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Review of the Rebound Hammer Method Estimating Concrete Compressive Strength on Site

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***Abstract*:** *Compressive strength of concrete is the most import ant input data for engineering calculations during the design of reinforced concrete structures. Compressive strength of concrete can be determined by testing of moulded specimens or by core specimens drilled from existing structures.*

Moulded specimens, however, do not always represent the actual condition of structural concrete and drilling of core specimens from certain structural members is not always possible (because of risk of the loss of structural stability or bad accessibility of the structural element to be examined).

With non-destructive testing (NDT) devices the measurements can be performed directly on the structural concrete and the strength of concrete can be estimated from the measured results with limited reliability.
One of these methods is a classic NDT method based on the surface hardness testing of concrete which became popular in the construction industry during the 1950's. Surface hardness testing is a long established NDT method for the strength estimation of materials.

Nowadays, the Schmidt rebound hammer is still the surface hardness testing device of the most widespread use for concrete. Rebound hammer can be used very easily and the measure of hardness (i.e. the rebound index) can be read directly on the display of the testing device.

This Communication aims to revisit this method emphasizing on its methodology and norms or standards that can guide its use on the assessment of the strength of concrete on site.

Keywords: *rebound hammer, compressive concrete strength, correlations.*

1. Introdocton

Compressive strength of concrete is the most import ant input data for engineering calculations during the design of reinforced concrete structures. Compressive strength of concrete can be determined by testing of moulded specimens or by core specimens drilled from existing structures.

In testing, the specimens are loaded up to failure to find compressive strength, usually under standardized laboratory testing conditions. Moulded specimens, however, do not always represent the actual condition of structural concrete and drilling of core specimens from certain structural members is not always possible (because of risk of the loss of structural stability or bad accessibility of the structural element to be examined).

With non-destructive testing (NDT) devices the measurements can be performed directly on the structural concrete and the strength of concrete can be estimated from the measured results with limited reliability.

Several different non-destructive testing (NDT) methods were developed to estimate the strength of concrete in structures. The most successful strength estimation methods involve principles, which make the direct or indirect consequences of the compressive strength determining factors measurable or (in some cases) provide strength estimation by moderately destructive in-situ measurements.

One of these methods is a classic NDT method based on the surface hardness testing of concrete which became popular in the construction industry during the 1950's. Surface hardness testing is a long established NDT method for the strength estimation of materials.

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Hardness testing was the first material testing practice from the 1600's in geology and engineering by the scratching hardness testing methods [1]; it is considered to be started in 1857 when David Kirkaldy; Scottish engineer set up the first material testing laboratory in London, Southwark [2]. The theoretical hardness research was initialized by the pioneering work of Heinrich Hertz in the 1880's [3]. Hertz's proposal formed also the basis of the indentation hardness testing methods by Brinell, 1900; Rockwell, 1920; Vickers, 1924 and Knoop, 1934 [4].

Increasing the hardness of concrete with age has led to the development of two methods to measure its compressive strength. These two methods are based on physical principles; indentation and rebound. Indentation methods have emerged in Germany in 1934 Introduced in the German standards in 1935 [5] and have been used in England and the USSR in three different forms:

- Testing pistol by Williams
- Spring hammer by Frank
- Pendulum hammer by Einbeck

In Switzerland Ernst Schmidt developed a spring impact hammer of which handling were found to be superior to its predecessors [6] and became very popular in the in-situ material testing due to the inexpensive testing device and its relatively simple use.

Nowadays, the Schmidt rebound hammer is still the surface hardness testing device of the most widespread use for concrete rather than devices of plastic indentation hardness testing. Rebound hammer can be used very easily and the measure of hardness (i.e. the rebound index) can be read directly on the display of the testing device.

The aim of rebound hammer tests is usually to find a relationship between surface hardness and compressive strength to be able to estimate the strength of concrete with an acceptable error.

To find a reliable method for strength estimation one should study all the influencing factors that can have any effect on the hardness measurement, and also that can have any effect on the variability of the strength of the concrete structure examined. The estimation should be based on an extensive study with the number of test results high enough to provide an acceptable reliability level. The estimation should take care of the rules of mathematical statistics.

2. Historical overview

In-situ surface hardness testing of materials is a long established method for performance control, mostly with the explicit or hidden aim of strength estimation.

In-situ testing of concrete structures was started in the 1930's. The testing methods at that time covered chisel blow tests, drilling tests, revolver or special design gun shooting tests, splitting tests, pull-out tests, strain measurements from loading tests [7].

Researchers adopted the Brinell method to cement mortar and concrete to find correlations between surface hardness and strength of concrete in the four decades following that Brinell introduced his ball indentation method for hardness testing of steel [8, 9, 10, 11, 12].

The first NDT device for in-place testing of the hardness of concrete was introduced in Germany in 1934 which also adopted the ball indentation hardness testing method; however, dynamic load was applied with a spring impact hammer [13].

The operating principle of the spring impact hammers (known as Frank hammer and Zorn hammer) was similar to that of the later Schmidt hammers; the impact was performed by a hammer mass that is accelerated by a tensioned spring. Similar device was developed in the UK in by Williams, 1936 [14].

Nowadays, the most widely used method for measuring the surface hardness of the concrete test hammer Schmidt (Schmidt rebound hammer), [1]. Originally developed in 1050 by Swiss engineer Ernest Schmidt and presented at the Swiss Federal Institute of Experimental testing and Zurich; the device is then developed by integrating a scale to read directly the index rebound [6, 15] and using a single spring instead of two for simplicity and practice [16, 17].

Introduced and developed by Proceeq SA, founded in 1954; hundreds of thousands of copies of the original Schmidt rebound hammer were made and used around the world [18]. This is undoubtedly the most commonly NDT test used to quickly assess the condition of a concrete structure.

Over the years, its application has been extended to test rocks and hardness tests of paper reels. The latest model PROCEQ Silver Schmidt, offers unprecedented benefits to users. The new instrument offers unmatched ease of use; readability of the index and rebound higher accuracy and a wide measuring range. A number of benefits have been incorporated, such as automatic correction of statements based on the direction of impact - eliminating the need to refer to the conversion curves of direction of impact. The rugged lightweight device allows automatic corrections for carbonation. Data collection and processing of test results comply with industry standards such as ASTM C805 / EN 12504-2 / BS 1881 part 202 / DIN 1048, part 2 / A 83.307 / ISO / DIS 8045.

3. Types of rebound hammers

Several hundred thousands of Schmidt rebound hammers are in uses worldwide (Baumann, 2006). In 1954 Proceq SA was founded and has been producing the original Schmidt rebound hammers since then, without any significant change in the operation of the device (Fig. 2.5) (Proceq, 2005).

One of the latest developments of the device was finalized in November 2007, since the Silver Schmidt hammers (Fig. 2.6) are available (Proceq, 2008a). The digitally recording Silver Schmidt hammers can also measure coefficient of restitution. With this change the direct relationship between the two hardness values can not be studied, moreover the long-term experience with the original rebound hammer, thus the considerable amount of rebound index data can not be used anymore.

Original Schmidt series N / L (Figure 1)

The reference for all hammers rebound and the base for the definition of each international standard on hammers rebound. Typical applications are the uniformity test, the identification of areas where the concrete quality is poor, and the evaluation of the compressive strength. The Original Schmidt type L is the ideal option for testing thin-walled elements with a thickness between 50 and 100 mm or to analyze small parts.

Figure 1: Original Schmidt type N/L

Original Schmidt series NR / LR (Figure 2)

With proven impact values recorded on the registered paper for easy version control. Greatly simplifies the calculation of the value of the bounce and control of the uniformity of the test object. The measuring ranges: 10 to 70 MPa. Values rebound are recorded as a bar graph on the registered paper. A roll of paper can save up to 4000 keystrokes.

Figure 2: Original Schmidt type NR/LR

Digi-Schmidt series ND / LD (Figure 3)

The first digital rebound hammer in the world with data storage, correcting the angle of impact and direct display of the compressive strength. Also corrects the carbonation ratio. It is accompanied by a number of preprogrammed correlation curves, allowing the user to select the one that best suits the c tested concrete. The Rebound values are stored in the electronic display device and can be automatically converted into values of compressive strength. All data and settings can be transferred to a computer for further evaluation with ProVista software. The memory capacity of the display device is sufficient for 10 sets of measuring.

Figure 4: Digi-Schmidt type ND/LD

Silver Schmidt series (ST / PC) N / L (Figure 5)

The rebound hammer with the most advanced dispersion characteristics, durability and unmatched measurement range. The correlation curves defined by the user for specific mixes that they can be loaded on the hammer in order to obtain the best estimate of the compressive strength.

A wide range may be obtained with the curves defined by the user. Large memory, automatic assessment according to predefined criteria and statistical software analysis tools significantly improve the application of conformity assessment. Silver Schmidt facilitates the creation of customized conversion curves specific to the composition of the concrete tested, thereby increasing significantly the reliability of estimated of compressive strength. This procedure is recommended in all guidelines and relevant international standards.

Figure 4: Silver Schmidt type ST/PC (N/L)

4. Operating principle of the rebound hammer

Physical Principle

The test hammer (rebound hammer) is intended to measure the surface hardness of concrete and there is an empirical relationship between the compressive strength of concrete and the rebound index which is a code consisting of a letter (giving an indication of the quality of the concrete) and a number (giving indication on the compressive strength). The hammer has an approximate mass of 1.8 kg and is suitable for laboratory tests as the test site. A feeder controlled by a spring on a plunger moves in a protection tube, the mass is projected against the concrete surface by the spring and rebound distance is measured on an arbitrary scale labeled from 10 to 100 [19, 20]. See Figure 5 and 6.

The surface on which the test is conducted can be horizontal, vertical, or at any other angle, a correction must be made to the readings to account for the angle of the strike. The correction to be made depends on the model of hammer requires only that the device is calibrated to the position where it will be used. Calibration can be done with cylindrical test pieces of 16 × 32 cm 3, made with the same composition as that of the concrete structure. According to ASTM-C805.

Measuring Equipment and Handling

The hammer, consisting of a steel hammer with a compressed spring which, when released, projects a striker rod steel in contact with the concrete surface. The moving speed of the hammer produced by the spring must be constant and reproducible. The steel hammer rebounding from the percussion rod or other steel rebound values must be measured on a linear scale secured to the frame of the instrument. The hammer is a cylindrical device composed of various elements illustration below (figure 5):

Equipment

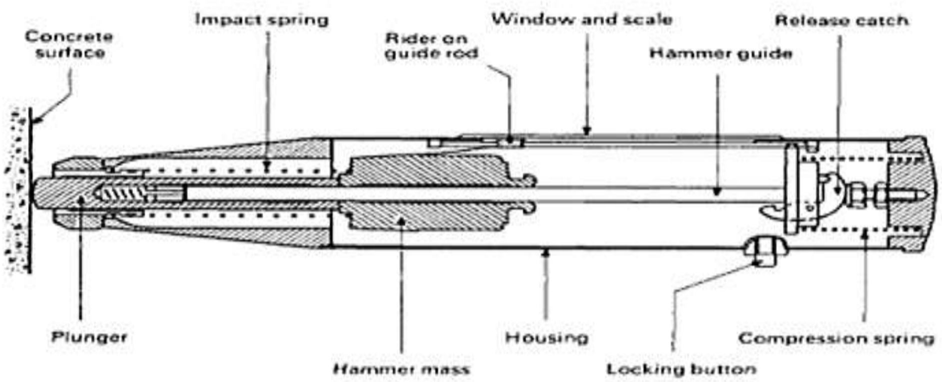

Figure 5: typical rebound hammer

Handling

The position of the pointer indicates rebound as a percentage of forward hammer travel; this is illustrated in figure 6.

In modern versions of rebound hammer an electronic measuring unit has been added to help ensure proper test results which can be recorded for later review or uploaded to a personal computer.

The scale is replaced by a displacement sensor which measures the rebound value.

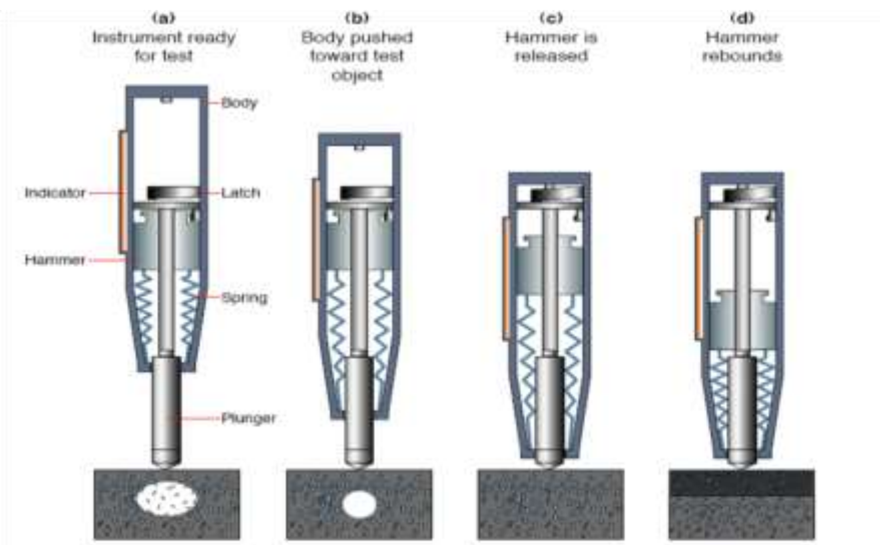

Figure 6: Operation of the rebound hammer

Calibration and Interpretation of Results

The new method of non-destructive concrete testing was acclaimed throughout the world. DIN 4240 was published in 1962 dealing with the SCHMIDT Hammer and its use.

However, as other investigators began to develop correlations between strength and rebound number, it became evident that there was not a unique relationship between strength and rebound number [19]. This lead to the often-stated recommendation that a correlation should be developed using the same concrete and forming materials as used in construction. Without such a correlation, the rebound hammer is useful only for detecting gross changes in concrete quality throughout a structure [20]. The issues of reliability of the rebound measurement and of calibration are key issues.

The first correction corresponds to the direction of impact (horizontal, vertical up and down), for which the calibration curve (which expresses the estimated compressive strength as a function of rebound number) must be shifted. The test hammer symbols in the diagram indicate the impact direction and the respective conversion curve. In many countries cylinders of 150x300mm are used as test specimens for whom conversion curves are available as well; figure 7.

A common factor that influences the reading is the carbonation of the concrete which starts from the surface and penetrates into the structure. Rebound numbers on a carbonated surface can be as much as 50% higher than non-carbonated surfaces.

Correction factors have been proposed by Tanigawa et al.[21] and in japanese and chinese guidelines (AIJ, 1983, JGJ/T 23-2001), but their values are very different and the more efficient way to compensate for this effect remains the calibration of the rebound values against the strength of core specimens taken from the structure.

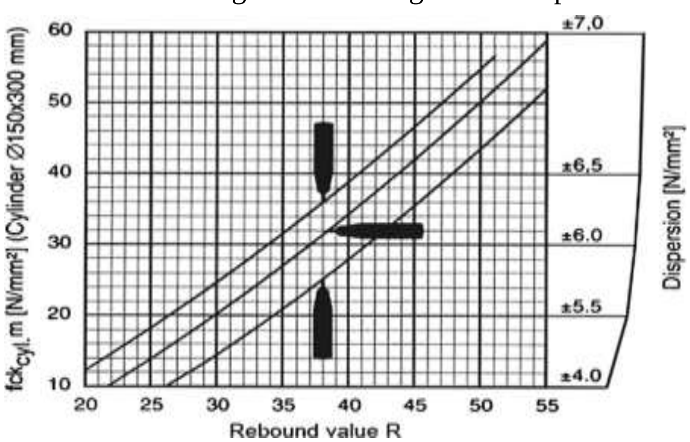

Fig. 7**:** Conversion curve for the average compressive strength measured On cylinders (f 150, H300mm)

Many factors have been recognized as influencing the rebound number; the influences of these factors are so great that it is very unlikely that a general calibration curve relating rebound hammer to strength, as provided by the equipment manufacturers, will be of any practical values, event by using a series of corrective coefficients. It is the reason why the EN 13791 has chosen a different approach for calibration: it gives a “basic curve” linking the rebound number and the estimated strength and the calibration process consists in shifting this basic curve accordingly to the results given by comparing the values of rebound number and true core strength measured at a given number of points.

5. Factors influencing the test hammer (rebound hammer)

Although the test hammer (rebound hammer) is a simple, quick and inexpensive to use control of the concrete it has some disadvantages and limitations that can significantly affect reliability. The test is affected by various factors, the most interesting are:

Smoothness of Surface under Test

Surface texture has an important effect on the accuracy of the test results. When a test is performed on a rough textured surface, the plunger tip causes excessive crushing and a reduced rebound number is measured.. It has been shown by Kolek [19] and Greene [16] that trowelled surfaces or surfaces made against metal forms yield rebound numbers 5 to 25% higher than surfaces made against wooden forms. This implies that if such surfaces are to be used, a special correlation curve or correction chart must be developed.

Size, Shape, and Rigidity of Test Specimens

If the concrete section or test specimen is small, such as a thin beam, wall, 152-mm cube, or 150 × 300-mm cylinder, any movement under the impact will lower the rebound readings. In such cases the member has to be rigidly held or backed up by a heavy mass.

It has been shown by Mitchell and Hoagland [22] that the restraining load for test specimens at which the rebound number remains constant appears to vary with the individual specimen.

Age of Test Specimen

Kolek [19] has indicated that the rate of gain of surface hardness of concrete is rapid up to the age of 7 days. It has been confirmed by Zoldners[23] and Victor [24] that for equal strength, higher rebound values are obtained on 7-day-old concrete than on 28-day-old concrete

Surface and Internal Moisture Condition of the Concrete

Klieger et al. [25] have shown that for a 3-year-old concrete differences up to 10 to 12 points in rebound numbers existed between specimens stored in a wet condition and laboratory-dry samples. This difference in rebound numbers represents approximately 14 MPa difference in compressive strength.

Type of Coarse Aggregate

According to Klieger et al. [25] for equal compressive strengths, concretes made with crushed limestone coarse aggregate show rebound numbers approximately 7 points lower than those for concretes made with gravel coarse aggregate, representing approximately 7 MPa difference in compressive strength.

Grieb[26] has shown that, even though the type of coarse aggregate used is the same, if it is obtained from different sources different correlation curves would be needed figure 8. At equal rebound numbers, the spread in compressive strength among the correlation curves varied from 1.7 to 3.9 MPa. Greene [27] found that the use of the test hammer on specimens and structures made of lightweight concrete showed widely differing results.

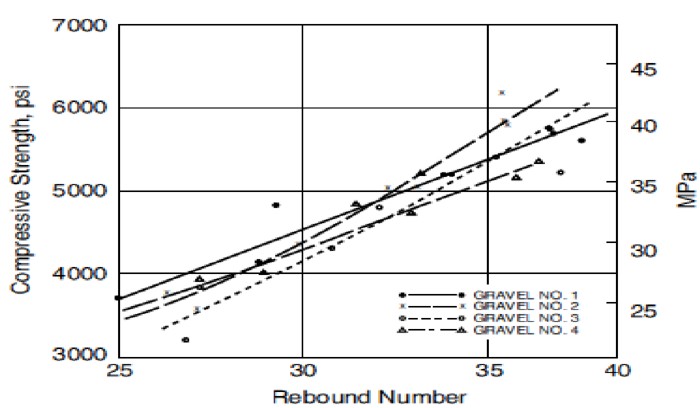

Figure 8: Effect of gravel from different sources on rebound numbers of concrete cylinders [26]

Type of Cement

According to Kolek [19], the type of concrete significantly affects the rebound number readings. High alumina cement concrete can have actual strengths 100% higher than those obtained using a correlation curve based on concrete made with ordinary portland cement. Also, supersulfated cement concrete can have 50% lower strength than obtained from the ordinary portland cement concrete correlation curves.

Type of Mold

Mitchell and Hoagland [22] have carried out studies to determine the effect of the type of concrete mold on the rebound number. There was no significant difference in the rebound readings between cylinders cased in steel molds and tin can molds, but the paper carton-molded specimens gave higher rebound numbers.

Carbonation of Concrete Surface

Surface carbonation of concrete significantly affects the Schmidt rebound hammer test results. The carbonation effects are more severe in older concretes when the carbonated layer can be several millimeters thick and in extreme cases up to 20 mm thick. In such cases, the rebound numbers can be up to 50% higher than those obtained on an un-carbonated concrete surface.

6. Relationship compressive strength - index rebounding (RN)

According to Malhotra and Carino [28], the accuracy of the assessment of the strength of specimens cast, preserved in cure and tested in laboratories to compression using hammers properly calibrated ranges of ± 15 ± 20%. However, the accuracy of the evaluation of the compressive strength of the concrete structure in the hammer is ± 25%. Carette and Malhotra [29] have conducted investigations to demonstrate the ability of the test hammer to determine the evolution of the compressive strength of concrete at the age of three days in order to optimize the time of formwork.

Boundy and Handros [30] suggested the use of the hammer in conjunction with a procedure for accelerated cure specimens for obtaining a rapid method for assessing the compressive strength of concrete. For testing in situ, Facaoaru [31] proposed meanwhile a combined test method based on the index rebound and measurement of ultrasonic waves. Another technique for locating a core zone to optimize the number of driving tests in the laboratory, the statistical evaluation should be conducted in accordance with applicable specifications.

7. Reliability and Limitation of results

Due to its simplicity, speed and low cost, the hammer rebound is, by far, the NDT device most widely used for concrete. Another major advantage for the evaluation of resistance is that this technique has a direct relationship with the mechanical properties of concrete than most other methods. But this simplicity can sometimes lead to careless handling.

The boundaries of the Schmidt hammer should be recognized, it should not be considered a substitute for testing compression, but rather as a method of determining the homogeneity of concrete in structures. Its use in assessing the compressive strength of the concrete is not recommended unless correlation tests were performed first.

8. Standards and guidelines for the use of the rebound hammer

The method of the hammer rebound (rebound hammer) has gained considerable popularity, and this fact has been covered by several norms and standards:

- ASTM C 805, Standard test method for rebound number of hardened concrete, Annual Book of ASTM standard, ASTM C805-85, Detroit, 1994.
- BS 1881 - Part 202 - Recommendations for Surface hardness tests by the rebound hammer, BSI, UK, 1986.
- DIN 4240 Kugelschlagprüfung von Beton mit dichtem Gefüge, Richtlinien für die Anwendung, 4-1962.
- EN 12504-2, Testing concrete in structures - Part 2. Non-destructive testing - determination of rebound number 2001.
- EN 13791, Assessment of in-situ compressive strength in structures and precast concrete, CEN, Brussels, 28p., 2007.
- JGJ / T 23-2001, J 155-2001, Technical specifi cation for inspection of concrete compressive strength by rebound method, 2001 (in China).

Some guidelines are also available on this subject:

- AIJ, Architectural Institute of Japan, nondestructive test Manual of methods for the assessment of concrete strength, p. 26, 1983 (in Japan)
- FHWA Guide to non-destructive testing of concrete, FHWA-SA-97-105, USDOT, Washington DC, 1997.
- VM Malhotra, NJ Carino, Handbook on nondestructive testing of concrete, CRC Press, 2004.

9. Conclusion

The test is described in ASTM C805 and EN 12504-2:2001 and is classified as a hardness test. The simplicity and speed of the test contrast with several drawbacks which can lead to misleading or useless results. The results of rebound hammer are significantly influenced by several factors [28, 32] such as: smoothness of test surface; size, shape, and rigidity of the specimens; age of the specimen; surface and internal moisture conditions of the concrete; type of coarse aggregate; type of cement; type of mould; carbonation of concrete surface.

The influences of the above mentioned factors are so great that it is very unlikely that a general calibration curve relating rebound hammer to strength, as provided by the equipment manufacturers, will be of any practical values.

A calibration curve for each concrete under testing have to be performed, taking into account the specimen condition, as well as a frequent check on a standard steel mass to verify spring performance or friction problem between the impacting mass and the plunger. EN 12504-2 standard recommends that calibration have to be performed on samples properly clamped between the plate of testing equipment under a compressive load of about 15% of concrete strength and in any case higher than 7 N/mm2. According to EN 13791:2003 standard rebound hammer test with calibration by means of cores test may be used for assessment of in situ strength. In situ strength can be estimated using a basic relationship and a determined factor for shifting the basic relationship curve to take into account of the specific concrete and production procedure. Calibration for a specific area of the concrete structure under evaluation have to be performed on a region large enough for at least 9 test location for rebound test and for taking out cores to be tested for in situ compressive strength.

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