The area is calculated from the measured dimensions d_1 and d_3. The compressive strength is rounded to the nearest 0.1 N/mm^2. From the obtained compressive strength f_c and the strength f_{be} with uncertain accuracy, the so-called correction factor α (according to ČSN 73 1373) can be calculated

$$\alpha = \frac{f_c}{f_{be}}.$$

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Instructor:

Hardness Measurement

Perform non-destructive testing on the test cube using the Original Schmidt N hardness tester: on one side of the cube, loaded in the test press, perform 10 measurements, which you will then evaluate in three ways:

1. Using the standard ČSN 73 1373, determine the strength with unguaranteed accuracy f_{be}.

Strike Number	1	2	3	4	5	6	7	8	9	10
Rebound Value R_i										
Strength Value $f_{be,i}$										

2. Using the standard EN 12504-2, determine the surface hardness of the concrete cube.

Here we recommend sorting the measured rebound values in descending or ascending order to make it easier to calculate the median:

Strike Number	1	2	3	4	5	6	7	8	9	10
Rebound Value R_i										
Sorted Descending or Ascending										

3. Using the standard EN 13791, determine the concrete strength class (for new construction in case of doubts).

Use the values from the previous step.

Median =

Minimum =

Perform non-destructive testing on the test cube using the SilverSchmidt N hardness tester: on the opposite side of the same test cube, loaded in the test press, perform 10 measurements and using the standard EN 13791, determine the concrete strength class.

Strike Number	1	2	3	4	5	6	7	8	9	10
Value Q_i										
Sorted Descending or Ascending										

Conclusion:

Determination of compressive strength f_c

After hardness measurement, determine the compressive strength of the test cube. Compare the actual compressive strength with the results of the hardness measurement, and determine the correction factor α.

Conclusion:

Tests conducted and report prepared by: