# POLITECNICO DI TORINO

**Master's Degree in Civil Engineering**

**Master's Degree Thesis**

# The Strength of Concrete in Existing RC Structures


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**July 2021**

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## Abstract

The compressive strength of the material is the main parameter to be correctly defined. It shows the material's actual state and giving the engineers the ability to decides the correct necessary decision.

Retrofitting or demolishing the existing reinforced concrete structures is usually taken based on this parameter that is generally obtained via destructive or non-destructive methods.
In some cases, especially in a large-scale region, the compressive strength is not obtained via test due to the difficulty and the high cost of performing the tests.
In such a case, the use of Strength-for- Age curves can be carried out where concrete strength is plotted as a function of the construction years.

In this thesis, we will try to study the reliability of such a case by considering some stored data of the performed tests during the construction years.
Furthermore,We will try to compare the results of these test data with the strength curve to study the reliability of the obtained results and understand the possible use of the strength for age curves.



**Keywords:** Old concrete strength, Existing reinforced structure, Retrofit,Demolish.

# Acknowledgements

I want to express my sincere thanks and appreciation to Politecnico di Torino university for giving me the chance to be a part of it. It was a pleasure and honor for me to follow two years here at this university.
I want to thanks all of the academic staff, especially my thesis supervisor, Prof Alssandro FANTILLI, for giving me a chance to work with him.
My mother, father, brothers, sister, friends, thank you all for your supports. Without it, I will not achieve anything.

*Sincerely,*
*Abdel Rahman Kayed*

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# Acronyms

**Ea**

Apparent activation energy

**RC**

Reinforced Concrete

**R**

Universal gas Constant

**T ref**

Equivalent reference temperature

**R cub**

Concrete Cube Strength

**DT**

Destructive Test

**NDT**

Non-Destructive Test

# Chapter 1

# Vulnerability of Existing RC Structures

Reinforced concrete is a combination between steel reinforcement bar and a mixture of Portland cement concrete, aggregates, additives, and water. This combination allows resisting several types of loading where concrete resists compression and steel resists the tension forces. Reinforced concrete was discovered by the end of the 19th century. After that, a significant development was carried out until it became the raw material in building structures.
In the past, concrete was not widely used in building constructions due to its limited tension resistance, but this problem was solved by adding steel bars to overcome the poor tensile problem.
However, nowadays, most of the structural elements are build using reinforced concrete materials such as slabs, walls, beams, columns, supports, frames, and more.

Reinforced concrete has many advantages such as :

- Compressive strength is higher concerning other building materials.
- Reinforced concrete can resist a good amount of tensile stresses due to the provided reinforced.
- It can be modeled in any required shape.
- Reinforced concrete material's durability is fair enough, and a reinforced concrete building system is more durable than any other building system.
- The resistance against fire and weather conditions is fair enough.

On the contrary, RC material may have some disadvantages such as :

- Tensile strength is about one-tenth of its compressive.
- Shrinkage may occur and leads to crack development and losses regarding its strength.
- The forms cost used for casting RC is relatively higher.[1]

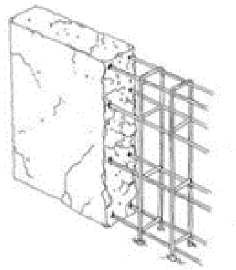


**Figure 1.1:** Reinforced Concrete material

The compressive strength of a material is the main parameter to be correctly obtained and can be defined as the resistance to failure under the application of given compressive loads.
It is the essential property of any given material that shows us an accurate observation of a given material's performance life during its surface life.
This parameter can be evaluated using either destructive or non-destructive methods.
In some cases, especially in a large-scale region, the compressive strength is not obtained via test due to the difficulty and the high cost of performing the tests.
In such a case, the use of strength for age curves can be carried out where concrete strength is plotted as a function of the construction years.

In this thesis, we will try to study the reliability of such a case by considering some stored data of the performed tests during the construction years, and we will try to compare the results of these test data with the strength curve to study the reliability of the obtained results and also try to understand the possible use of the strength for age-curves.

Existing RC structures are facing several problems where many researchers try to investigate these problems. They try to summarize them and found a solution for them.

Some of these problems are the following :

## 1.1 Seismic Actions

According to earlier codes, many existing structures were designed based on gravity loads without including sufficiently lateral actions. Many of these structures are still in action due to the high cost of replacements.
The old design approach was capable of giving a proper strength against only the lateral failures.

The new codes start focusing on design member's details and reinforcements to achieve adequate strength requirements and overall ductility and deformability.

During recent earthquake events, many existing RC buildings designed based on earlier codes did not behave well due to lack of ductility and inadequate lateral resistance capacity, so it is necessary to choose a proper economic intervention to assess the actual lateral load resistance and failure modes.
It is also essential to define the weakest and vulnerable elements in the structure.

The seismic assessment of existing RC structures starts taking more attention in several new codes, such as the Euro-code, that focus on strengthening and retrofitting existing structures.
Several structural system weaknesses are mainly caused by :

- Incomplete load path.
- Strength and stiffness discontinuities.
- Mass irregularities.
- Eccentricities.

The observations and investigations show that a non-ductile cross-section is characterized by :

1. Inadequate column shear capacity due to insufficient transverse reinforcement ties in columns to provide shear resistance and confinement.
2. Improper lap splices.
3. The main reinforcement bars due to lateral loads are located in a region where the column's highest moments and stress are achieved.
4. Absence of reinforcement in the joint part is also observed.
5. Inadequate beam shear resistance where plastic hinges located at beam ends are often poorly confined.

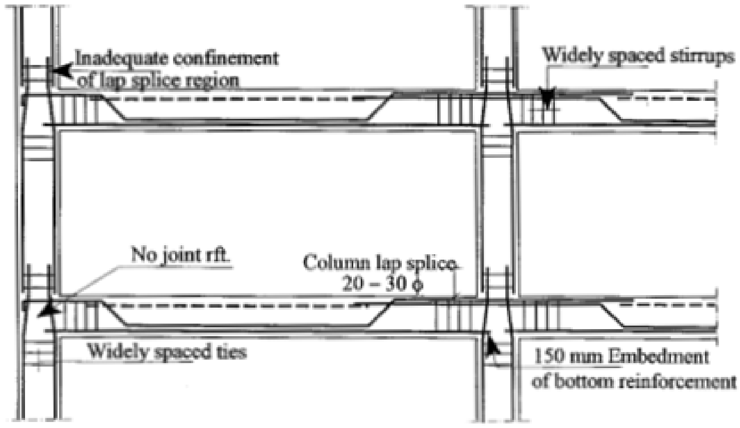



**Figure 1.2:** reinforcement details in existing structure

## 1.2 Corrosion

Durability problems represent one of the most critical issues affecting existing Reinforced Concrete (RC) building's structural performance. The primary cause of degradation of RC structures is the corrosion of steel bars that mainly result from carbonation and chloride ion penetration. Steel corrosion changes the bonding properties between the steel elements and concrete that directly affects the concrete and steel mechanical properties.
Corrosion phenomena that occur in existing structures directly lead to a tremendous potential loss in the structural capacity. It is known that corrosion products increase the rebar's volume with resulting cracking and spalling of the concrete cover and reducing the rebar's cross-section. It is necessary to predict corrosion consequences to protect the materials against any failure that may occur.
Furthermore, corrosion phenomena occurrence reduces stiffness, bond properties, anchorage capacity, flexural and shear strengths that affect the safety factor against failure and the behavior under the service conditions. This deterioration of the deformation capacity leads to the loss of confinement and decreased strength and ductility properties at section and element levels.
When steel corrosion occurs in the structure, it may cause a reduction in steel reinforcement in a critical region that can result in a formation of plastic hinges that may evolve into a collapse mechanism.
It can be easily said as corrosion advances in the structure. It leads to an overall capacity reduction of the whole system, deflections and cracks will appear.
According to many studies, the level of cracking produced by loads is directly affected by the corrosion rate. Comparing the other types of degradation, generally,

corrosion phenomena are faster. This phenomenon starts by entering the humidity, oxygen, and other detrimental materials into the concrete microstructures.

**Figure 1.3:** Corrosion Effects on the Durability of Reinforced Concrete Structure

In general, corrosion of reinforcing steel is one of the main reasons for the deterioration of reinforced concrete (RC) structures. The deterioration process associated with corrosion is usually divided into two stages.
The initiation stage is related to chloride or CO2 penetration and a propagation stage during which structural deterioration develops.
Finally, RC structures assessment is necessary to check the strength and performance by considering a conservative study to avoid economic and human losses.This balance requires the assessment to be carried for this time and for a future time.

## 1.3 Thermal Effects

Thermal changes directly affect RC structure's physical and mechanical properties and may occur due to :

1. Fires.
2. External factors.
3. High atmospheric temperatures.

The structure is subjected to temperature loads that lead to thermal stress in most of the structural elements where these stresses are comparable or even higher than the stresses induced by live loads or dead loads. They can lead to significant damage if they are not considered correctly during the design phase. These temperature variations cause several distortions in the elements of the structure.
The materials have a complex behavior during high-temperature events due to the differences in each thermal expansion coefficient constitution. During the design

process of reinforced concrete elements, the difference between the maximum temperature observed during the early hydration period and the minimum temperature observed in the service condition should be considered.
Concrete has a low elastic modulus and compressive strength during an early age. The changing in temperature directly affects the concrete water content and consequently concrete creep and shrinkage phenomena. The high temperature rises in the long term can directly lead to the presence of cracks.
The changing temperature potentially affects the section's stiffness and leads to crack formation that plays an essential factor as a potential indicator of overall performance. Also, it significantly affects the deflection of the building structure. The presence of large cracks requires a necessary action since it leads to deterioration of concrete and causes a massive decrease in stiffness, so rehabilitation or replacement is required.

## 1.4 Cracks

Cracking of the reinforced concrete is a widespread phenomenon during the life period of a structure.Cracks have various causes and take different appearances at early ages and later on at mature age. At the early age of concrete, the cracks observed result from the differential settlement, plastic shrinkage, temperature gradients.
However, the cracks usually occur at the mature stage due to shrinkage, climatic temperature changes, frost, corrosion, and chemical reactions.
Thermal cracking at early ages is caused by restrained thermal movements originating from the concrete's hydration process.
Moreover, they were formed during the cooling phase of the hydration.Also, they can be observed as surface cracks or through cracks in the structure.
Cracks due to plastic settlement and shrinkage can be significant and should be avoided by appropriate actions during execution. During the live performance of the structure, cracks developed as a result of loads and environmental factors.
Cracks in RC elements are mainly occurring due to the low tensile strength of concrete.
According to Mehta and Gerwick 1982 "The cracks form in concrete varies in widths, numbers, geometry, depths..."These factors affect the initiation and propagation of corrosion of steel in RC. Cracks can be observed in two different shapes, the transverse cracks, where they are perpendicular to the reinforcing steel, and longitudinal cracks (parallel to longitudinal reinforcing bars).
In General, most cracks observed on the RC structure are the transverse crack. However, Longitudinal cracks are usually observed after the corrosion of steel, and they are more dangerous than transverse cracks for corrosion as more steel areas

are exposed to the aggressive environment.
Additionally, longitudinal cracks are evidence of the critical development of corrosion on the reinforcing steel.
The appearance of cracks causes several distortions in the materials and significantly reduces the material's mechanical properties. Additionally, the presence of cracks also affects the durability properties.
In general, the structure is subjected to a particular load that leads to the appearance of microcracks. If this load is large enough, a crack network will appear, which leads to several distortions in the structure that affect the materials' performance life.

# Chapter 2

# Concrete Strength

The compressive strength of a material can be defined as the resistance to failure under the application of given compressive loads. It is the essential property of any given material that shows us an accurate observation of a given material's performance life during its surface life.
Many design codes such as the (ACI 318-14, CSA A23.3-14) have chosen the 28 days compressive strength of concrete as the minimum accepted concrete strength for cylinders or cube samples.
Concrete strength represents the mechanical properties of the material, and it can be considered an essential factor for the indications of durability performance. It can be estimated by dividing the load that causes the sample's failure over the sample's cross-section area, and the results can be reported as a load per unit area (MPa). In terms of specific values, the strength ranges between 17 MPa and 28 MPa for a Residential structure, where this range of values can be higher for a commercial structure. Furthermore, compressive strength can exceed 70 MPa for a specified structure application, such as for bridges.

Many factors play a significant role in affecting the quality of concrete compressive strength, such as :

- The type of cement.
- The aggregates types and size.
- Water content.
- Various admixtures.

The water-cement ratio can represent the concrete compressive strength quality as it has an inversely proportional relationship. As it increases, the compressive strength will decrease. Many tests can be applied to find the strength of concrete material, and these tests are applied to check that the mixture achieved the request requirements. These tests range based on their structural element damage that varies from destructive to non-destructive damage.

## 2.1 Compressive Test of Concrete

Many tests can be performed to determine concrete strength, where the compression test is the most famous performed test that provides us guidelines about the material's overall performance.
The samples are prepared and tested according to the specified used standards such as the (ASTM standard) following an exact specified procedure. The test sample shapes and dimensions can be either cylinder samples (15 cm x 30 cm ) or cube samples (15cm x 15cm x15cm), depending on the applied code.
Furthermore, based on the test result, the concrete work can either accepted or rejected depending on the code request. During the test, a compressive load is applied gradually until the sample's failure. After that, the compressive strength is evaluated by dividing the load that causes the sample's failure over the sample's cross-section area, and the results can be reported as a load per unit area (MPa). Codes usually specified the number of days requires before performing the test, where the 28 days after mixing are usually considered the representative.

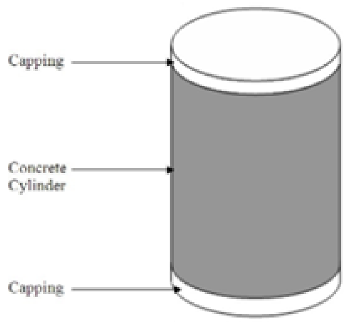



**Figure 2.1:** Concrete Cylinder Sample

The quality of compressive strength is affected by several factors, such as:

- Cement Type.
- Aggreagtes type and size.
- Water-cement Ratio.

- Curing of Concrete.
- The mix design.
- Enviromental Conditions.

The test samples taken from the field are prepared following a proper procedure depend on the applied codes:

**Figure 2.2:** Making and Curing Cylinders in the field

1. From each truck mixer, codes specify the number of representative samples taken where it is necessary to make sure that concrete state reached the needed request by making the slump test.
2. The concrete is placed in the cylinder molds on a different equal layer depending on the mold's size using a specified scoop.
3. Every layer is struck 25 times using a specified tamping rod, distributing uniformly over the cross-section through its depth.
4. Press the outside mold carefully from 10 to 15 times using a rubber mallet to close the voids left by the tamping rod.
5. Made a flat surface using a trowel. After that, install the cap and move the samples into an initial curing place for storage.
6. For the initial curing, the samples should be stored up to 48 hr. in a specified temperature range to avoid moisture loss.

7. After the initial curing, the final curing is started by placing the samples in a wet environment until the testing date.

Finally, the test is carried out following a proper procedure :

- The test starts by placing the concrete in the mold and compact it properly to reduce the number of voids.

- After 24 hr. the mold should be placed in water for curing where codes have been decided the days of curing before performing the tests.

- The test is usually performed after 7, 14, and 28 days.

- Finally, the concrete sample is placed on a specified apparatus where the load is applied gradually until the specimen's failure.

In conclusion, the designer specified the required strength needed to design the structural elements, and this value will be included in the job documents. The concrete mixture is usually designed to have an average value higher than the required designed strength of the structural elements to avoid the risk of not reaching the minimum design strength requirements.
Finally, the tests are carried out to compare the obtained test values with the necessary design values and then try to make suitable decisions based on the applied code request. When a failure in the obtained test results is observed, it is necessary to understand and check if the failures result from a bad quality concrete mixture or it is due to human mistakes during the application of the tests.


**Figure 2.3:** Compression machine

## 2.2 Core Sampling In-Situ

One of the most famous tests carried out in site to check the compressive strength of concrete is taking core samples. This test is considered a destructive test where some cores are taken from the structural elements to ensure that the concrete reached the request performance. The Cores samples are usually considered for testing the actual state of concrete properties in existing RC structures, such as the compressive strength, carbonation level, permeability, and more.

“According to new research the core samples can also be used for the following reasons:

1. Strength and density determination.
2. Depth of carbonation of concrete.
3. Chemical analysis.
4. Water/gas permeability.
5. Petrographic analysis.
6. ASHTO Chloride permeability test.” (Core Sampling and Testing of Concrete and Factors Affecting Strength, n.d.)[2].

Codes usually specify the number of samples to be taken from each area. For example, when the core is taken to determine concrete strength, at least three specimens should be taken from each location. Furthermore, the codes specify some necessary request to respect and follow where :

- The minimum diameter requires to be at least three times the maximum nominal aggregate size.
- The length should be at least twice the diameter.
- The concrete should be at least 28 days old.

The engineering judgments decide the location and number of the performed test by considering the applied code where it is necessary to take care of the possible effects of reinforcement positions.
The core samples taken from the structural elements should be placed in water for at least 48 hours before performing the test.
When the specimens are removed from storage place into the testing location, it is necessary to keep the cores in wet conditions.
Furthermore, codes specify that the length to diameter ratio must not be less than

1.94. Otherwise, a correction factor must be applied.

“According to the ASTM standards the following correction table can be observed

| Ratio of length of cylinder to diameter (L/D) | Strength correction factor |
|---|---|
| 1.75 | 0.98 |
| 1.5 | 0.96 |
| 1.25 | 0.93 |
| 1 | 0.8 |

**Table 2.1:** Correction Factor for Ratio of Length of Cone to its Diameter

(Testing of Concrete Cores for Strength – Sampling and Procedure, n.d.).” [3]

The core is then placed on a specified machine where the load is applied gradually until the sample’s failure.
The strength is estimated by dividing the applied load that caused the sample’s failure over the core sample’s cross-section, and the results are reported in Mpa.
The average values of the specimens taken from the same location are considered as a batch representative where the single difference variation of each core should not exceed ± 15 percent of the average.
If this condition is not achieved, the test should be repeated.

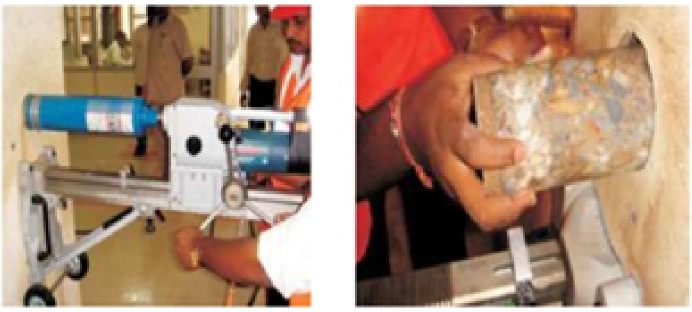


**Figure 2.4:** Core Extraction and Testing

“Its is necessary that for each core specimen, the following information should be clearly defined :

1. The ID Mark.

2. The Test Date.

3. The Age of the Core Sample.

4. Weight and dimensions of the specimens

5. The Curing conditions.

6. The Area of the core sample.

7. The maximum failure achieved load.

8. The Computed compressive strength.

9. The appearance and type of fractures were observed."(V.M. Malhotra et al.,2006).

**Figure 2.5:** Core Samples

Finally, several factors can play an essential role in affecting the compressive strength of the extracted core samples, such as:

- The aggregate type and size.
- The appearance of steel reinforcements.
- Height/diameter ratio
- The Age of Concrete.
- The Drilling Conditions.
- The site condition versus the lab conditions.

## 2.3 Schmidt Rebound Hammer Test

Different researchers have developed various non-destructive methods to assess concrete's in-place strength. One of the most famous methods developed by Ernst Schmidt is the Schmidt Rebound Hammer test, and it is used to estimate concrete's compressive strength without damaging the structural elements.
The hammer can be placed vertically, horizontally, upwards, downwards, and at any specified angle.

The Rebound hammer test can be classified into two distinct groups depending on their impact energy level produce.

- The first one is type N hammers that usually have a higher energy output to cover more structural elements, and it is used when these structural elements have a thickness more or equal to 100 mm.
- The second one is the type L hammers that usually generate lower impact energy levels and are used when the structural elements have a thickness lower than 100 mm.

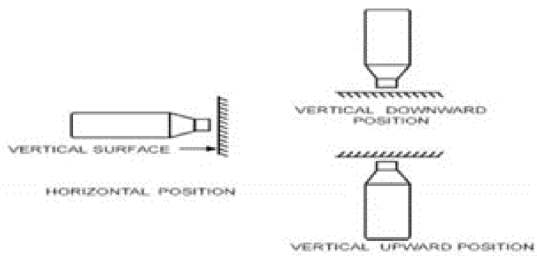



**Figure 2.6:** Rebound hammer Positions

According to the Indian code, the Schmidt hammer test can be used for several objectives such as:

1. To estimate the strength through relating the index value and the compressive strength.
2. To control the concrete structure depending on the standard requirements.
3. To control the uniformity of concrete.
4. To find a quality combination between one concrete element concerning another one.

The test can help the engineers to check if the concrete materials meet the applied code's request requirement and to make a suitable decision based on its purpose.

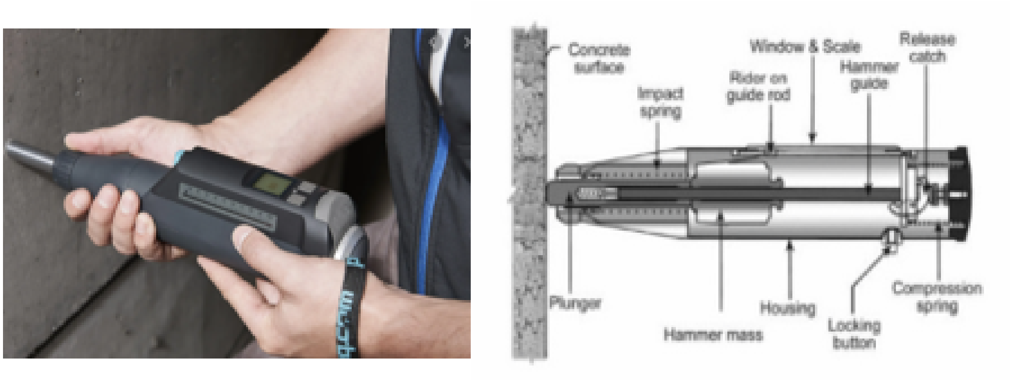



**Figure 2.7:** Rebound Hammer Instrument

Additionally, the concrete hammer test can be a brilliant choice for rapid assessments of hardened concrete. Before performing the test, it is necessary to ensure that the surface is smooth, clean, and dry. After that, an impact will occur between the concrete surface and the plunger rod as it will be pressed until the spring-loaded mass release. A different impact level is required for each different application, and according to IS 13311(2)-1992.

"The following table has been summarized some of these applications.

| Applications | Approximate Impact Energy in N.m |
|---|---|
| For Normal Weight Concrete | 2.25 |
| For light weight concrete | 0.75 |
| For mass concrete testing | 30 |

**Table 2.2:** Impact Energy for Rebound Hammers for Different Applications As per IS:13311(2)-1992

That is necessary to respect and follow". (Testing of Concrete Cores for Strength – Sampling and Procedure, n.d.)[3].

The test results are directly affected by several factors such as:

1. The surface's smoothness.
2. The size, shape of specimens.

3. The concrete's water contents condition.

4. The types of cement and aggregates.

The rebound number obtained is used to estimate the hardness properties of concrete and can be defined as the degree of the mass bounces back.
According to the ASTMC805 standard, "The test locations should be selected such that a wide range of rebound numbers in the structure is obtained and to establish a relationship between rebound number and concrete strength, Inspectors should take a minimum of 2 replicate cores from 6 or more locations (12 concrete cores in total) with different rebound numbers". (ACI 228.1R)

"The following table shows that how the rebound number can represent the quality of applied concrete.

| Average Rebound Number | Quality of Concrete |
|---|---|
| >40 | Very Good hard layer |
| 30 to 40 | Good layer |
| 20 to 30 | Fair |
| <20 | Poor concrete |
| 0 | Delaminated |

**Table 2.3:** Quality of Concrete for different values of Rebound number

Based on the manual of the hammer used". (Testing of Concrete Cores for Strength – Sampling and Procedure, n.d.)[3].

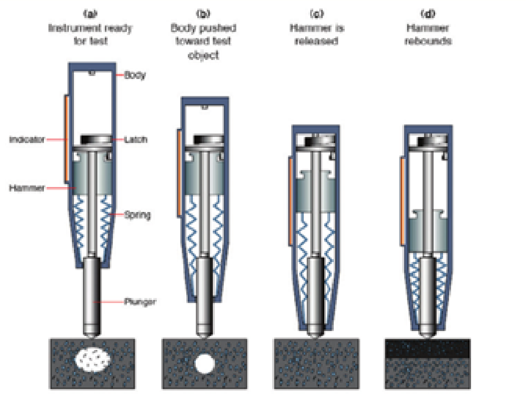



**Figure 2.8:** Rebound Hammer Test procedure

## 2.4 Ultrasonic Pulse Velocity Test or UPV Test

Ultrasonic Pulse Velocity Test is a non-destructive method used to determine the compressive strength of concrete without damaging the structure and can be performed on-site or in the lab, and it is also known as the UPV test method.
Using the UPV method with the help of an ultrasonic pulse velocity tester, the strength is obtained by estimating the material's homogeneity and integrity. This method is used for the analysis of deterioration as well as for quality control.
During the test, the travel time produced by the transducer is measured, and once the path length that is the distance between the two probes is obtained, then the pulse velocity can be calculated by dividing the length by time (V=L/T).

It was observed that the highest the velocity obtained, the better quality of concrete material is observed.

"According to some Reschers, the UPV of concrete is classified into four types .

| Pulse Velocity (Km/second) | Concrete Quality Grading |
|---|---|
| Above 4.5 | Excellent |
| 3.5 to 4.5 | Good |
| 3 to 3.5 | Medium |
| Below 3 | Doubtful |

**Table 2.4:** Quality of Concrete based on the measured velocity

depending on the intended application and the Pulse velocity observed." (Yew et al., 2014).[4]

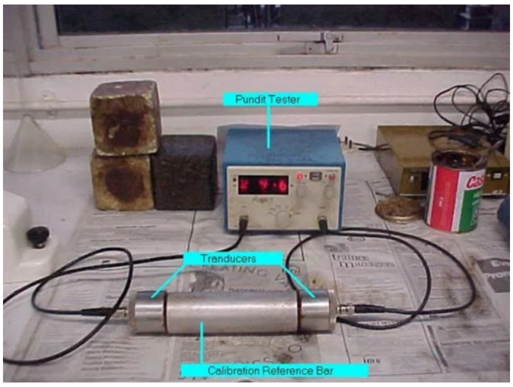



**Figure 2.9:** Ultrasonic Pulse Velocity Testing Instrument

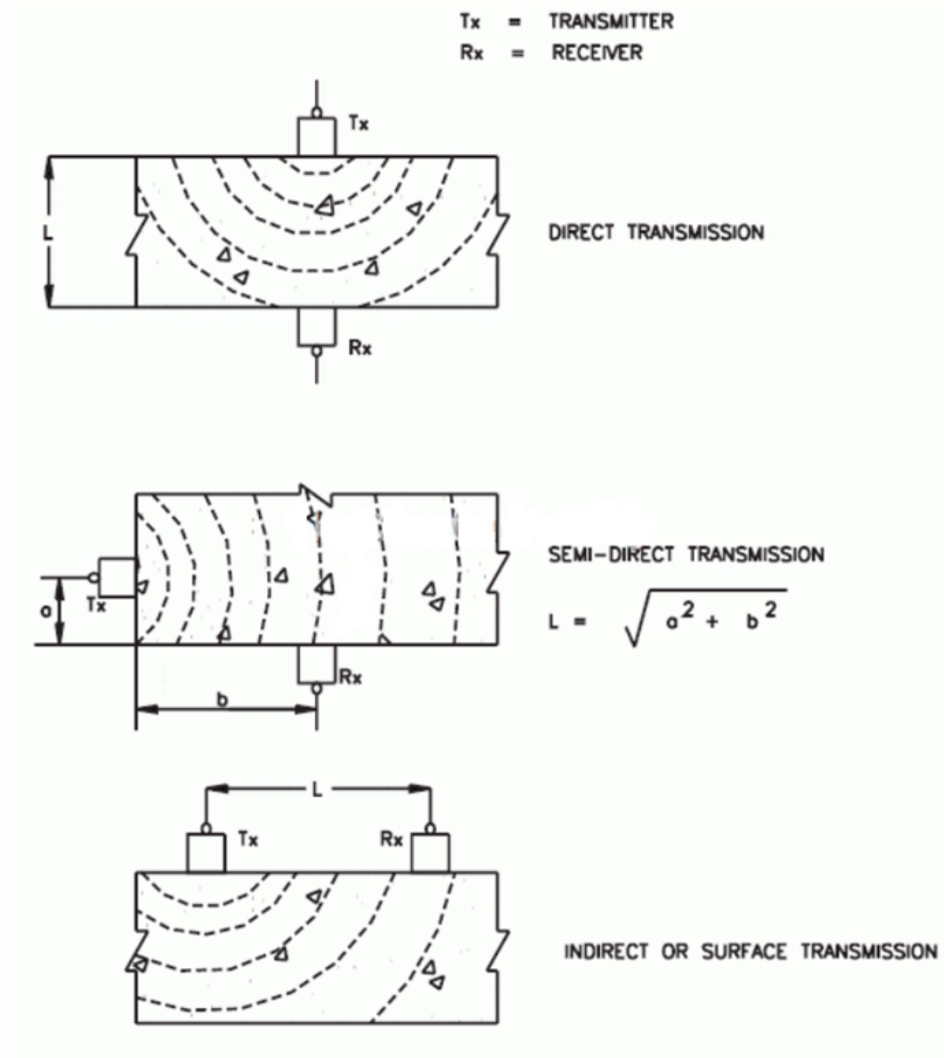



**Figure 2.10:** Method of propagating and receiving pulses

The test results are affected by several factors such as :

- The presence of reinforcement.
- Age of concrete.
- water content.
- The travel distance of the wave.

The water contents have two significant influences on the pulse velocity, the first one is chemical influence, and the other is physical. These influences directly

affect the estimation of concrete's compressive strength since between an accurately cured and other structural elements with the same concrete material, a significant difference in the pulse velocity can observe.
Furthermore, the various curing conditions during the cement material's hydration procedure can lead to a massive difference in the moisture content, so these factors must be accurately considered in evaluating the compressive strength.
It is possible to identify the corrosion-prone locations based on the hammer and Pulse velocity readings obtained.

Where "some Authors provide us a guideline about the Possible observed results.

| Test Results | Interpretations |
|---|---|
| High UPV values,high rebound number | Not corrosion prone |
| Medium range UPV values, low rebound numbers | Surface delamination,low quality of surface concrete, corrosion prone |
| Low UPV, high rebound numbers | Not corrosion prone, however, to be confirmed by chemical tests, carbonation, pH |
| Low UPV, low rebound numbers | Corrosion prone, requires chemical and electrochemical tests. |

**Table 2.5:** Identification of corrosion Prone Location based in Pulse velocity and hammer readings.

shown in table 2.5". (What Is Ultrasonic Testing of Concrete for Compressive Strength? n.d.).[4]

## 2.5 Penetration Test

This test measures concrete's compressive strength by firing a probe on a concrete surface with a known force value. The test starts by pushing a ¼-inch diameter steel probe into a concrete structural material using a Specific powder. The test can estimate the compressive strength of concrete up to 110 MPa.
This method is also known as the Windsor Probe test where is considered a Non-destructive test as it caused minor damage to the structural elements and can be performed on the site. During the test, the strength is evaluated from the depth of penetration of a metal rod driven into concrete.
The penetration is inversely proportional to the concrete strength, where the test results are directly affected by the strength of the aggregate and the smoothness of the concrete surface.

The test can be used for several reasons such as :

1. Determination of the concrete uniformity.

2. Identify the concrete quality and the deteriorated zones.

3. Estimate the concrete strength on-site.

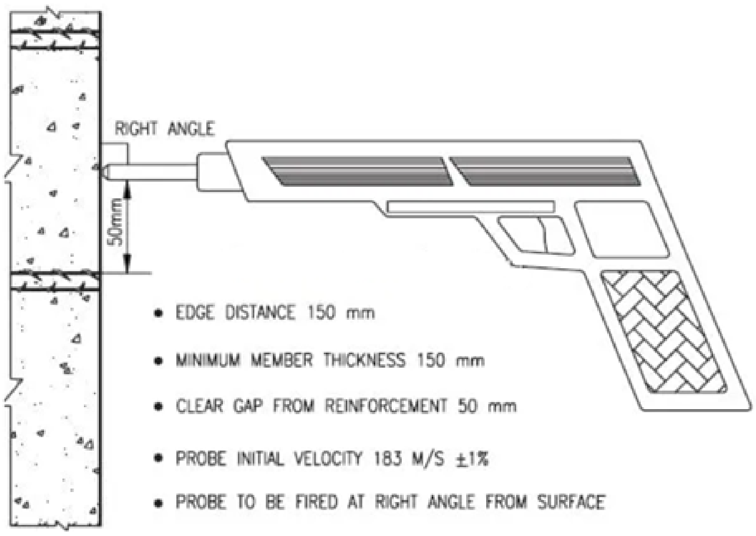



**Figure 2.11:** Windsor Probe Gun

The test follows a proper procedure in order to evaluate the strength of concrete where :

- Firstly, the device is placed on the concrete surface test location.
- Mount a probe in the driver unit.
- The driver is on the positioning device.
- Shot the probe into the concrete surface.
- The positioning device is removed, and the probe is taped on the exposed end.
- Finally, the base measuring plate is placed over the probe.

The aggregate strength plays an essential factor in this test as the degree of penetration is inversely proportional to the strength.

During the test operations, some considerations should be respectful and follow, such as :

1. If the probe is sloped concerning the concrete's surface, the average of four measurements taken around and parallel to the probe should be considered.

**Figure 2.12:** Penetration Resistance Testing

2. The test is not valid and should be repeated if the probe is not firmly embedded.
3. When the average depth of three penetration tests is more than 8.4 mm of concrete made by the maximum aggregate size of 25 mm, the test should be repeated.
4. When the average depth of three penetration tests is more than 11.7 mm of concrete made by the maximum aggregate size of 50 mm, the test should be repeated.

**Figure 2.13:** Penetration Resistance Test

The concrete penetration resistance is evaluated by measuring the probe length driven into the concrete surface, so it is necessary to find a possible relationship between the concrete strength and penetration resistance.
The test results should be connected with other data obtained from concrete cores or cylinders, so a regression analysis is applied to obtain the best fit between the compressive strength and penetration test results.

Various parameters can affect the test results, such as the size, type of aggregates, and the location of steel reinforcements.

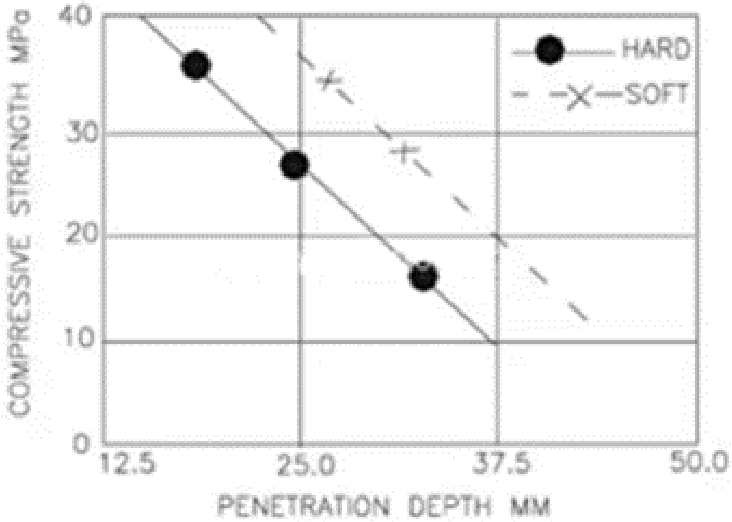



**Figure 2.14:** Penetration Test Results for Hard and Soft Surfaces

In conclusion, the probe penetration resistance is directly affected by the concrete strength and the coarse aggregate's nature.

## 2.6 Combined NDT Methods (SonReb Method)

The strength of concrete is the main parameter to be correctly defined and used to assess the existing RC structure's performance assessment. Many destructive and non-destructive tests are used to estimate the compressive strength of concrete. Furthermore, several Research studies the critical use of the combination method between different non-destructive methods. The combination between the Rebound hammer test and UPV, known as the SonReb method, is one of the most famous used combinations developed by RILEM Technical Committees, depending on the Romanian I. Facaoaru engineer's Research (Facaoaru, 1961).

According to Pucinotti (2007), This combination is favorable and has many advantages such as :

- The strength can be estimated at the concrete surface and in-depth levels.

- No damage to the structural elements.
- Higher accuracy level in terms of results can be achieved.
- Fast execution.

This test's combination allows to partially compensate for the errors made by using the two methodologies individually. The combination process improves the observed result's reliability by combing the results obtained from the various tests using some empirical formulas provided by several researchers.

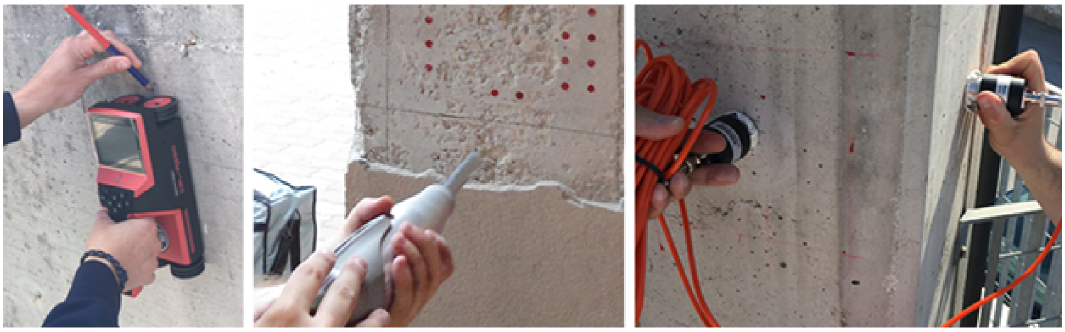


**Figure 2.15:** Applying SonReb Method

These improvements occur by considering several correction factors such as:

- The aggregate types and size.
- Cement-water content.
- Physical and Chemical factors.

To have the best results for material strength prediction.

Several Techniques are mainly used to predict the concrete strength based on the SonReb measurements that are:

- Computational modeling.
- Artificial intelligence.
- Parametric multi-variable regression models.

Computational modeling is generally dependent on modeling complex physical phenomena, and it is not practically considered. However, the regression model is usually used in practice since it is easy to be implemented. Moreover, the regression

model can reflect the accuracy of the estimation values and can be very helpful to provide exactly the estimations that will not affect the result's predictions. During the years, many regression models were developed and used for SonReb measurements to correctly predict the concrete compressive strength.
The application of the SonReb method requires the evaluation of the local values of the ultrasonic speed V and the rebound index S, from which it is possible to obtain the strength of the concrete RC using specified expressions.

According to Pucinotti 2005 " the law of correlation among compressive strength, Rebound Hammer index and ultrasonic velocity can be expressed as :

$$R_{cub} = a.I_r^b.V_{us}^c$$

where a and b can be obtained via the least square method." (Pucinotti,2005) Additionally, In the literature, "many empirical formulas can be used to estimate the compressive strength of concrete based on SonReb method ,such as :

| Author | Year | Formulation | Units | Sample type |
|---|---|---|---|---|
| Bellander | 1979 | $R_{cub} = 0.00082 \cdot I_r^3 + 11.03 \cdot V_{us} - 32.7$ | MPa, km/s | A |
| Meynink, Samarin | 1979 | $f_{cyl} = -24.1 + 1.24 \cdot I_r + 0.058 \cdot V_{us}^4$ | [MPa, km/s | B |
| Giacchetti, Lacquaniti | 1980 | $R_{cub} = 7.695 \cdot 10^{-11} \cdot V_{us}^{2.6} \cdot I_r^{1.4}$ | MPa, m/s | C |
| Bocca, Cianfrone | 1983 | $R_{cub} = 2.765 \cdot 10^{-9} \cdot V_{us}^{2.487} \cdot I_r^{1.3114}$ | kg/cm$^2$, m/s | A |
| Samarin, Dhir | 1984 | $f_{cyl} = -12 + 0.1 \cdot V_{us}^4 + 0.76 \cdot I_r$ | MPa, km/s | B |
| Gašparik | 1992 | $R_{cub} = 0.0286 \cdot I_r^{1.246} \cdot V_{us}^{1.85}$ | MPa, km/s | D |
| RILEM | 1993 | $R_{cub} = 9.27 \cdot 10^{-11} \cdot I_r^{1.4} \cdot V_{us}^{2.6}$ | MPa, m/s | A |
| Di Leo, Pascale | 1994 | $R_{cub} = 1.2 \cdot 10^{-9} \cdot V_{us}^{2.446} \cdot I_r^{1.058}$ | MPa, m/s | B |
| Arioğlu, Köylüoğlu | 1996 | $R_{cub} = 0.00153 \cdot (I_r^3 \cdot V_{us}^4)^{0.611}$ | MPa, km/s | D |
| Ramyar Kol | 1996 | $f_{cyl} = -39.57 + 1.532 \cdot I_r + 5.0614 \cdot V_{us}$ | MPa, km/s | D |
| Kheder | 1999 | $R_{cub} = 0.0158 \cdot I_r^{1.1171} \cdot V_{us}^{0.4254}$ | MPa, m/s | A |
| Beconcini, Formichi | 2003 | $f_{cyl} = 5.9 + 2.712 \cdot 10^{-15} \cdot I_r \cdot V_{us}^4$ | MPa, m/s | C |
| Caiaro et al. | 2003 | $R_{cub} = 1.74 \cdot 10^{-7} \cdot I_r^{-0.0674} \cdot V_{us}^{2.36}$ | MPa, m/s | A |
| Del Monte et al. | 2004 | $R_{cub} = 4.40 \cdot 10^{-7} \cdot (I_r^2 \cdot V_{us}^3)^{0.5634}$ | MPa, m/s | C |
| Menditto et al. | 2004 | $R_{cub} = 0.00004 \cdot I_r^{1.88148} \cdot V_{us}^{0.80840}$ | MPa, m/s | A |
| Faella et al. (a) | 2009 | $R_{cub} = 2.6199 \cdot 10^{-8} \cdot I_r^{0.5341} \cdot V_{us}^{2.2878}$ | MPa, m/s | C |
| Faella et al. (b) | 2009 | $R_{cub} = 0.26511 \cdot I_r + 0.01385 \cdot V_{us} - 34.51583$ | MPa, m/s | C |

**Figure 2.16:** Formulations to define the Rcub with the SonReb method

Many of them have been calibrated upon data related to compressive tests of cubic concrete samples (A) or cylindrical concrete samples (B) as prepared in the laboratory, while other ones have been calibrated on data related to compressive tests of cores, as extracted from existing buildings (C)". ("New Predictive Models to Evaluate Concrete Compressive Strength Using the SonReb Method," 2019, p.2). [5]

In conclusion, SonReb Method is the most used combination around the world. This method correlates the strength obtained from the ultrasonic velocity test with the rebound hammer index. Additionally, it improves the reliability of the Non-destructive tests that are less reliable if they are separately considered. SonReb combinations have many advantages as the Rebound hammer test provides a rebound number information for concrete near the surface, where the ultrasonic pulse velocity test provides information related to the concrete's interior properties. This technique improves the accuracy by using various correction factors, taking into account the influence of different concrete mixture proportions.

## 2.7 Maturity Method

The maturity test is another Non-destructive technique used to estimate the compressive strength of concrete based on its temperature history. This test is a measurement of how far hydration phenomena is progressed. During the test, the temperature is recorded as a function of time using specified maturity equipment. The maturity test applies the principle that the concrete properties and strength are directly affected by age and temperature history.


**Figure 2.17:** Concrete Maturity Instrument

The test gives a simple technique to evaluate the concrete compressive strength in-site during construction quickly. This concept assumes that the concrete sample with the same maturity will have the same strength value. Maturity is represented by an index value measured in the field depending on the obtained temperature history. After that, the strength in place can be evaluated using the strength relationship and the index value.
The strength gain rate in concrete can predict the concrete strength correctly as it depends on its time-temperature history. Finally, the probe locations must be correctly selected to cover the entire concrete area.

Several factors play an essential role in the reliability of the obtained results, such as:

- Aggregate properties.
- Water-Cement ratio.
- Cement properties.
- Curing temperature.

Several maturity functions exist where the empirical formula provided by Freiesleben-Hansen and Pedersen is the most frequently used.
"In this equation, the function converts the actual age of concrete correctly at a specific reference temperature. Additionally, this function also considers the cement activation energy that influences the initial hydration kinetics temperature.

$$te(T_{ref}) = \sum_{0}^{t} exp(\frac{Ea}{R}(\frac{1}{273 + T_{ref}} - \frac{1}{273 + T})\Delta t$$

where:

- te(Tref) is the equivalent age at the reference temperature that is usually assumed to be 20 °C.
- The actual time interval is Delta t .
- T is the average concrete temperature during interval Delta t.
- Ea is the apparent activation energy in J/mol .
- R is the universal gas constant (8.3144 J/mol/K)". (Maturity Approach Applied to Concrete by Means of Vicat Tests, 2008, p. 446)[6].

The maturity method follows a proper procedure to evaluate the in-place compressive strength where :

1. The Possible relationship between the strength and maturity should be determined for the concrete mixture used in the project.
2. Monitor the test specimen's temperature history using temperature probes embedded in one or more of the cylinders.
3. Measure the compressive strength of test cylinders at different ages that will be used later to obtain the maturity function.

4. The temperature history should be recorded using a specified machine at the locations where exposure conditions are critical.

5. Evaluate the maturity index based on the recorded temperature and age of concrete.

6. Finally, the strength in-place can be determined from the estimated maturity index and the obtained strength-maturity relationship.

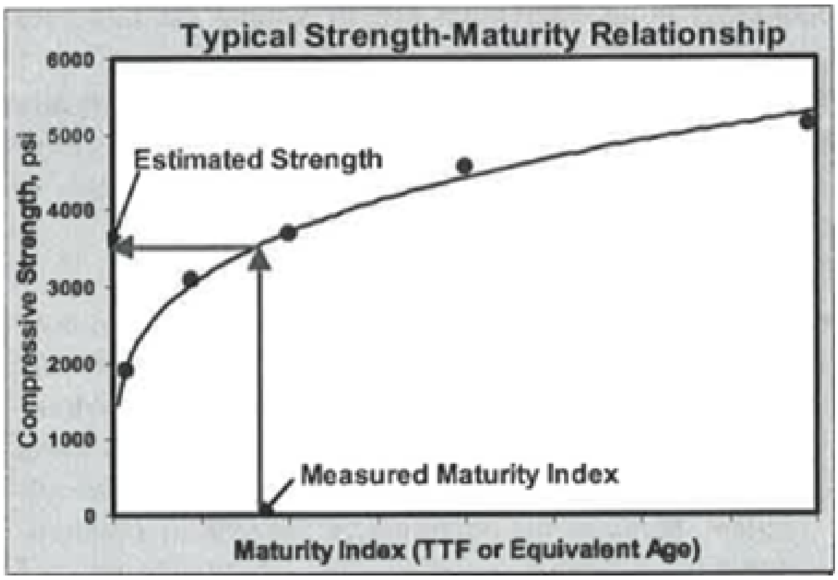



**Figure 2.18:** Typical Strength-Maturity Relationship

There are some limitations in the maturity test that can lead to a wrong estimation of the in-place compressive strength, such as :

- The concrete material observed in the structure does not correspond to the one used in the calibration lab test because of different materials used, air content, and more.

- The appearance of high early temperature ages will lead to incorrect results in terms of long-term strength.

- Concrete must be correctly cured, consolidated, and placed to allow the suitable cement hydration process.

- Finally, the use of in-correct temperature that not correctly considered a representative for the concrete .

In conclusion, this test is defined as a relationship between temperature, time, and strength represented by index value obtained at the site in real-time.Furthermore, this test has a significant advantage in estimating the strength in-site easily and quickly.

## 2.8 Pull-Off Resistance Methods

This test has been developed in the 70s to evaluate the strength of concrete in-site.The Pull off test measures the tensile force required to pull a disc bonded to the concrete surface with an epoxy or polyester resin. In addition to that, the test can estimate the concrete's resistance and verify the adhesion strength of the repairing material.
This technique is efficiently effective for beams and slabs and observes an appropriate application in the short section's structural elements.The given provided force can indicate the compressive and tensile force of concrete material using empirical charts.

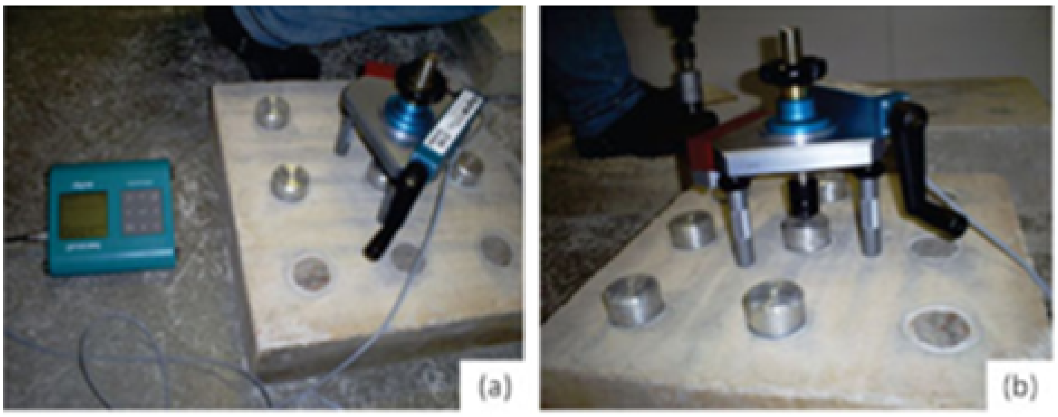



**Figure 2.19:** Pull Off Testing Equipment

The Pull-off strength can be evaluated by dividing the tensile force that causes failure over the disc area, and by using some empirical correlations, the compressive strength can be obtained. This test can be beneficial due to its simplicity and can be applied to various structural conditions where its efficiency is affected by aggregate size and quality.

The testing equipment consist of :

- Metal test disc.
- Draw bolt.

- Core drill.
- Epoxy.
- Jack.

The load and location of the failure are recorded directly using a specified measuring instrument.

Many factors affect the results obtained from this test, such as:

1. Concrete properties.
2. The position and orientation of aggregates onto the disc.
3. The type of disc material.
4. The thickness and diameter of the disc.
5. The speed load application.

The strength is directly proportional to the pull-off force, and by the relationship between force and compressive strength, the in-situ concrete's compressive strength can be determined. Some limitations should be respected during the test, such as it is not recommended to apply the test when the aggregates size greater than 38 mm . Additionally, this test requires special attention when the inserts are placed to reduce the air voids under the disc.

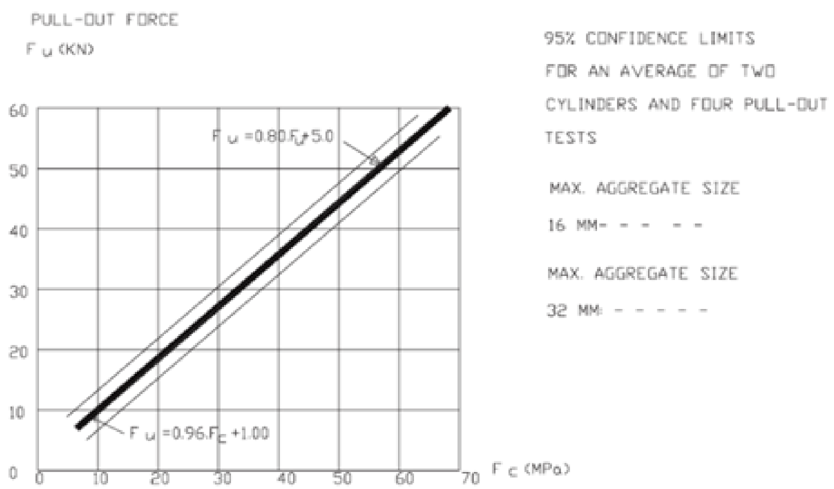



**Figure 2.20:** Pull-off Compressive strength Relationship

The holes that appear in concrete during the test are firstly cleaned from dust by a blower. After that, using epoxy glue, it will be primed. Finally, the hole will be filled with modified mortar, and the surface should be smoothed.

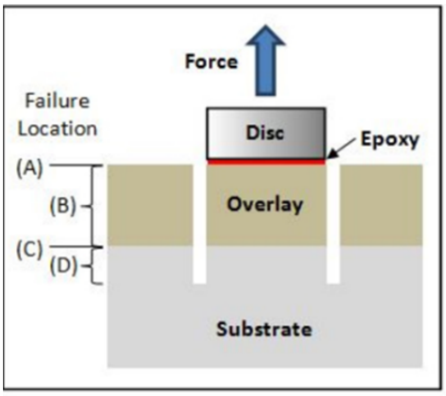



**Figure 2.21:** Concrete Pull-Off Testing Schematic and Failure Planes

# Chapter 3

# Strength-for-Age Curves

The compressive strength of concrete is the main parameter for performing any structural analysis of an existing structure, so this parameter should be correctly defined through either destructive or Non-destructive methods.

The analysis of concrete building structures build in a seismic zone should aims to:

- Improve structural safety to raise its mechanical properties.
- Improve the vulnerability to have a complete view of the destructive phenomena.

In the first case, the structural analysis is carried out based on verifying that the design effects are lower than the design strength. Thus, to estimate the design strength, concrete material's compressive strength is the main parameter to be evaluated through either destructive or non-destructive tests. The compression test performed on the extracted cores is usually considered the most reliable method to evaluate the compressive strength. However, when compression tests cannot be carried out, other indirect estimations through non-destructive techniques can be performed, such as the UPV method. In some cases, such as in a large-scale analysis, especially for historical buildings, the compressive strength is not obtained via tests but evaluated through indirect measurement methods such as the use of strength curves. The strength curve for the existing structure is created based on the collected, stored data of the performed test after 28 days of casting.

Fantilli et al. use the data stored in the Politecnico di Torino university laboratory to construct age-strength curves. They follow accurate statistical techniques to construct the strength for age-curve that will be shown in the following: "Firstly, the compressive test's collected data is plotted in a histogram for the years 1935,1955,1975, and 2002.

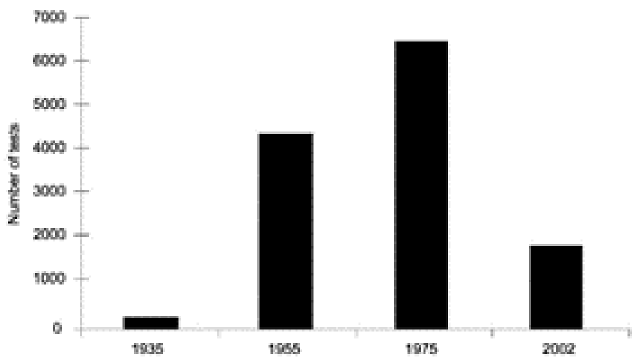



**Figure 3.1:** Number of Compression test performed in Politecnico lab during specified years

Once the number of strength values is large enough, statistical analysis has been carried out each year. Then, the strength value evaluated for each year has been divided into 20 different groups that range from 0 to 100 MPa. Finally, for each set, the density probability (fi) has been estimated.

$$f_i = \frac{n_i}{n}$$

Where:

- n is the number of the tests performed in a single year.
- ni is the number of tests whose strength can be included in the i-th group .

| Rc (MPa) | 1935 | | 1955 | | 1975 | | 2002 | |
|---|---|---|---|---|---|---|---|---|
| | Gauss | Real | Gauss | Real | Gauss | Real | Gauss | Real |
| **σ** | 9.89 | | 8.73 | | 13.19 | | 11.88 | |
| Minimum | | 1.23 | | 2.79 | | 3.18 | | 8.83 |
| 5% Percentile | 2.06 | 5.97 | 6.46 | 8.76 | 12 | 14.33 | 23.97 | 27.94 |
| 25% Percentile | 11.66 | 11.03 | 14.94 | 14.33 | 24.81 | 23.89 | 35.5 | 36.02 |
| μ | 18.33 | 18.33 | 20.82 | 20.82 | 33.7 | 33.7 | 43.51 | 43.51 |
| 75% Percentile | 25 | 22.78 | 26.7 | 25.88 | 42.6 | 42.21 | 51.52 | 48.75 |
| 95% Percentile | 34.61 | 39.1 | 35.18 | 37.03 | 55.41 | 56.71 | 63.06 | 67.37 |
| Maximum | | 54.55 | | 101.94 | | 91.58 | | 127.05 |
| Median | | 15.97 | | 19.57 | | 32.65 | | 42.022 |

**Figure 3.2:** Statistical analysis Results

The distribution of the probability density of the analyzed year has been evaluated and plotted in the following diagrams.
Furthermore, the mean and standard deviation has also been calculated.

The table summarizes the mean value and standard deviation calculated and summarizes the maximum and minimum compressive strength values. Additionally, the median and percentiles of the normal and real distributions, respectively, have been reported.

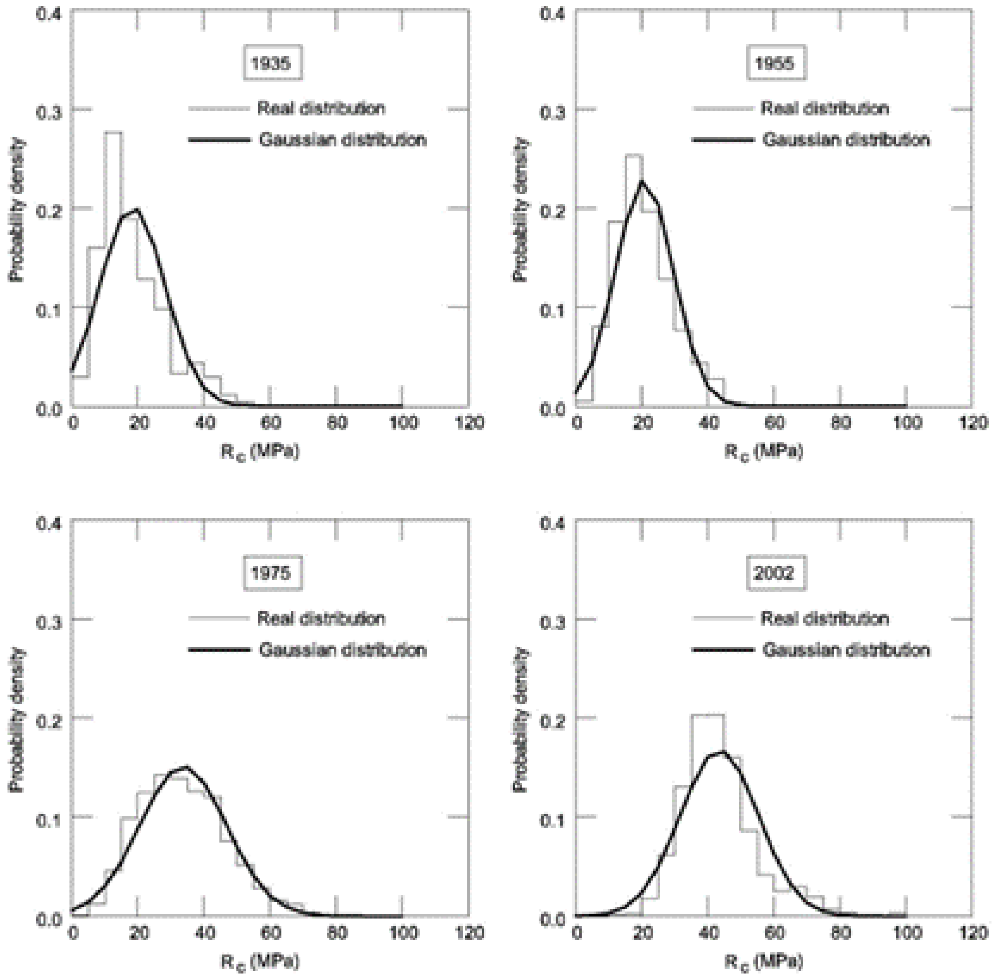



**Figure 3.3:** Probability density distributions as a function of the compression tests

Finally, the strength for age-curve in the case of Gaussian and real distributions

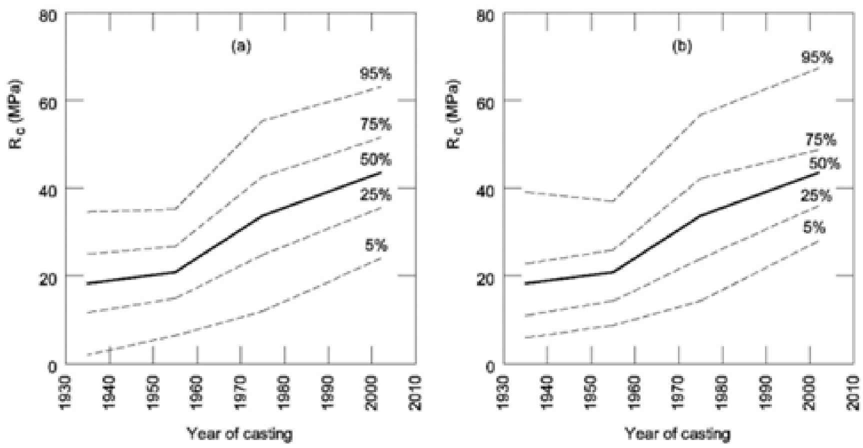



**Figure 3.4:** The "Strength Curves" evaluated in case of Gaussian (a) and real (b) distributions.

of probability density has been constructed through plotting the value of Rc obtained as a function of the casting years." (Fantilli et al.,2015)[7]

# Chapter 4

# Comparing Test data and the Strength-for-Age Curves

Many destructive and non-destructive tests are carried out over the years to evaluate concrete's compressive strength correctly. This parameter is defined to provide us the exact properties of the concrete material where the engineering judgments and the necessary actions are taken based on the obtained results.
In this chapter, the test results of a Compression test, Rebound test, SonReb test, and more carried out for various structural constructions constructed in different years are collected from some trusted lab's stored data. These tests are carried out by following and respecting the regulations and the requirements of the standards used. After that, the obtained results are plotted in the strength for age curves to compare and study such a curve's possible use.

## 4.1 Data Collection

The work starts by collecting the test stored data over the years from several trusted labs where various construction sites are considered, such as :

- Hospital building constructed in Genova 1930.
- School Building has been built in Turin, Piedmont region 1981.
- Commercial building in Turin 1953.

Furthermore, different structures are also considered, and the test results and the company that made the test are known, but it will not be mentioned since it is confidential data that cannot be shared.
The Results of the Non-destructive data and the results obtained by the Strength

curve will be compared with the data obtained by the compression test to study the possible use of such a curve. Furthermore, the reliability and the percentage of errors will be calculated following the least square method.
(As a note, All the test results are summarized and shown in the Appendix-Tables chapter without mentioning the structure's exact name and locations).

## 4.2 Plotting the data in Strength-for-Age Curve

The data has been classified according to the type of applied test to three main categories :

1. Compression Test.

2. Rebound Hammer Test.

3. SonReb Test.

The test results are plotted in the strength-for-age curves to observe and analyze the obtained results.

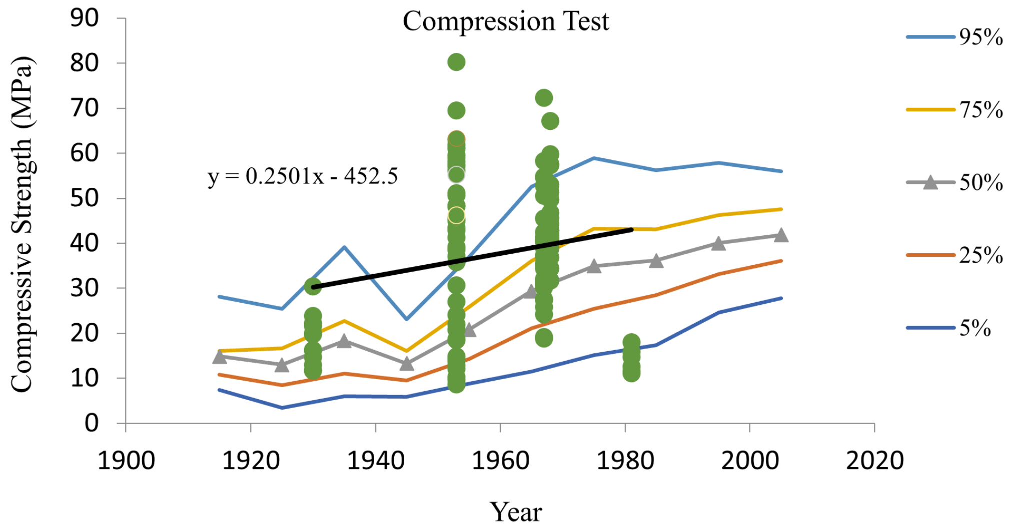



**Figure 4.1:** Variations of Compression Test Results as a function of Construction years

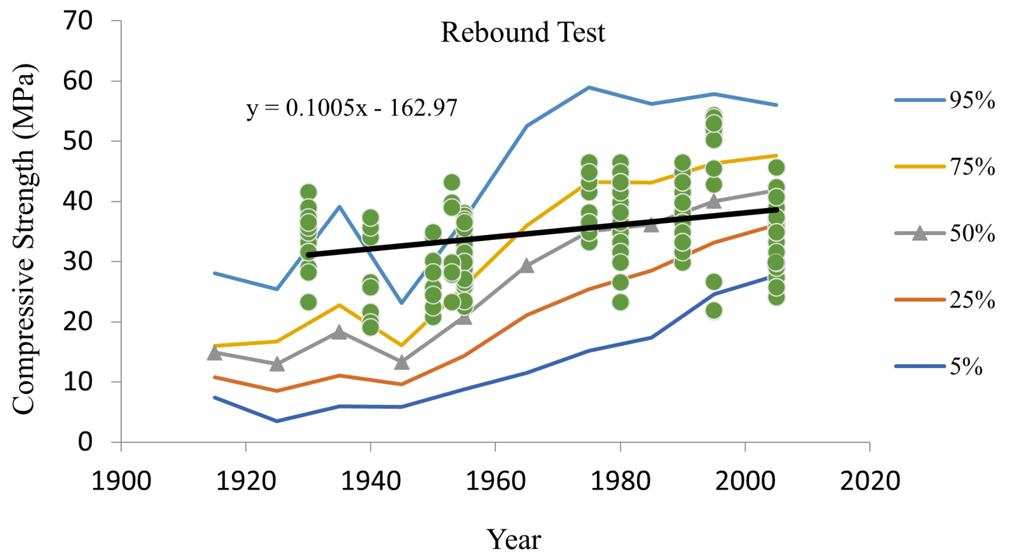



**Figure 4.2:** Variations of Rebound Hammer Test Results as a function of Construction years

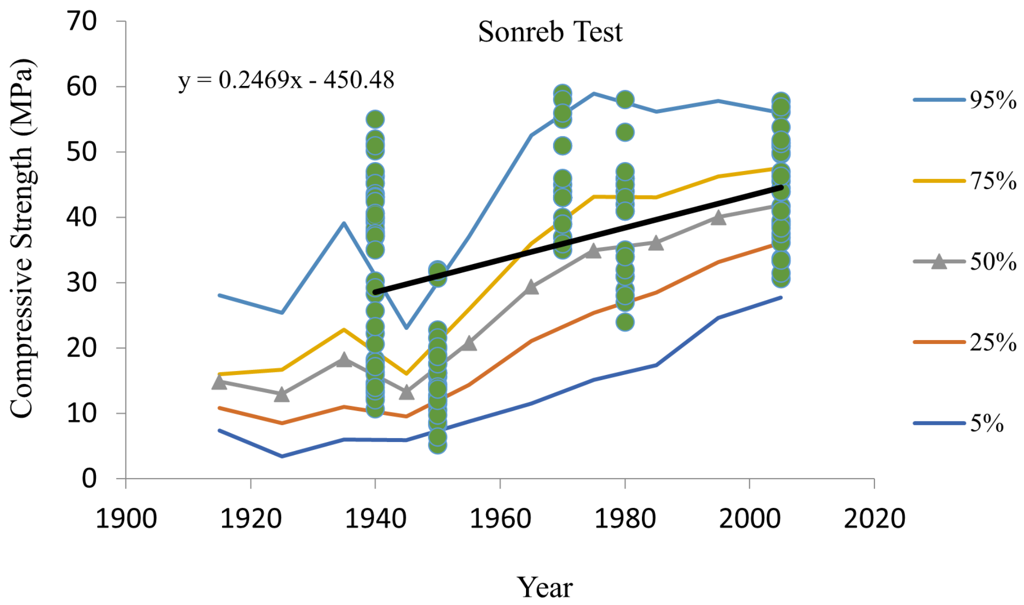



**Figure 4.3:** Variations of SonReb Test Results as a function of Construction years

## 4.3 Data Collection and Plotting of the Selected Structure

Three different structures constructed at a different decade are selected in order to make a reliable comparison. After that, the average values of test results are evaluated, and then the data are plotted in the strength for age curves. Finally, the standard error has been estimated to understand the reliability of using such a curve.

| Construction Year | Test Type | Element Name | Test Date | Strength (MPa) |
|---|---|---|---|---|
| 1930 | Compression | P001 | 14/11/2014 | 13 |
| 1930 | Compression | P002 | 14/11/2014 | 11.8 |
| 1930 | Compression | P003 | 14/11/2014 | 16.3 |
| 1930 | Compression | P004 | 14/11/2014 | 19.8 |
| 1930 | Compression | T1 | 14/11/2014 | 16.3 |
| 1930 | Compression | P1 | 14/11/2014 | 30.4 |
| 1930 | Compression | P2 | 14/11/2014 | 22.2 |
| 1930 | Compression | P9 | 14/11/2014 | 23.8 |
| 1930 | Compression | P10 | 14/11/2014 | 21.6 |
| 1930 | Compression | P201 | 14/11/2014 | 20 |
| 1930 | Compression | P202 | 14/11/2014 | 11.7 |
| 1930 | Compression | P204 | 14/11/2014 | 14.7 |
| | | | **Average** | **18.5** |
| 1953 | Compression | S04-08 | 2/2/2019 | 13.9 |
| 1953 | Compression | S04-13 | 2/2/2019 | 9.7 |
| 1953 | Compression | S04-16 | 2/2/2019 | 14.9 |
| 1953 | Compression | S04-01 | 2/2/2019 | 15.8 |
| 1953 | Compression | S04-02-B | 2/2/2019 | 20.8 |
| 1953 | Compression | S04-17 | 2/2/2019 | 22.3 |
| 1953 | Compression | S04-02-A | 2/2/2019 | 18.5 |
| 1953 | Compression | S04-15 | 2/2/2019 | 19.3 |
| 1953 | Compression | S04-03 | 2/2/2019 | 14.1 |
| 1953 | Compression | S04-05 | 2/2/2019 | 12.1 |
| 1953 | Compression | S04-04 | 2/2/2019 | 12.6 |
| 1953 | Compression | S04-14 | 2/2/2019 | 12.8 |

| Construction Year | Test Type | Element Name | Test Date | Strength (MPa) |
|---|---|---|---|---|
| 1953 | Compression | S04-27 | 2/2/2019 | 12.8 |
| 1953 | Compression | S04-24 | 2/2/2019 | 17.9 |
| 1953 | Compression | S04-25 | 2/2/2019 | 12.8 |
| 1953 | Compression | S04-32 | 2/2/2019 | 14 |
| 1953 | Compression | S04-26 | 2/2/2019 | 16 |
| 1953 | Compression | S04-26 | 2/2/2019 | 16 |
| 1953 | Compression | S04-28 | 2/2/2019 | 11.3 |
| 1953 | Compression | S04-20 | 2/2/2019 | 13.2 |
| 1953 | Compression | S04-34 | 2/2/2019 | 18.7 |
| 1953 | Compression | S04-33 | 2/2/2019 | 16 |
| 1953 | Compression | S04-19 | 2/2/2019 | 17.3 |
| 1953 | Compression | S04-23 | 2/2/2019 | 16.4 |
| 1953 | Compression | S04-22 | 2/2/2019 | 17.8 |
| 1953 | Compression | S04-21 | 2/2/2019 | 15.9 |
| 1953 | Compression | S04-07 | 2/2/2019 | 14.6 |
| 1953 | Compression | S04-10 | 2/2/2019 | 17.3 |
| 1953 | Compression | S04-31 | 2/2/2019 | 17 |
| 1953 | Compression | S04-06 | 2/2/2019 | 15.8 |
| 1953 | Compression | S04-09 | 2/2/2019 | 16.8 |
| 1953 | Compression | S04-30 | 2/2/2019 | 15.1 |
| 1953 | Compression | S04-12 | 2/2/2019 | 17.6 |
| | | | **Average** | **15.7** |
| 1981 | Compression | GF column 27 | 15/7/2014 | 24 |
| 1981 | Compression | GF column 24 | 15/7/2014 | 26.4 |
| 1981 | Compression | GF column 14 | 15/7/2014 | 18.9 |
| 1981 | Compression | B column 14 | 15/7/2014 | 27.3 |
| 1981 | Compression | B column 24 | 15/7/2014 | 22.6 |
| 1981 | Compression | B column 16 | 15/7/2014 | 24.9 |
| | | | **Average** | **24** |

**Table 4.1:** Compression Test Results

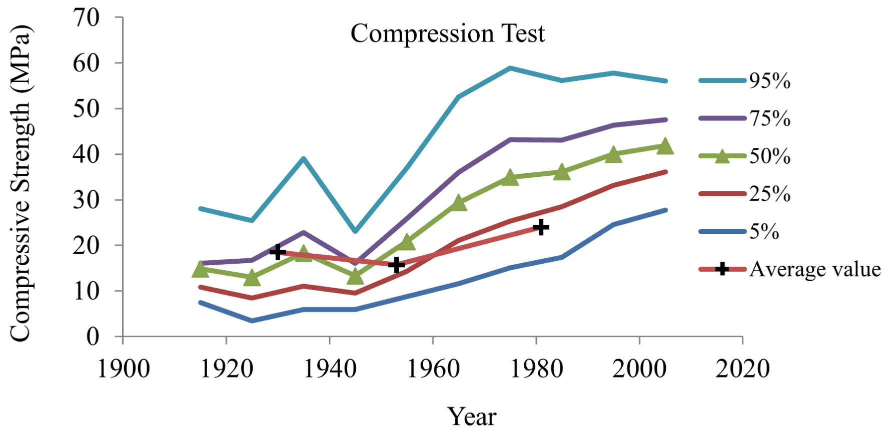



**Figure 4.4:** Average value of Compression Test Results as a function of Construction years

| Construction Year | Test Type | Element Name | Test Date | Strength (MPa) |
|---|---|---|---|---|
| 1930 | Rebound | P001 | 14/11/2014 | 18 |
| 1930 | Rebound | P002 | 14/11/2014 | 15.8 |
| 1930 | Rebound | P003 | 14/11/2014 | 13.7 |
| 1930 | Rebound | P004 | 14/11/2014 | 19.1 |
| 1930 | Rebound | T1 | 14/11/2014 | 17.3 |
| 1930 | Rebound | P1 | 14/11/2014 | 14.4 |
| 1930 | Rebound | P2 | 14/11/2014 | 15.8 |
| 1930 | Rebound | P9 | 14/11/2014 | 14.9 |
| 1930 | Rebound | P10 | 14/11/2014 | 18.4 |
| 1930 | Rebound | P201 | 14/11/2014 | 17.3 |
| 1930 | Rebound | P202 | 14/11/2014 | 15.4 |
| 1930 | Rebound | P204 | 14/11/2014 | 11.9 |
| | | | **Average** | **16** |
| 1953 | Rebound | S04-08 | 2/2/2019 | 17.1 |
| 1953 | Rebound | S04-13 | 2/2/2019 | 15.6 |
| 1953 | Rebound | S04-16 | 2/2/2019 | 17 |

| Construction Year | Test Type | Element Name | Test Date | Strength (MPa) |
|---|---|---|---|---|
| 1953 | Rebound | S04-01 | 2/2/2019 | 16.9 |
| 1953 | Rebound | S04-02-B | 2/2/2019 | 22.4 |
| 1953 | Rebound | S04-17 | 2/2/2019 | 24.7 |
| 1953 | Rebound | S04-02-A | 2/2/2019 | 19.3 |
| 1953 | Rebound | S04-15 | 2/2/2019 | 14.2 |
| 1953 | Rebound | S04-03 | 2/2/2019 | 14.8 |
| 1953 | Rebound | S04-05 | 2/2/2019 | 15.8 |
| 1953 | Rebound | S04-04 | 2/2/2019 | 16.4 |
| 1953 | Rebound | S04-14 | 2/2/2019 | 15.8 |
| 1953 | Rebound | S04-27 | 2/2/2019 | 17.8 |
| 1953 | Rebound | S04-24 | 2/2/2019 | 16.8 |
| 1953 | Rebound | S04-25 | 2/2/2019 | 16.9 |
| 1953 | Rebound | S04-32 | 2/2/2019 | 17.8 |
| 1953 | Rebound | S04-26 | 2/2/2019 | 19.2 |
| 1953 | Rebound | S04-28 | 2/2/2019 | 18.7 |
| 1953 | Rebound | S04-20 | 2/2/2019 | 17.3 |
| 1953 | Rebound | S04-34 | 2/2/2019 | 19.4 |
| 1953 | Rebound | S04-33 | 2/2/2019 | 17.4 |
| 1953 | Rebound | S04-19 | 2/2/2019 | 17.8 |
| 1953 | Rebound | S04-23 | 2/2/2019 | 18.4 |
| 1953 | Rebound | S04-22 | 2/2/2019 | 19.8 |
| 1953 | Rebound | S04-21 | 2/2/2019 | 23.6 |
| 1953 | Rebound | S04-07 | 2/2/2019 | 17.8 |
| 1953 | Rebound | S04-10 | 2/2/2019 | 19.5 |
| | | | **Average** | **18** |
| 1981 | Rebound | GF column 27 | 15/7/2014 | 29.7 |

| Construction Year | Test Type | Element Name | Test Date | Strength (MPa) |
|---|---|---|---|---|
| 1981 | Rebound | GF column 24 | 15/7/2014 | 27.6 |
| 1981 | Rebound | GF column 14 | 15/7/2014 | 27.3 |
| 1981 | Rebound | B column 14 | 15/7/2014 | 28.4 |
| 1981 | Rebound | B column 24 | 15/7/2014 | 25.7 |
| 1981 | Rebound | B column 16 | 15/7/2014 | 29.2 |
| | | | **Average** | **28** |

**Table 4.2:** Rebound Test Results

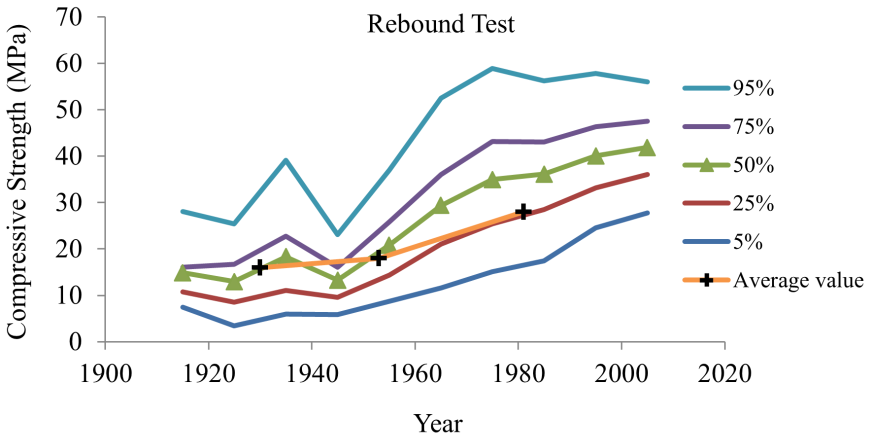



**Figure 4.5:** Average value of Rebound Test Results as a function of Construction years

| Construction Year | Test Type | Element Name | Test Date | Strength (MPa) |
|---|---|---|---|---|
| 1930 | SonReb | P001 | 14/11/2014 | 24.3 |
| 1930 | SonReb | P002 | 14/11/2014 | 19.5 |
| 1930 | SonReb | P003 | 14/11/2014 | 17.8 |
| 1930 | SonReb | P004 | 14/11/2014 | 21.4 |
| 1930 | SonReb | T1 | 14/11/2014 | 23.4 |
| 1930 | SonReb | P1 | 14/11/2014 | 25.7 |
| 1930 | SonReb | P2 | 14/11/2014 | 20.4 |
| 1930 | SonReb | P9 | 14/11/2014 | 21.6 |

| Construction Year | Test Type | Element Name | Test Date | Strength (MPa) |
|---|---|---|---|---|
| 1930 | SonReb | P10 | 14/11/2014 | 23.7 |
| 1930 | SonReb | P201 | 14/11/2014 | 18.7 |
| 1930 | SonReb | P202 | 14/11/2014 | 22.7 |
| 1930 | SonReb | P204 | 14/11/2014 | 24.9 |
| | | | **Average** | **22** |
| 1953 | SonReb | S04-08 | 2/2/2019 | 12.4 |
| 1953 | SonReb | S04-13 | 2/2/2019 | 15.7 |
| 1953 | SonReb | S04-16 | 2/2/2019 | 19.3 |
| 1953 | SonReb | S04-01 | 2/2/2019 | 11.4 |
| 1953 | SonReb | S04-02-B | 2/2/2019 | 15.9 |
| 1953 | SonReb | S04-17 | 2/2/2019 | 17.3 |
| 1953 | SonReb | S04-02-A | 2/2/2019 | 12.8 |
| 1953 | SonReb | S04-15 | 2/2/2019 | 14.7 |
| 1953 | SonReb | S04-03 | 2/2/2019 | 15.9 |
| 1953 | SonReb | S04-05 | 2/2/2019 | 16.8 |
| 1953 | SonReb | S04-04 | 2/2/2019 | 19.3 |
| 1953 | SonReb | S04-14 | 2/2/2019 | 14.1 |
| 1953 | SonReb | S04-27 | 2/2/2019 | 13.8 |
| 1953 | SonReb | S04-24 | 2/2/2019 | 15.7 |
| 1953 | SonReb | S04-25 | 2/2/2019 | 17.8 |
| 1953 | SonReb | S04-32 | 2/2/2019 | 14.3 |
| 1953 | SonReb | S04-26 | 2/2/2019 | 18.6 |
| 1953 | SonReb | S04-28 | 2/2/2019 | 15.7 |
| 1953 | SonReb | S04-20 | 2/2/2019 | 14.9 |
| 1953 | SonReb | S04-34 | 2/2/2019 | 11.7 |
| 1953 | SonReb | S04-33 | 2/2/2019 | 12.8 |
| 1953 | SonReb | S04-19 | 2/2/2019 | 14.6 |
| 1953 | SonReb | S04-23 | 2/2/2019 | 15.8 |
| 1953 | SonReb | S04-22 | 2/2/2019 | 18.7 |
| 1953 | SonReb | S04-21 | 2/2/2019 | 17.8 |

| Construction Year | Test Type | Element Name | Test Date | Strength (MPa) |
|---|---|---|---|---|
| 1953 | SonReb | S04-07 | 2/2/2019 | 19.3 |
| 1953 | SonReb | S04-10 | 2/2/2019 | 22.1 |
| 1953 | SonReb | S04-31 | 2/2/2019 | 20.4 |
| 1953 | SonReb | S04-06 | 2/2/2019 | 14.8 |
| 1953 | SonReb | S04-09 | 2/2/2019 | 15.3 |
| 1953 | SonReb | S04-30 | 2/2/2019 | 14.3 |
| 1953 | SonReb | S04-12 | 2/2/2019 | 17.4 |
| | | | **Average** | **15.98** |
| 1981 | SonReb | GF column 27 | 15/7/2014 | 36.8 |
| 1981 | SonReb | GF column 24 | 15/7/2014 | 33.1 |
| 1981 | SonReb | GF column 14 | 15/7/2014 | 31.9 |
| 1981 | SonReb | B column 14 | 15/7/2014 | 37.6 |
| 1981 | SonReb | B column 24 | 15/7/2014 | 31.1 |
| 1981 | SonReb | B column 16 | 15/7/2014 | 33.6 |
| | | | **Average** | **34** |

**Table 4.3:** SonReb Test Results

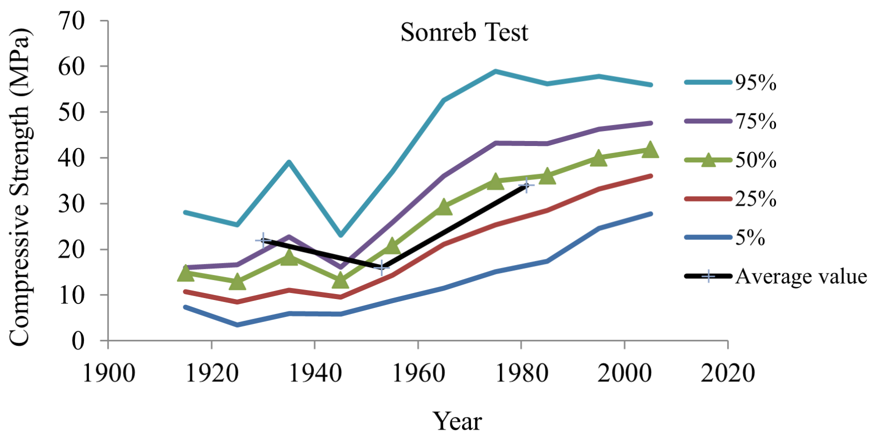



**Figure 4.6:** Average value of SonReb Test Results as a function of Construction years

## 4.4 Analysis of the Data

Firstly, the collected data of Rebound and SonReb tests are plotted as a function of their construction years to make a comparison with our reference strength data that are represented by DT results.
In the following graphs, the average strength values have been evaluated and plotted to see the evolution of fc results concerning time.

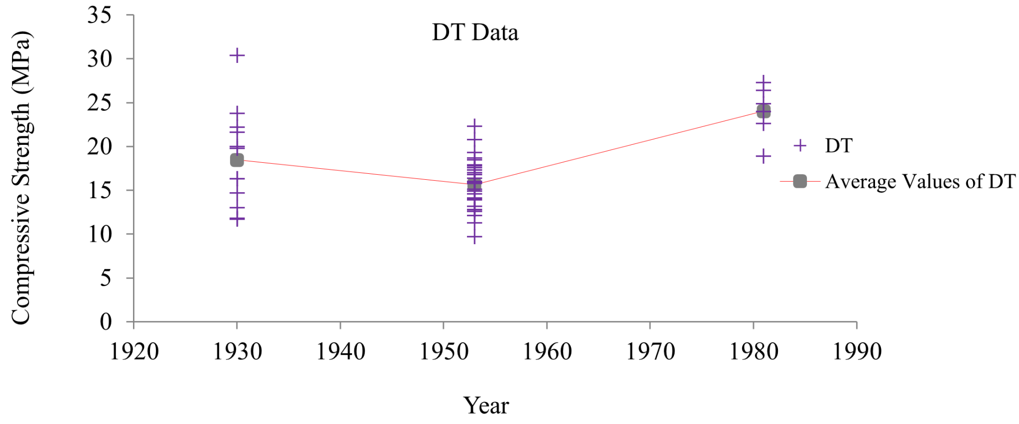



**Figure 4.7:** Variations of collected DT Data

The curve of strength with years are reported in Fig 4.8,4.9, and 4.10 where the results obtained with the three types of NDT are reported respectively.

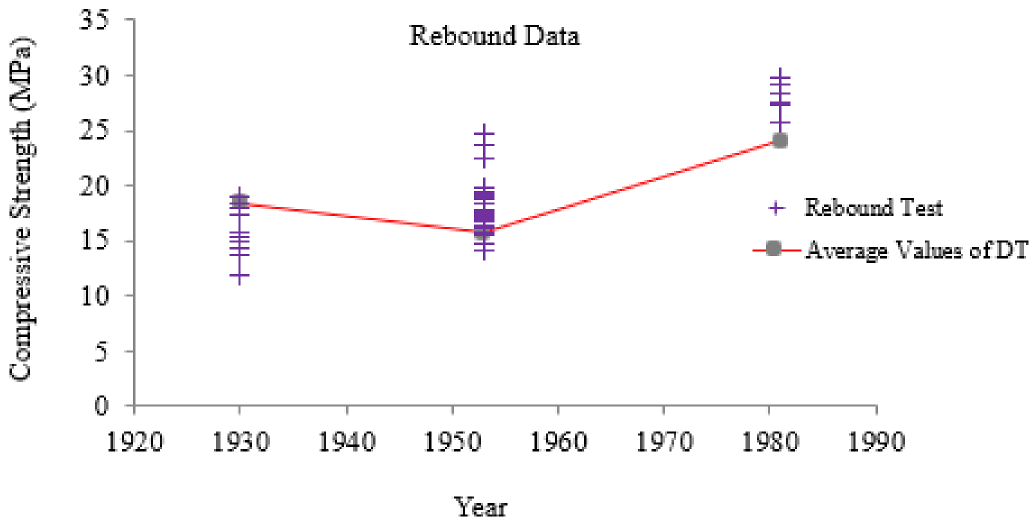



**Figure 4.8:** Variations of collected Rebound Data

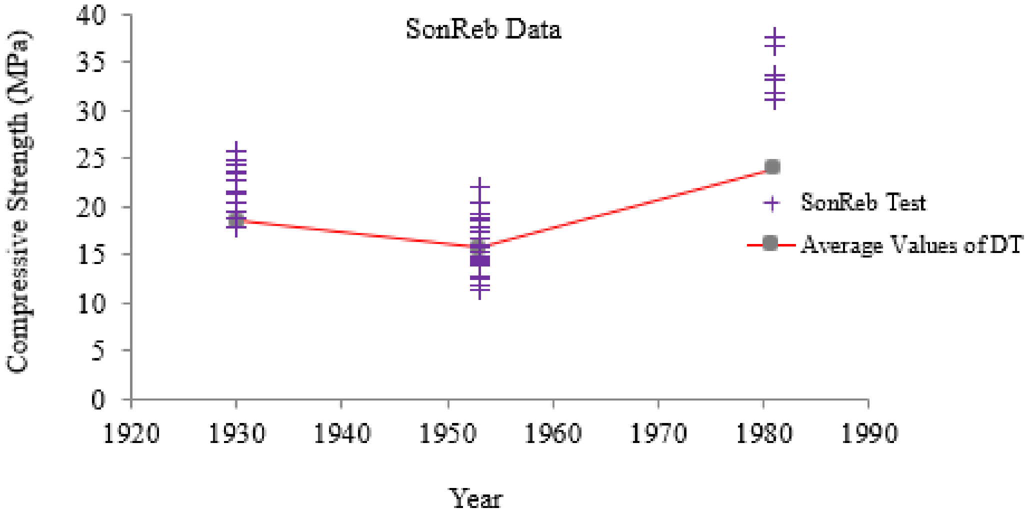



**Figure 4.9:** Variations of collected SonReb Data

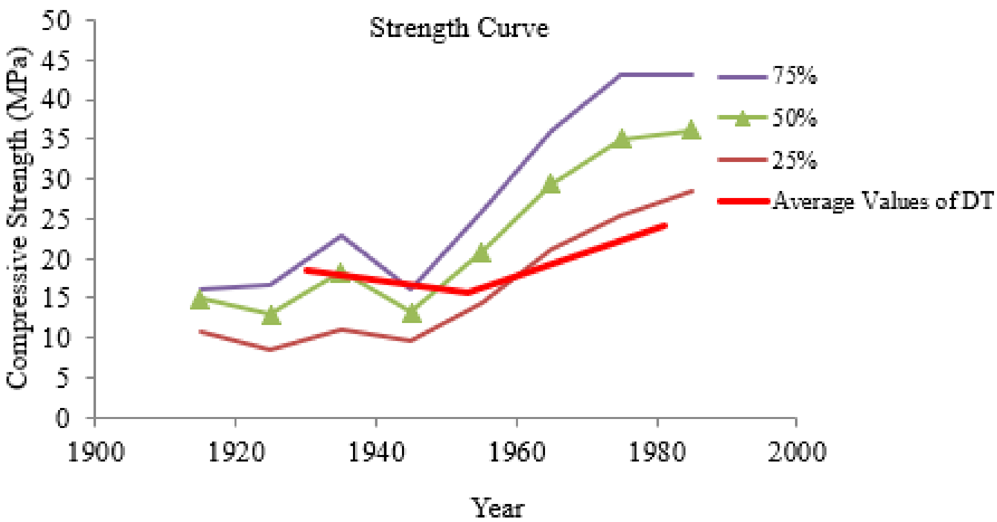



**Figure 4.10:** Variations of Strength Curve values for selected years

Concerning the average DT results, the strength values could be overestimated as shown in the results of the Rebound test for the structure constructed in 1930 or underestimated such as the SonReb test results for the structure constructed in 1981.
Thus, it is important to have a multi-parameter analysis to select the best type of NDT.

### 4.4.1 Prediction Reliability,Cost and Representativity of NDT

To define the best NDT ,it is necessary to anaylze them with respect to three main properties:

1. Prediction Reliability.
2. Cost.
3. Test Representativity.

Reliability is defined as the consistency of the measurement. A test can be called reliable when the results are exactly repeated under the same conditions.
Based on this definition, we calculate the standard error by applying the following equation.

$$StandardError = \frac{Rc(NDT) - Rc(DT)}{Rc(DT)} \tag{4.1}$$

Where :

- Rc(DT) corresponds to the average value obtained for each year.

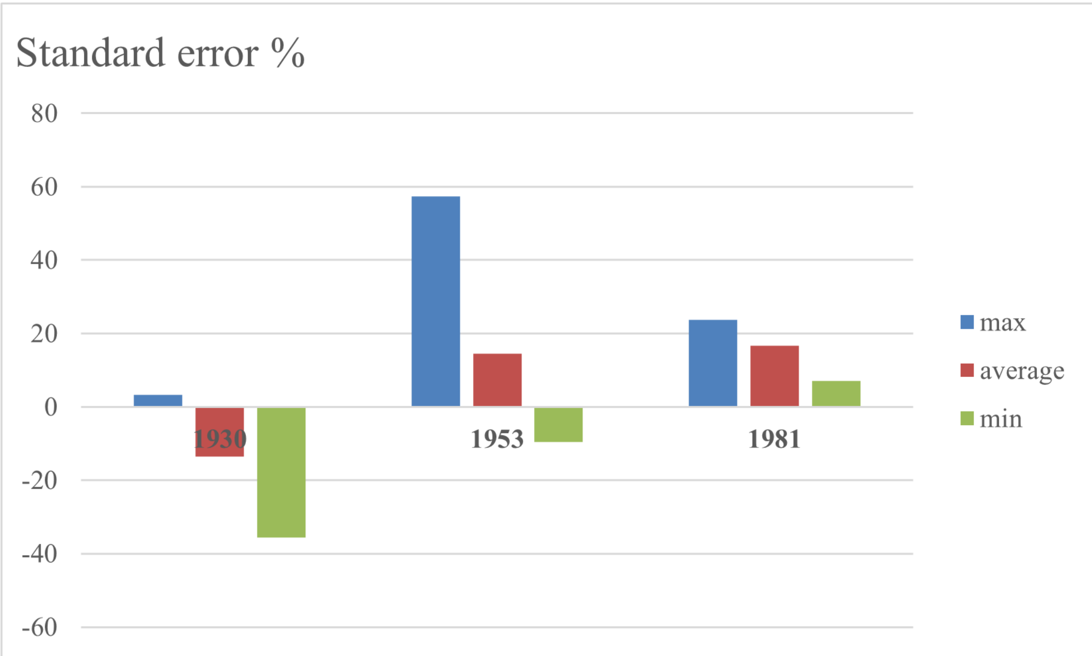



**Figure 4.11:** Standrad error variations between Rebound data and DT

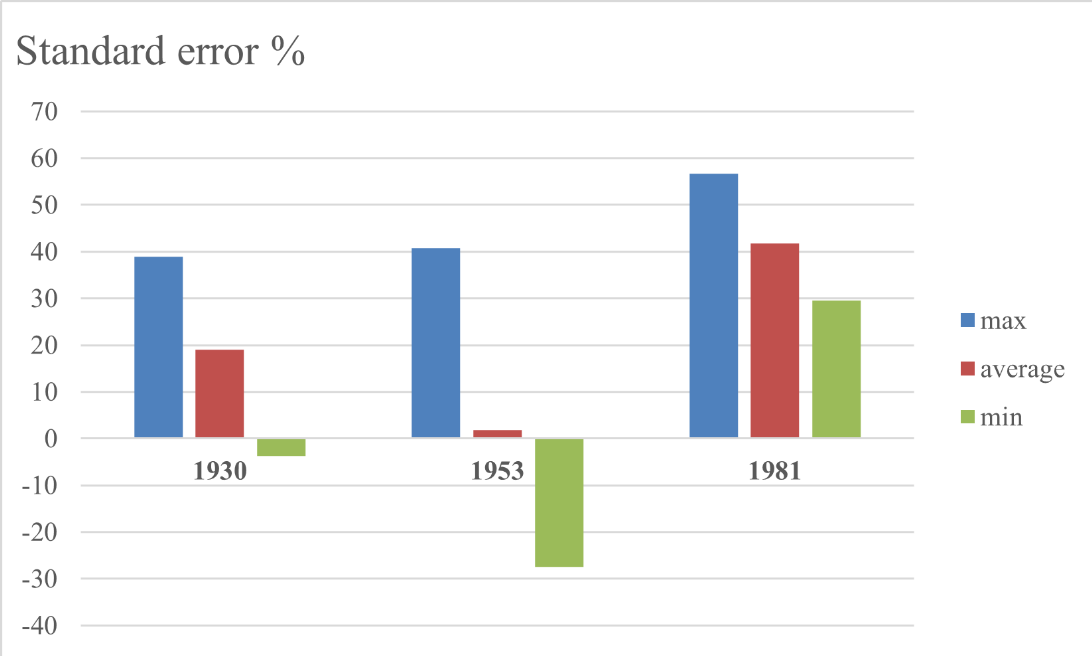



**Figure 4.12:** Standrad error variations between SonReb data and DT

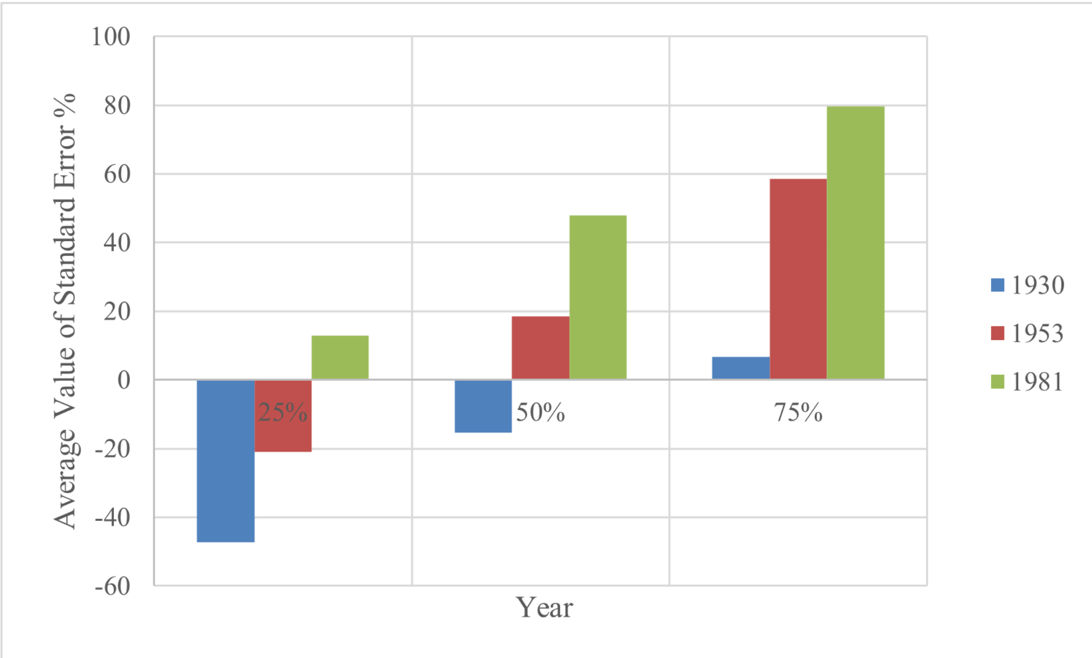



**Figure 4.13:** Standrad error variations between Strength Curve and DT

The obtained graphs show a variation in the results, concerning the DT data as the standard error calculated shows that the strength could be underestimated as shown in the case of (Rebound 1930) or overestimated such as the case of (SonReb 1981).
The results obtained by the strength curve especially for the structure constructed in 1930 can be very useful results concerning DT.

Considering the advantages of using the strength curve especially for no cost and less time needed to obtain the results, the underestimated value obtained for compressive strength can be considered as a good approximation in the design process.

According to Politecnico di Torino lab, the following Table summarizes the costs of each different test.
The representative value of each different test are considered based on the correspondence characteristic of the applied test.

**Table 4.4:** Time,Cost and Represnetativity of the Tests

| Test Type | Cost x Test | Representativity | Time |
|---|---|---|---|
| Rebound | 50 € | 0.5 | 0.25 |
| SonReb | 180 € | 0.75 | 0.5 |
| DT | 150 € | 1 | 0 |
| Strength Curve | 0 € | 0.25 | 1 |

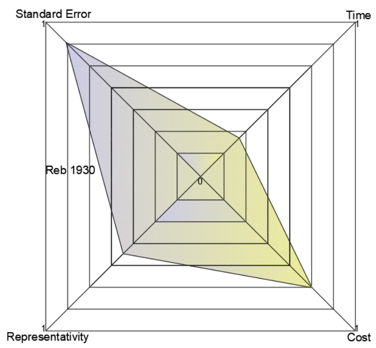
### 4.4.2 Discussion on Results

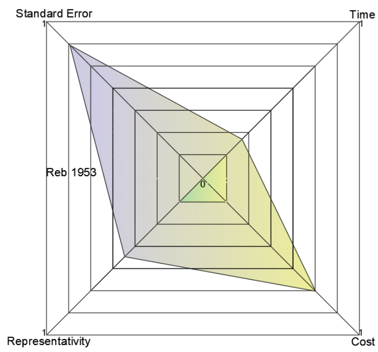
A Multi-parameter comparision among the NDT are applied where the following graphs are obtained.
The following table summarizes the area calculated for all different cases with respect to the optimal case that are characterized by (1,0,0,0)(0,1,0,0)(0,0,1,0)(0,0,0,1) coordinates where x,y,z and k corresponds to Test Repesentativity,Cost,Standard error and Time,respectively.
The following graphs show, Firstly the rebound test covers a good area in comparison with the optimal case, this means that the rebound test can be used if we have a little budget to spend.
On the contrary, the SonReb Method shows a low performance especially due to cost which is higher than Rebound and Strength for ages curves and this method is preferable for only one structure due to the high cost of application.
Finally, the strength curves show the best results as it covers the highest area, and

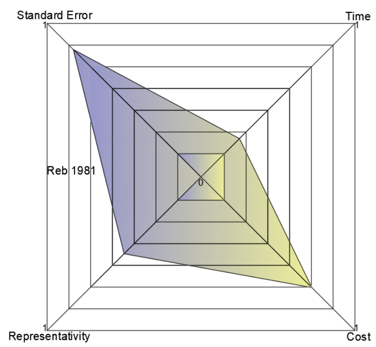
this method is preferable in case of a large number of buildings, Furthermore it is also preferable in terms of obtaining the results in less time .

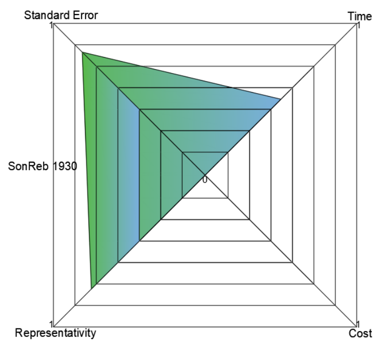
**Table 4.5:** Results Anaylsis

| Test Type | Year | Area optimal | Area | Ratio % |
|---|---|---|---|---|
| | 1930 | | 0.596 | 29.81 |
| Rebound | 1953 | | 0.589 | 29.44 |
| | 1981 | | 0.581 | 29.06 |
| | 1930 | | 0.506 | 25.31 |
| SonReb | 1953 | 2 | 0.613 | 30.63 |
| | 1981 | | 0.363 | 18.13 |
| | 1930 | | 0.956 | 47.81 |
| Strength Curve | 1953 | | 1.119 | 55.93 |
| | 1981 | | 1.165 | 58.26 |



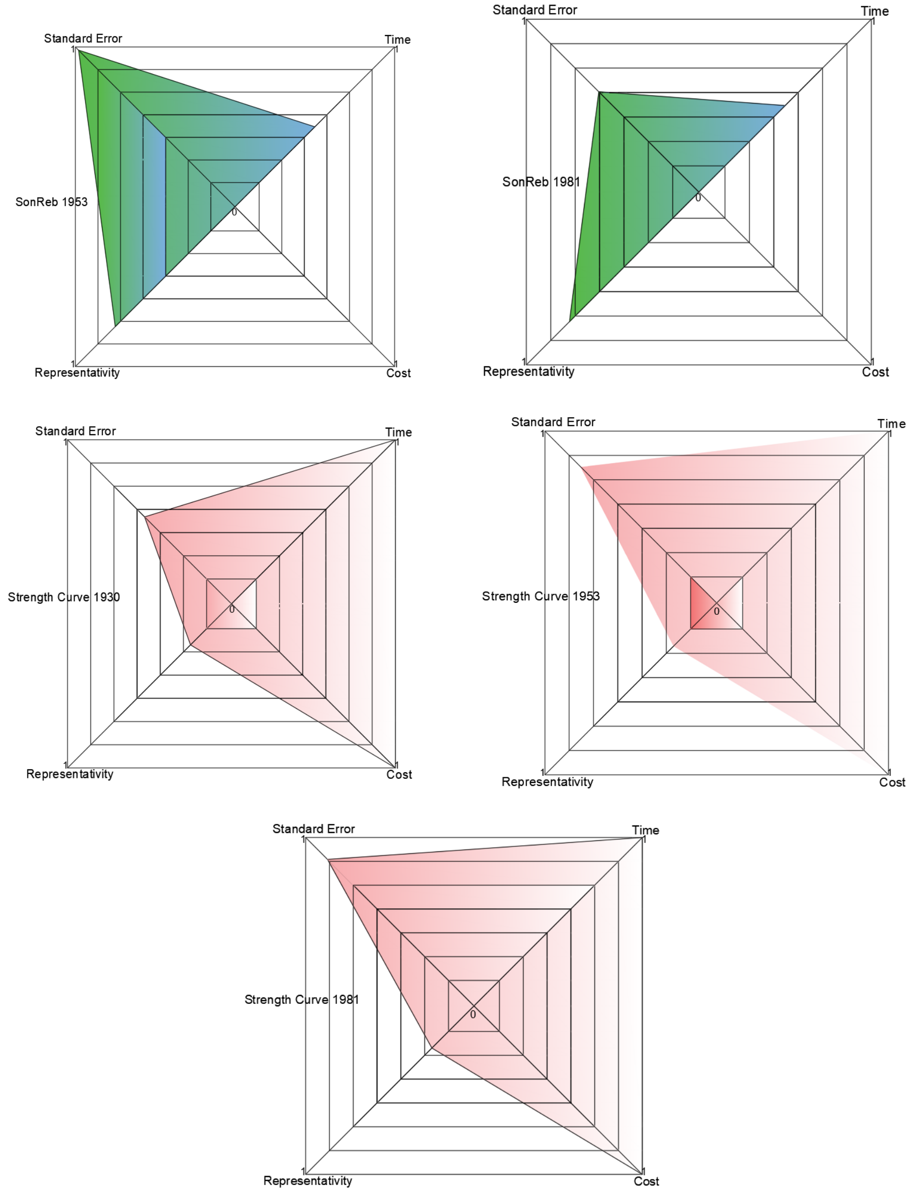



**Figure 4.14:** Multi-criteria comparison among NDT

# Chapter 5

# Conclusions

Destructive and non-destructive methods are the most reliable methods to estimate the compressive strength,However, in some cases, it is necessary to find another method to estimate this parameter, especially in a large-scale region, where the compressive strength is not obtained via test due to the difficulty and the high cost of performing the tests.
In such a case, the use of strength for age curves can be carried out where concrete strength is plotted as a function of the construction years.

It has been concluded from the analysis and comparsion of the experimental results obtained that :

- The stored test data in the trusted labs give beneficial information concerning the evolution of compressive strength data over the past years.
- It is also necessary to understand that the strength curve can be a helpful method for assessing the entire concrete structure, so if degradation phenomena are observed, correction factors are necessarily required to apply.

Thus, future studies should be devoted to the calibration of these correction factors to obtain the best possible results.

Finally, based on the selected structures, the following conclusions are observed :

- The structures built before the 2nd war have a higher strength in comparison with the new structure.It is mainly due to the use of old cement powders and large particles of aggregates size.
- However, after the 2nd war, the manufacturing technologies advanced, and the regulations specified our requirements and controlled the size of aggregates

and the cement powder used to achieve the necessary strength by avoiding economic losses.

Hence, the new building achieved the necessary compressive strength with a reliable economic value.

# Appendix A

# Appendix-Tables

| Construction years | Construction Site | Test Type | Structural element | Test Date | Compressive strength (MPa) |
|---|---|---|---|---|---|
| 1900-2000 | Industrial Factory | Sclerometer Test | Column 1 | 26/07/2017 | 51.6 |
| 1900-2000 | Industrial Factory | Sclerometer Test | Column 2 | 26/07/2017 | 61.7 |
| 1900-2000 | Industrial Factory | Sclerometer Test | Column 3 | 26/07/2017 | 61.7 |
| 1900-2000 | Industrial Factory | Sclerometer Test | Column 4 | 26/07/2017 | 65.5 |
| 1900-2000 | Industrial Factory | Sclerometer Test | Column 5 | 26/07/2017 | 62.1 |
| 1900-2000 | Industrial Factory | Sclerometer Test | Column 6 | 26/07/2017 | 63.4 |
| 1900-2000 | Industrial Factory | Sclerometer Test | Column 7 | 26/07/2017 | 72.8 |
| 1900-2000 | Industrial Factory | Sclerometer Test | Column 8 | 26/07/2017 | 65 |
| 1900-2000 | Industrial Factory | Sclerometer Test | Column 9 | 26/07/2017 | 60.9 |
| 1900-2000 | Industrial Factory | Sclerometer Test | Column 10 | 26/07/2017 | 54.8 |
| 1900-2000 | Industrial Factory | Sclerometer Test | Column 11 | 26/07/2017 | 62.1 |
| 1900-2000 | Industrial Factory | Sclerometer Test | Column 12 | 26/07/2017 | 62.5 |
| 1900-2000 | Industrial Factory | Sclerometer Test | Column 13 | 26/07/2017 | 60.5 |
| 1900-2000 | Industrial Factory | Sclerometer Test | Column 14 | 26/07/2017 | 75.9 |
| 1900-2000 | Industrial Factory | Sclerometer Test | Column 15 | 26/07/2017 | 63.8 |
| 1900-2000 | Industrial Factory | Sclerometer Test | Beam-Foundation 9-12 | 26/07/2017 | 26.1 |
| 1900-2000 | Industrial Factory | Sclerometer Test | Beam-Foundation 7-8 | 26/07/2017 | 32.1 |
| 1900-2000 | Industrial Factory | Sclerometer Test | Beam-Foundation 6-9 | 26/07/2017 | 26.4 |
| 1940 | Residential Building | Sclerometer Test | Column 1 | 18/12/2017 | 66 |
| 1940 | Residential Building | Sclerometer Test | Column 2 | 18/12/2017 | 56 |
| 1940 | Residential Building | Sclerometer Test | Column 3 | 18/12/2017 | 32 |
| 1940 | Residential Building | Sclerometer Test | Column 4 | 18/12/2017 | 43 |
| 1940 | Residential Building | Sclerometer Test | Column 5 | 18/12/2017 | 41 |
| 1940 | Residential Building | Sclerometer Test | Column 6 | 18/12/2017 | 45 |
| 1940 | Residential Building | Sclerometer Test | Column 7 | 18/12/2017 | 45 |
| 1940 | Residential Building | Sclerometer Test | Column 8 | 18/12/2017 | 32 |
| 1940 | Residential Building | Sclerometer Test | Column 9 | 18/12/2017 | 64 |
| 1940 | Residential Building | Sclerometer Test | Column 10 | 18/12/2017 | 64 |
| 1940 | Residential Building | Sclerometer Test | Column 11 | 18/12/2017 | 46 |
| 1940 | Residential Building | Sclerometer Test | Column 12 | 18/12/2017 | 64 |
| 1940 | Residential Building | Sclerometer Test | Column 13 | 18/12/2017 | 41 |
| 1940 | Residential Building | Sclerometer Test | Column 14 | 18/12/2017 | 43 |
| 1940 | Residential Building | Sclerometer Test | Column 15 | 18/12/2017 | 45 |
| 1940 | Residential Building | Sclerometer Test | Column 16 | 18/12/2017 | 64 |
| 1940 | Residential Building | Sclerometer Test | Column 17 | 18/12/2017 | 43 |
| 1940 | Residential Building | Sclerometer Test | Column 18 | 18/12/2017 | 45 |
| 1940 | Residential Building | Sclerometer Test | Column 19 | 18/12/2017 | 31 |
| 1940 | Residential Building | Sclerometer Test | Column 20 | 18/12/2017 | 68 |
| 2005 | Residential building | Windsor Probe Test | C 8 | 19/3/2019 | 56.1 |
| 2005 | Residential building | Sclerometer Test | C 1 | 19/3/2019 | 55 |
| 2005 | Residential building | Sclerometer Test | C 2 | 19/3/2019 | 47 |
| 2005 | Residential building | Sclerometer Test | C 3 | 19/3/2019 | 51 |
| 2005 | Residential building | Sclerometer Test | C 4 (Base) | 19/3/2019 | 45 |
| 2005 | Residential building | Sclerometer Test | C 5 (Top) | 19/3/2019 | 45 |
| 2005 | Residential building | Sclerometer Test | C 6 (Top) | 19/3/2019 | 45 |
| 2005 | Residential building | Sclerometer Test | C 7 (Base) | 19/3/2019 | 45 |
| 2005 | Residential building | Sclerometer Test | C 8 | 19/3/2019 | 47 |
| 2005 | Residential building | Sclerometer Test | C 9 | 19/3/2019 | 49 |

| Construction years | Construction Site | Test Type | Structural element | Test Date | Compressive strength (MPa) |
|---|---|---|---|---|---|
| 2005 | Residential building | Sclerometer Test | C 12 | 19/3/2019 | 38 |
| 2005 | Residential building | Sclerometer Test | C 13 | 19/3/2019 | 47 |
| 2005 | Residential building | Sclerometer Test | C 14 (Top) | 19/3/2019 | 33 |
| 2005 | Residential building | Sclerometer Test | C 15 (Base) | 19/3/2019 | 42 |
| 2005 | Residential building | Sclerometer Test | C 16 | 19/3/2019 | 36 |
| 2005 | Residential building | Sclerometer Test | C 18 | 19/3/2019 | 36 |
| 2005 | Residential building | Sclerometer Test | C 21 (Base) | 19/3/2019 | 44 |
| 2005 | Residential building | Sclerometer Test | C 22 | 19/3/2019 | 49 |
| 2005 | Residential building | Sclerometer Test | C 23 | 19/3/2019 | 40 |
| 2005 | Residential building | Sclerometer Test | C 24 | 19/3/2019 | 35 |
| 2005 | Residential building | Sclerometer Test | C 25 | 19/3/2019 | 35 |
| 2005 | Residential building | Sclerometer Test | C 27 | 19/3/2019 | 43 |
| 2005 | Residential building | Sclerometer Test | C 28 | 19/3/2019 | 36 |
| 2005 | Residential building | Sclerometer Test | C 29 | 19/3/2019 | 29 |
| 2005 | Residential building | Sclerometer Test | C 30 | 19/3/2019 | 29 |
| 2005 | Residential building | Sclerometer Test | C 32 | 19/3/2019 | 31 |
| 2005 | Residential building | Sclerometer Test | C 33 | 19/3/2019 | 42 |
| 2005 | Residential building | Sclerometer Test | C 34 | 19/3/2019 | 45 |
| 2005 | Residential building | Sclerometer Test | C 35 | 19/3/2019 | 36 |
| 2005 | Residential building | Sclerometer Test | C 37 | 19/3/2019 | 36 |
| 2005 | Residential building | Sclerometer Test | C 38 | 19/3/2019 | 36 |
| 2005 | Residential building | Sclerometer Test | C 39 | 19/3/2019 | 38 |
| 2005 | Residential building | Sclerometer Test | C 40 | 19/3/2019 | 42 |
| 2005 | Residential building | SonReb Method | C 1 | 19/3/2019 | 73.9 |
| 2005 | Residential building | SonReb Method | C 2 | 19/3/2019 | 50.9 |
| 2005 | Residential building | SonReb Method | C 3 | 19/3/2019 | 57.8 |
| 2005 | Residential building | SonReb Method | C 4 (Base) | 19/3/2019 | 51.5 |
| 2005 | Residential building | SonReb Method | C 5 (Top) | 19/3/2019 | 49.7 |
| 2005 | Residential building | SonReb Method | C 6 (Top) | 19/3/2019 | 51 |
| 2005 | Residential building | SonReb Method | C 7 (Base) | 19/3/2019 | 49.9 |
| 2005 | Residential building | SonReb Method | C 8 | 19/3/2019 | 56.1 |
| 2005 | Residential building | SonReb Method | C 9 | 19/3/2019 | 56.9 |
| 2005 | Residential building | SonReb Method | C 12 | 19/3/2019 | 41.7 |
| 2005 | Residential building | SonReb Method | C 13 | 19/3/2019 | 51.3 |
| 2005 | Residential building | SonReb Method | C 14 (Top) | 19/3/2019 | 33.7 |
| 2005 | Residential building | SonReb Method | C 15 (Base) | 19/3/2019 | 44.5 |
| 2005 | Residential building | SonReb Method | C 16 | 19/3/2019 | 38.8 |
| 2005 | Residential building | SonReb Method | C 18 | 19/3/2019 | 39.3 |
| 2005 | Residential building | SonReb Method | C 21 (Base) | 19/3/2019 | 47 |
| 2005 | Residential building | SonReb Method | C 22 | 19/3/2019 | 53.8 |
| 2005 | Residential building | SonReb Method | C 23 | 19/3/2019 | 43.9 |
| 2005 | Residential building | SonReb Method | C 24 | 19/3/2019 | 36.9 |
| 2005 | Residential building | SonReb Method | C 25 | 19/3/2019 | 36.1 |
| 2005 | Residential building | SonReb Method | C 27 | 19/3/2019 | 45.5 |
| 2005 | Residential building | SonReb Method | C 28 | 19/3/2019 | 39.1 |

| Construction years | Construction Site | Test Type | Structural element | Test Date | Compressive strength (MPa) |
|---|---|---|---|---|---|
| 2005 | Residential building | Sclerometer Test | C 29 | 19/3/2019 | 30.6 |
| 2005 | Residential building | Sclerometer Test | C 30 | 19/3/2019 | 31.5 |
| 2005 | Residential building | Sclerometer Test | C 32 | 19/3/2019 | 33.5 |
| 2005 | Residential building | Sclerometer Test | C 33 | 19/3/2019 | 44 |
| 2005 | Residential building | Sclerometer Test | C 34 | 19/3/2019 | 51.8 |
| 2005 | Residential building | Sclerometer Test | C 35 | 19/3/2019 | 39.5 |
| 2005 | Residential building | Sclerometer Test | C 37 | 19/3/2019 | 37.5 |
| 2005 | Residential building | Sclerometer Test | C 38 | 19/3/2019 | 38.4 |
| 2005 | Residential building | Sclerometer Test | C 39 | 19/3/2019 | 41 |
| 2005 | Residential building | Sclerometer Test | C 40 | 19/3/2019 | 46.3 |
| 1930 | Hospital Building | Sclerometer Test | P001 | 14/11/2014 | 42 |
| 1930 | Hospital Building | Sclerometer Test | P002 | 14/11/2014 | 34 |
| 1930 | Hospital Building | Sclerometer Test | P003 | 14/11/2014 | 40 |
| 1930 | Hospital Building | Sclerometer Test | P004 | 14/11/2014 | 42.5 |
| 1930 | Hospital Building | Sclerometer Test | P1 | 14/11/2014 | 44 |
| 1930 | Hospital Building | Sclerometer Test | P10 | 14/11/2014 | 50 |
| 1930 | Hospital Building | Sclerometer Test | P12 | 14/11/2014 | 46 |
| 1930 | Hospital Building | Sclerometer Test | P2 | 14/11/2014 | 47 |
| 1930 | Hospital Building | Sclerometer Test | P7 | 14/11/2014 | 45 |
| 1930 | Hospital Building | Sclerometer Test | P9 | 14/11/2014 | 35 |
| 1930 | Hospital Building | Sclerometer Test | T1 | 14/11/2014 | 34 |
| 1930 | Hospital Building | Sclerometer Test | P201 | 14/11/2014 | 38 |
| 1930 | Hospital Building | Sclerometer Test | P202 | 14/11/2014 | 28 |
| 1930 | Hospital Building | Sclerometer Test | P204 | 14/11/2014 | 38 |
| 1930 | Hospital Building | Sclerometer Test | P205 | 14/11/2014 | 34 |
| 1930 | Hospital Building | Sclerometer Test | P210 | 14/11/2014 | 42 |
| 1930 | Hospital Building | Sclerometer Test | P212 | 14/11/2014 | 42 |
| 1930 | Hospital Building | Sclerometer Test | P311 | 14/11/2014 | 43 |
| 1930 | Hospital Building | Sclerometer Test | P319 | 14/11/2014 | 44 |
| 1981 | School Building | Sclerometer Test | P1 | 21/07/2014 | 38 |
| 1981 | School Building | Sclerometer Test | P2 | 21/07/2014 | 52 |
| 1981 | School Building | Sclerometer Test | P3 | 21/07/2014 | 52 |
| 1981 | School Building | Sclerometer Test | P4 | 21/07/2014 | 38 |
| 1981 | School Building | Sclerometer Test | P5 | 21/07/2014 | 32 |
| 1981 | School Building | Sclerometer Test | P6 | 21/07/2014 | 28 |
| 1981 | School Building | Sclerometer Test | P7 | 21/07/2014 | 36 |
| 1981 | School Building | Sclerometer Test | P8 | 21/07/2014 | 28 |
| 1981 | School Building | Sclerometer Test | P9 | 21/07/2014 | 28 |
| 1981 | School Building | Sclerometer Test | P10 | 21/07/2014 | 32 |
| 1981 | School Building | Sclerometer Test | P11 | 21/07/2014 | 28 |
| 1955 | Car Parking | Sclerometer Test | S01-01 | 2/2/2019 | 59 |
| 1955 | Car Parking | Sclerometer Test | S01-02 | 2/2/2019 | 48 |
| 1955 | Car Parking | Sclerometer Test | S01-03 | 2/2/2019 | 47 |
| 1955 | Car Parking | Sclerometer Test | S01-04 | 2/2/2019 | 62 |
| 1955 | Car Parking | Sclerometer Test | S01-05 | 2/2/2019 | 57 |

| Construction years | Construction Site | Test Type | Structural element | Test Date | Compressive strength (MPa) |
|---|---|---|---|---|---|
| 1955 | Car Parking | Sclerometer Test | S01-06 | 2/2/2019 | 64 |
| 1955 | Car Parking | Sclerometer Test | S01-07 | 2/2/2019 | 61 |
| 1955 | Car Parking | Sclerometer Test | S01-08 | 2/2/2019 | 64 |
| 1955 | Car Parking | Sclerometer Test | S01-09 | 2/2/2019 | 55 |
| 1955 | Car Parking | Sclerometer Test | S01-10 | 2/2/2019 | 61 |
| 1955 | Car Parking | Sclerometer Test | S01-11 | 2/2/2019 | 57 |
| 1955 | Car Parking | Sclerometer Test | S01-12 | 2/2/2019 | 50 |
| 1955 | Car Parking | Sclerometer Test | S01-13 | 2/2/2019 | 49 |
| 1955 | Car Parking | Sclerometer Test | S01-14 | 2/2/2019 | 41 |
| 1955 | Car Parking | Sclerometer Test | S01-15 | 2/2/2019 | 45 |
| 1955 | Car Parking | Sclerometer Test | S01-16 | 2/2/2019 | 51 |
| 1955 | Car Parking | Sclerometer Test | S01-17 | 2/2/2019 | 57 |
| 1955 | Car Parking | Sclerometer Test | S01-20 | 2/2/2019 | 48 |
| 1955 | Car Parking | Sclerometer Test | S01-24 | 2/2/2019 | 44 |
| 1955 | Car Parking | Sclerometer Test | S01-25 | 2/2/2019 | 44 |
| 1955 | Car Parking | Sclerometer Test | S01-26 | 2/2/2019 | 52 |
| 1955 | Car Parking | Sclerometer Test | S01-27 | 2/2/2019 | 46 |
| 1955 | Car Parking | Sclerometer Test | S01-28 | 2/2/2019 | 45 |
| 1955 | Car Parking | Sclerometer Test | S01-29 | 2/2/2019 | 45 |
| 1955 | Car Parking | Sclerometer Test | S01-31 | 2/2/2019 | 60 |
| 1955 | Car Parking | Sclerometer Test | S01-33 | 2/2/2019 | 48 |
| 1955 | Car Parking | Sclerometer Test | S01-34 | 2/2/2019 | 43 |
| 1955 | Car Parking | Sclerometer Test | S01-35 | 2/2/2019 | 56 |
| 1955 | Car Parking | Sclerometer Test | S01-38 | 2/2/2019 | 44 |
| 1955 | Car Parking | Sclerometer Test | S01-39 | 2/2/2019 | 56 |
| 1955 | Car Parking | Sclerometer Test | S01-40 | 2/2/2019 | 63 |
| 1950 | School building | Sclerometer Test | Column 1 | 12/11/2017 | 41 |
| 1950 | School building | Sclerometer Test | Column 2 | 12/11/2017 | 36.3 |
| 1950 | School building | Sclerometer Test | Column 3 | 12/11/2017 | 25 |
| 1950 | School building | Sclerometer Test | Column 4 | 12/11/2017 | 36.3 |
| 1950 | School building | Sclerometer Test | Beam 5 | 12/11/2017 | 27 |
| 1950 | School building | Sclerometer Test | Column 6 | 12/11/2017 | 41 |
| 1950 | School building | Sclerometer Test | Column 7 | 12/11/2017 | 31 |
| 1950 | School building | Sclerometer Test | Column 8 | 12/11/2017 | 29.5 |
| 1950 | School building | Sclerometer Test | Column 9 | 12/11/2017 | 42 |
| 1950 | School building | Sclerometer Test | Column 10 | 12/11/2017 | 34 |
| 1950 | School building | SonReb Method | Column 1 | 12/11/2017 | 31 |
| 1950 | School building | SonReb Method | Column 2 | 12/11/2017 | 18 |
| 1950 | School building | SonReb Method | Column 3 | 12/11/2017 | 10 |
| 1950 | School building | SonReb Method | Column 4 | 12/11/2017 | 13 |
| 1950 | School building | SonReb Method | Beam 5 | 12/11/2017 | 7 |
| 1950 | School building | SonReb Method | Column 6 | 12/11/2017 | 21 |
| 1950 | School building | SonReb Method | Column 7 | 12/11/2017 | 13.5 |
| 1950 | School building | SonReb Method | Column 8 | 12/11/2017 | 15.4 |
| 1950 | School building | SonReb Method | Column 9 | 12/11/2017 | 17 |

| Construction years | Construction Site | Test Type | Structural element | Test Date | Compressive strength (MPa) |
|---|---|---|---|---|---|
| 1990-2000 | Industrial Factory | SonReb Method | Column 1 | 26/07/2017 | 53.3 |
| 1990-2000 | Industrial Factory | SonReb Method | Column 2 | 26/07/2017 | 67.3 |
| 1990-2000 | Industrial Factory | SonReb Method | Column 3 | 26/07/2017 | 70.2 |
| 1990-2000 | Industrial Factory | SonReb Method | Column 4 | 26/07/2017 | 77.7 |
| 1990-2000 | Industrial Factory | SonReb Method | Column 5 | 26/07/2017 | 68.3 |
| 1990-2000 | Industrial Factory | SonReb Method | Column 6 | 26/07/2017 | 74.2 |
| 1990-2000 | Industrial Factory | SonReb Method | Column 7 | 26/07/2017 | 83.1 |
| 1990-2000 | Industrial Factory | SonReb Method | Column 8 | 26/07/2017 | 75.3 |
| 1990-2000 | Industrial Factory | SonReb Method | Column 9 | 26/07/2017 | 73.6 |
| 1990-2000 | Industrial Factory | SonReb Method | Column 10 | 26/07/2017 | 58.4 |
| 1990-2000 | Industrial Factory | SonReb Method | Column 11 | 26/07/2017 | 76.8 |
| 1990-2000 | Industrial Factory | SonReb Method | Column 12 | 26/07/2017 | 73.4 |
| 1990-2000 | Industrial Factory | SonReb Method | Column 13 | 26/07/2017 | 68.7 |
| 1990-2000 | Industrial Factory | SonReb Method | Column 14 | 26/07/2017 | 78.3 |
| 1990-2000 | Industrial Factory | SonReb Method | Column 15 | 26/07/2017 | 72.6 |
| 1990-2000 | Industrial Factory | SonReb Method | Beam foundation 9-12 | 26/07/2017 | 20.3 |
| 1990-2000 | Industrial Factory | SonReb Method | Beam foundation 7-8 | 26/07/2017 | 24.6 |
| 1990-2000 | Industrial Factory | SonReb Method | Beam foundation 6-9 | 26/07/2017 | 25.7 |
| 1940 | Residential building | SonReb Method | Column 1 | 18/12/2017 | 44.8 |
| 1940 | Residential building | SonReb Method | Column 2 | 18/12/2017 | 38.4 |
| 1940 | Residential building | SonReb Method | Column 3 | 18/12/2017 | 12.8 |
| 1940 | Residential building | SonReb Method | Column 4 | 18/12/2017 | 15.6 |
| 1940 | Residential building | SonReb Method | Column 5 | 18/12/2017 | 41.4 |
| 1940 | Residential building | SonReb Method | Column 6 | 18/12/2017 | 42.7 |
| 1940 | Residential building | SonReb Method | Column 7 | 18/12/2017 | 39.7 |
| 1940 | Residential building | SonReb Method | Column 8 | 18/12/2017 | 49.2 |
| 1940 | Residential building | SonReb Method | Column 9 | 18/12/2017 | 17.6 |
| 1940 | Residential building | SonReb Method | Column 10 | 18/12/2017 | 53 |
| 1940 | Residential building | SonReb Method | Column 11 | 18/12/2017 | 37 |
| 1940 | Residential building | SonReb Method | Column 12 | 18/12/2017 | 37.6 |
| 1940 | Residential building | SonReb Method | Column 13 | 18/12/2017 | 44.3 |
| 1940 | Residential building | SonReb Method | Column 14 | 18/12/2017 | 28.7 |
| 1940 | Residential building | SonReb Method | Column 15 | 18/12/2017 | 24.4 |
| 1940 | Residential building | SonReb Method | Column 16 | 18/12/2017 | 37.3 |
| 1940 | Residential building | SonReb Method | Column 17 | 18/12/2017 | 42.5 |
| 1940 | Residential building | SonReb Method | Column 18 | 18/12/2017 | 18.9 |
| 1940 | Residential building | SonReb Method | Column 19 | 18/12/2017 | 4.8 |
| 1940 | Residential building | SonReb Method | Column 20 | 18/12/2017 | 37.3 |
| 1970 | Bridge structure | SonReb Method | Campata 2 via dx | Oct-13 | 62.4 |
| 1970 | Bridge structure | SonReb Method | Campata 7 via dx | Oct-13 | 48.2 |
| 1970 | Bridge structure | SonReb Method | Campata 10 via dx | Oct-13 | 52.3 |
| 1970 | Bridge structure | SonReb Method | Campata 3 via dx | Oct-13 | 52.1 |
| 1970 | Bridge structure | SonReb Method | Campata 4 via dx | Oct-13 | 45.5 |
| 1970 | Bridge structure | SonReb Method | Campata 5 via dx | Oct-13 | 45.7 |
| 1970 | Bridge structure | SonReb Method | Campata 6 via dx | Oct-13 | 72 |
| 1970 | Bridge structure | SonReb Method | Campata 8 via dx | Oct-13 | 54.4 |
| 1970 | Bridge structure | SonReb Method | Campata 9 via dx | Oct-13 | 43.1 |

| Construction years | Construction Site | Test Type | Structural element | Test Date | Compressive strength (MPa) |
|---|---|---|---|---|---|
| 1970 | Bridge structure | SonReb Method | Spalla TE via dx | Oct-13 | 52.1 |
| 1970 | Bridge structure | SonReb Method | Spalla Rm 1 via dx | Oct-13 | 70.7 |
| 1970 | Bridge structure | SonReb Method | Spalla Rm 2 via dx | Oct-13 | 67.3 |
| 1970 | Bridge structure | SonReb Method | Pila 1 via dx | Oct-13 | 53.1 |
| 1970 | Bridge structure | SonReb Method | Pila 8 via dx | Oct-13 | 44.5 |
| 1970 | Bridge structure | SonReb Method | Pila 9 via dx | Oct-13 | 55.7 |
| 1970 | Bridge structure | SonReb Method | Pila 3 via dx | Oct-13 | 52.9 |
| 1970 | Bridge structure | SonReb Method | Pila 4 via dx | Oct-13 | 67.8 |
| 1970 | Bridge structure | SonReb Method | Pila 5 via dx | Oct-13 | 47.4 |
| 1970 | Bridge structure | SonReb Method | Pila 6 via dx | Oct-13 | 61.9 |
| 1970 | Bridge structure | SonReb Method | Pila 7 via dx | Oct-13 | 48 |
| 1980 | Bridge structure | SonReb Method | Campata 3 via sx | Oct-13 | 70.7 |
| 1980 | Bridge structure | SonReb Method | Campata 7 via sx | Oct-13 | 55 |
| 1980 | Bridge structure | SonReb Method | Campata 9 via sx | Oct-13 | 53.6 |
| 1980 | Bridge structure | SonReb Method | Campata 2 via sx | Oct-13 | 50.3 |
| 1980 | Bridge structure | SonReb Method | Campata 4 via sx | Oct-13 | 51.3 |
| 1980 | Bridge structure | SonReb Method | Campata 5 via sx | Oct-13 | 56.3 |
| 1980 | Bridge structure | SonReb Method | Campata 6 via sx | Oct-13 | 55.8 |
| 1980 | Bridge structure | SonReb Method | Campata 8 via sx | Oct-13 | 55.3 |
| 1980 | Bridge structure | SonReb Method | Campata 10 via sx | Oct-13 | 64.5 |
| 1980 | Bridge structure | SonReb Method | Spalla TE 1 via sx | Oct-13 | 38.5 |
| 1980 | Bridge structure | SonReb Method | Spalla TE 2 via sx | Oct-13 | 35.6 |
| 1980 | Bridge structure | SonReb Method | Spalla RM via sx | Oct-13 | 33.4 |
| 1980 | Bridge structure | SonReb Method | Pila 1 via sx | Oct-13 | 41.5 |
| 1980 | Bridge structure | SonReb Method | Pila 8 via sx | Oct-13 | 42.6 |
| 1980 | Bridge structure | SonReb Method | Pila 9 via sx | Oct-13 | 34.7 |
| 1980 | Bridge structure | SonReb Method | Pila 3 via sx | Oct-13 | 39.7 |
| 1980 | Bridge structure | SonReb Method | Pila 4 via sx | Oct-13 | 29.8 |
| 1980 | Bridge structure | SonReb Method | Pila 5 via sx | Oct-13 | 41.5 |
| 1980 | Bridge structure | SonReb Method | Pila 6 via sx | Oct-13 | 52.4 |
| 1980 | Bridge structure | SonReb Method | Pila 7 via sx | Oct-13 | 50.6 |
| 1978-1982 | Bridge structure | Sclerometer Test | Pila 5 via sx (R1) | Oct-13 | 42 |
| 1978-1982 | Bridge structure | Sclerometer Test | Pila 5 via sx (R2) | Oct-13 | 42 |
| 1978-1982 | Bridge structure | Sclerometer Test | Pila 5 via sx (R3) | Oct-13 | 46 |
| 1978-1982 | Bridge structure | Sclerometer Test | Pila 5 via sx (R4) | Oct-13 | 46 |
| 1978-1982 | Bridge structure | Sclerometer Test | Pila 5 via sx (R5) | Oct-13 | 48 |
| 1978-1982 | Bridge structure | Sclerometer Test | Pila 5 via sx (R6) | Oct-13 | 40 |
| 1978-1982 | Bridge structure | Sclerometer Test | Pila 5 via sx (R7) | Oct-13 | 42 |
| 1978-1982 | Bridge structure | Sclerometer Test | Pila 5 via sx (R8) | Oct-13 | 40 |
| 1978-1982 | Bridge structure | Sclerometer Test | Pila 5 via sx (R9) | Oct-13 | 44 |
| 1978-1982 | Bridge structure | Sclerometer Test | Pila 5 via sx (R10) | Oct-13 | 44 |
| 1978-1982 | Bridge structure | Sclerometer Test | Pila 13 via sx (R1) | Oct-13 | 42 |
| 1978-1982 | Bridge structure | Sclerometer Test | Pila 13 via sx (R2) | Oct-13 | 40 |

| Construction years | Construction Site | Test Type | Structural element | Test Date | Compressive strength (MPa) |
|---|---|---|---|---|---|
| 1978-1982 | Bridge structure | Sclerometer Test | Pila 13 via sx (R3) | Oct-13 | 40 |
| 1978-1982 | Bridge structure | Sclerometer Test | Pila 13 via sx (R4) | Oct-13 | 40 |
| 1978-1982 | Bridge structure | Sclerometer Test | Pila 13 via sx (R5) | Oct-13 | 44 |
| 1978-1982 | Bridge structure | Sclerometer Test | Pila 13 via sx (R6) | Oct-13 | 40 |
| 1978-1982 | Bridge structure | Sclerometer Test | Pila 13 via sx (R7) | Oct-13 | 38 |
| 1978-1982 | Bridge structure | Sclerometer Test | Pila 13 via sx (R8) | Oct-13 | 40 |
| 1978-1982 | Bridge structure | Sclerometer Test | Pila 13 via sx (R9) | Oct-13 | 40 |
| 1978-1982 | Bridge structure | Sclerometer Test | Pila 13 via sx (R10) | Oct-13 | 40 |
| 1988-1992 | Bridge structure | Sclerometer Test | Pila 4 via dx (R1) | Oct-13 | 50 |
| 1988-1992 | Bridge structure | Sclerometer Test | Pila 4 via dx (R2) | Oct-13 | 52 |
| 1988-1992 | Bridge structure | Sclerometer Test | Pila 4 via dx (R3) | Oct-13 | 46 |
| 1988-1992 | Bridge structure | Sclerometer Test | Pila 4 via dx (R4) | Oct-13 | 48 |
| 1988-1992 | Bridge structure | Sclerometer Test | Pila 4 via dx (R5) | Oct-13 | 50 |
| 1988-1992 | Bridge structure | Sclerometer Test | Pila 4 via dx (R6) | Oct-13 | 46 |
| 1988-1992 | Bridge structure | Sclerometer Test | Pila 4 via dx (R7) | Oct-13 | 48 |
| 1988-1992 | Bridge structure | Sclerometer Test | Pila 4 via dx (R8) | Oct-13 | 48 |
| 1988-1992 | Bridge structure | Sclerometer Test | Pila 4 via dx (R9) | Oct-13 | 48 |
| 1988-1992 | Bridge structure | Sclerometer Test | Pila 4 via dx (R10) | Oct-13 | 48 |
| 1988-1992 | Bridge structure | Sclerometer Test | Pila 14 via dx (R1) | Oct-13 | 44 |
| 1988-1992 | Bridge structure | Sclerometer Test | Pila 14 via dx (R2) | Oct-13 | 40 |
| 1988-1992 | Bridge structure | Sclerometer Test | Pila 14 via dx (R3) | Oct-13 | 42 |
| 1988-1992 | Bridge structure | Sclerometer Test | Pila 14 via dx (R4) | Oct-13 | 42 |
| 1988-1992 | Bridge structure | Sclerometer Test | Pila 14 via dx (R5) | Oct-13 | 44 |
| 1988-1992 | Bridge structure | Sclerometer Test | Pila 14 via dx (R6) | Oct-13 | 40 |
| 1988-1992 | Bridge structure | Sclerometer Test | Pila 14 via dx (R7) | Oct-13 | 42 |
| 1988-1992 | Bridge structure | Sclerometer Test | Pila 14 via dx (R8) | Oct-13 | 40 |
| 1988-1992 | Bridge structure | Sclerometer Test | Pila 14 via dx (R9) | Oct-13 | 42 |
| 1988-1992 | Bridge structure | Sclerometer Test | Pila 14 via dx (R10) | Oct-13 | 40 |
| 1988-1992 | Bridge structure | Sclerometer Test | Pila 22 via dx (R1) | Oct-13 | 40 |
| 1988-1992 | Bridge structure | Sclerometer Test | Pila 22 via dx (R2) | Oct-13 | 36 |
| 1988-1992 | Bridge structure | Sclerometer Test | Pila 22 via dx (R3) | Oct-13 | 40 |
| 1988-1992 | Bridge structure | Sclerometer Test | Pila 22 via dx (R4) | Oct-13 | 42 |
| 1988-1992 | Bridge structure | Sclerometer Test | Pila 22 via dx (R5) | Oct-13 | 38 |
| 1988-1992 | Bridge structure | Sclerometer Test | Pila 22 via dx (R6) | Oct-13 | 42 |
| 1988-1992 | Bridge structure | Sclerometer Test | Pila 22 via dx (R7) | Oct-13 | 42 |
| 1988-1992 | Bridge structure | Sclerometer Test | Pila 22 via dx (R8) | Oct-13 | 44 |
| 1988-1992 | Bridge structure | Sclerometer Test | Pila 22 via dx (R9) | Oct-13 | 42 |
| 1988-1992 | Bridge structure | Sclerometer Test | Pila 22 via dx (R10) | Oct-13 | 42 |
| 1973-1977 | Bridge structure | Sclerometer Test | Pila 2 via sx (R1) | Oct-13 | 44 |
| 1973-1977 | Bridge structure | Sclerometer Test | Pila 2 via sx (R2) | Oct-13 | 42 |
| 1973-1977 | Bridge structure | Sclerometer Test | Pila 2 via sx (R3) | Oct-13 | 44 |
| 1973-1977 | Bridge structure | Sclerometer Test | Pila 2 via sx (R4) | Oct-13 | 44 |
| 1973-1977 | Bridge structure | Sclerometer Test | Pila 2 via sx (R5) | Oct-13 | 42 |

| Construction years | Construction Site | Test Type | Structural element | Test Date | Compressive strength (MPa) |
|---|---|---|---|---|---|
| 1973-1977 | Bridge structure | Sclerometer Test | Pila 2 via sx (R6) | Oct-13 | 42 |
| 1973-1977 | Bridge structure | Sclerometer Test | Pila 2 via sx (R7) | Oct-13 | 42 |
| 1973-1977 | Bridge structure | Sclerometer Test | Pila 2 via sx (R8) | Oct-13 | 42 |
| 1973-1977 | Bridge structure | Sclerometer Test | Pila 2 via sx (R9) | Oct-13 | 42 |
| 1973-1977 | Bridge structure | Sclerometer Test | Pila 2 via sx (R10) | Oct-13 | 42 |
| 1973-1977 | Bridge structure | Sclerometer Test | Pila 9 via dx (R1) | Oct-13 | 42 |
| 1973-1977 | Bridge structure | Sclerometer Test | Pila 9 via dx (R2) | Oct-13 | 40 |
| 1973-1977 | Bridge structure | Sclerometer Test | Pila 9 via dx (R3) | Oct-13 | 40 |
| 1973-1977 | Bridge structure | Sclerometer Test | Pila 9 via dx (R4) | Oct-13 | 42 |
| 1973-1977 | Bridge structure | Sclerometer Test | Pila 9 via dx (R5) | Oct-13 | 44 |
| 1973-1977 | Bridge structure | Sclerometer Test | Pila 9 via dx (R6) | Oct-13 | 46 |
| 1973-1977 | Bridge structure | Sclerometer Test | Pila 9 via dx (R7) | Oct-13 | 44 |
| 1973-1977 | Bridge structure | Sclerometer Test | Pila 9 via dx (R8) | Oct-13 | 44 |
| 1973-1977 | Bridge structure | Sclerometer Test | Pila 9 via dx (R9) | Oct-13 | 42 |
| 1973-1977 | Bridge structure | Sclerometer Test | Pila 9 via dx (R10) | Oct-13 | 44 |
| 1973-1977 | Bridge structure | Sclerometer Test | Campata 1 via sx (R1) | Oct-13 | 54 |
| 1973-1977 | Bridge structure | Sclerometer Test | Campata 1 via sx (R2) | Oct-13 | 56 |
| 1973-1977 | Bridge structure | Sclerometer Test | Campata 1 via sx(R3) | Oct-13 | 54 |
| 1973-1977 | Bridge structure | Sclerometer Test | Campata 1 via sx(R4) | Oct-13 | 50 |
| 1973-1977 | Bridge structure | Sclerometer Test | Campata 1 via sx (R5) | Oct-13 | 56 |
| 1973-1977 | Bridge structure | Sclerometer Test | Campata 1 via sx (R6) | Oct-13 | 56 |
| 1973-1977 | Bridge structure | Sclerometer Test | Campata 1 via sx (R7) | Oct-13 | 54 |
| 1973-1977 | Bridge structure | Sclerometer Test | Campata 1 via sx (R8) | Oct-13 | 54 |
| 1973-1977 | Bridge structure | Sclerometer Test | Campata 1 via sx(R9) | Oct-13 | 52 |
| 1973-1977 | Bridge structure | Sclerometer Test | Campata 1 via sx (R10) | Oct-13 | 54 |
| 1973-1977 | Bridge structure | Sclerometer Test | Campata 9 via dx (R1) | Oct-13 | 54 |
| 1973-1977 | Bridge structure | Sclerometer Test | Campata 9 via dx (R2) | Oct-13 | 56 |
| 1973-1977 | Bridge structure | Sclerometer Test | Campata 9 via dx (R3) | Oct-13 | 56 |
| 1973-1977 | Bridge structure | Sclerometer Test | Campata 9 via dx (R4) | Oct-13 | 54 |
| 1973-1977 | Bridge structure | Sclerometer Test | Campata 9 via dx (R5) | Oct-13 | 56 |
| 1973-1977 | Bridge structure | Sclerometer Test | Campata 9 via dx (R6) | Oct-13 | 54 |
| 1973-1977 | Bridge structure | Sclerometer Test | Campata 9 via dx (R7) | Oct-13 | 56 |
| 1973-1977 | Bridge structure | Sclerometer Test | Campata 9 via dx (R8) | Oct-13 | 54 |
| 1973-1977 | Bridge structure | Sclerometer Test | Campata 9 via dx (R9) | Oct-13 | 56 |
| 1973-1977 | Bridge structure | Sclerometer Test | Campata 9 via dx (R10) | Oct-13 | 54 |
| 1977-1980 | Bridge structure | Sclerometer Test | Pila 5 via dx (R1) | 23/7/2012 | 52 |
| 1977-1980 | Bridge structure | Sclerometer Test | Pila 5 via dx (R2) | 23/7/2012 | 52 |
| 1977-1980 | Bridge structure | Sclerometer Test | Pila 5 via dx (R3) | 23/7/2012 | 54 |
| 1977-1980 | Bridge structure | Sclerometer Test | Pila 5 via dx (R4) | 23/7/2012 | 56 |
| 1977-1980 | Bridge structure | Sclerometer Test | Pila 5 via dx (R5) | 23/7/2012 | 54 |
| 1977-1980 | Bridge structure | Sclerometer Test | Pila 5 via dx (R6) | 23/7/2012 | 52 |
| 1977-1980 | Bridge structure | Sclerometer Test | Pila 5 via dx (R7) | 23/7/2012 | 54 |
| 1977-1980 | Bridge structure | Sclerometer Test | Pila 5 via dx (R8) | 23/7/2012 | 56 |
| 1977-1980 | Bridge structure | Sclerometer Test | Pila 5 via dx (R9) | 23/7/2012 | 58 |
| 1977-1980 | Bridge structure | Sclerometer Test | Pila 5 via dx (R10) | 23/7/2012 | 52 |

| Construction years | Construction Site | Test Type | Structural element | Test Date | Compressive strength (MPa) |
|---|---|---|---|---|---|
| 1977-1980 | Bridge structure | Sclerometer Test | Pila 17 via dx (R1) | 23/7/2012 | 50 |
| 1977-1980 | Bridge structure | Sclerometer Test | Pila 17 via dx (R2) | 23/7/2012 | 52 |
| 1977-1980 | Bridge structure | Sclerometer Test | Pila 17 via dx (R3) | 23/7/2012 | 52 |
| 1977-1980 | Bridge structure | Sclerometer Test | Pila 17 via dx (R4) | 23/7/2012 | 48 |
| 1977-1980 | Bridge structure | Sclerometer Test | Pila 17 via dx (R5) | 23/7/2012 | 50 |
| 1977-1980 | Bridge structure | Sclerometer Test | Pila 17 via dx (R6) | 23/7/2012 | 46 |
| 1977-1980 | Bridge structure | Sclerometer Test | Pila 17 via dx (R7) | 23/7/2012 | 50 |
| 1977-1980 | Bridge structure | Sclerometer Test | Pila 17 via dx (R8) | 23/7/2012 | 52 |
| 1977-1980 | Bridge structure | Sclerometer Test | Pila 17 via dx (R9) | 23/7/2012 | 50 |
| 1977-1980 | Bridge structure | Sclerometer Test | Pila 17 via dx (R10) | 23/7/2012 | 50 |
| 1977-1980 | Bridge structure | Sclerometer Test | Campata 17 via dx (R1) | 23/7/2012 | 54 |
| 1977-1980 | Bridge structure | Sclerometer Test | Campata 17 via dx (R2) | 23/7/2012 | 54 |
| 1977-1980 | Bridge structure | Sclerometer Test | Campata 17 via dx (R3) | 23/7/2012 | 52 |
| 1977-1980 | Bridge structure | Sclerometer Test | Campata 17 via dx (R4) | 23/7/2012 | 54 |
| 1977-1980 | Bridge structure | Sclerometer Test | Campata 17 via dx (R5) | 23/7/2012 | 56 |
| 1977-1980 | Bridge structure | Sclerometer Test | Campata 17 via dx (R6) | 23/7/2012 | 56 |
| 1977-1980 | Bridge structure | Sclerometer Test | Campata 17 via dx (R7) | 23/7/2012 | 54 |
| 1977-1980 | Bridge structure | Sclerometer Test | Campata 17 via dx (R8) | 23/7/2012 | 54 |
| 1977-1980 | Bridge structure | Sclerometer Test | Campata 17 via dx (R9) | 23/7/2012 | 56 |
| 1977-1980 | Bridge structure | Sclerometer Test | Campata 17 via dx (R10) | 23/7/2012 | 52 |
| 1988-1992 | Bridge structure | Sclerometer Test | Pila 6 via sx (R1) | 23/7/2012 | 44 |
| 1988-1992 | Bridge structure | Sclerometer Test | Pila 6 via sx (R2) | 23/7/2012 | 44 |
| 1988-1992 | Bridge structure | Sclerometer Test | Pila 6 via sx (R3) | 23/7/2012 | 40 |
| 1988-1992 | Bridge structure | Sclerometer Test | Pila 6 via sx (R4) | 23/7/2012 | 44 |
| 1988-1992 | Bridge structure | Sclerometer Test | Pila 6 via sx (R5) | 23/7/2012 | 46 |
| 1988-1992 | Bridge structure | Sclerometer Test | Pila 6 via sx (R6) | 23/7/2012 | 42 |
| 1988-1992 | Bridge structure | Sclerometer Test | Pila 6 via sx (R7) | 23/7/2012 | 44 |
| 1988-1992 | Bridge structure | Sclerometer Test | Pila 6 via sx (R8) | 23/7/2012 | 46 |
| 1988-1992 | Bridge structure | Sclerometer Test | Pila 6 via sx (R9) | 23/7/2012 | 40 |
| 1988-1992 | Bridge structure | Sclerometer Test | Pila 6 via sx (R10) | 23/7/2012 | 44 |
| 1988-1992 | Bridge structure | Sclerometer Test | Campata 7 via sx (R1) | 23/7/2012 | 54 |
| 1988-1992 | Bridge structure | Sclerometer Test | Campata 7 via sx (R2) | 23/7/2012 | 52 |
| 1988-1992 | Bridge structure | Sclerometer Test | Campata 7 via sx (R3) | 23/7/2012 | 54 |
| 1988-1992 | Bridge structure | Sclerometer Test | Campata 7 via sx (R4) | 23/7/2012 | 52 |
| 1988-1992 | Bridge structure | Sclerometer Test | Campata 7 via sx (R5) | 23/7/2012 | 54 |
| 1988-1992 | Bridge structure | Sclerometer Test | Campata 7 via sx (R6) | 23/7/2012 | 54 |
| 1988-1992 | Bridge structure | Sclerometer Test | Campata 7 via sx (R7) | 23/7/2012 | 56 |
| 1988-1992 | Bridge structure | Sclerometer Test | Campata 7 via sx (R8) | 23/7/2012 | 54 |
| 1988-1992 | Bridge structure | Sclerometer Test | Campata 7 via sx(R9) | 23/7/2012 | 54 |
| 1988-1992 | Bridge structure | Sclerometer Test | Campata 7 via sx (R10) | 23/7/2012 | 54 |
| 1981 | School building | Compression Test | Ground floor column N:27 | 15/07/2014 | 18 |
| 1981 | School building | Compression Test | Ground floor column N:24 | 15/07/2014 | 14.7 |
| 1981 | School building | Compression Test | Ground floor column N:14 | 15/07/2014 | 15.9 |
| 1981 | School building | Compression Test | Basement column N:14 | 15/07/2014 | 11.1 |
| 1981 | School building | Compression Test | Basement column N:24 | 15/07/2014 | 12.6 |
| 1981 | School building | Compression Test | Basement column N:16 | 15/07/2014 | 11.6 |

| Construction years | Construction Site | Test Type | Structural element | Test Date | Compressive strength (MPa) |
|---|---|---|---|---|---|
| 1953 | University building | Compression Test | Basement column C3 | 19/05/2016 | 13.9 |
| 1953 | University building | Compression Test | Basement column C4 | 19/05/2016 | 9.7 |
| 1953 | University building | Compression Test | Basement column C6 | 19/05/2016 | 14.9 |
| 1953 | University building | Compression Test | Ground floor column C9 | 19/05/2016 | 22 |
| 1953 | University building | Compression Test | Ground floor column C10 | 19/05/2016 | 20.8 |
| 1953 | University building | Compression Test | Ground floor column C12 | 19/05/2016 | 27 |
| 1953 | University building | Compression Test | First floor column C16 | 19/05/2016 | 18.5 |
| 1953 | University building | Compression Test | First floor column C18 | 19/05/2016 | 18.7 |
| 1953 | University building | Compression Test | Second floor column C19 | 19/05/2016 | 14.1 |
| 1953 | University building | Compression Test | Second floor column C22 | 19/05/2016 | 12.1 |
| 1953 | University building | Compression Test | Third floor column C23 | 19/05/2016 | 8.6 |
| 1953 | University building | Compression Test | Third floor column C31 | 19/05/2016 | 12.8 |
| 1953 | University building | Compression Test | Third floor column C32 | 19/05/2016 | 10.3 |
| 1968 | Office Building | Compression Test | SU01/ 62-64-CTP1 Beam | 20/10/2014 | 42.8 |
| 1968 | Office Building | Compression Test | SU01 / 64-CP1 Column | 20/10/2014 | 42.2 |
| 1968 | Office Building | Compression Test | SU02 / 53-55-CTP2 Beam | 20/10/2014 | 34.4 |
| 1968 | Office Building | Compression Test | SU02 / 53-CP2 Column | 20/10/2014 | 53 |
| 1968 | Office Building | Compression Test | SU03 / 49-51-CTP3 Beam | 20/10/2014 | 45.6 |
| 1968 | Office Building | Compression Test | SU03-51-CP3 Column | 20/10/2014 | 42.8 |
| 1968 | Office Building | Compression Test | SU04 / 42-44-CTP4 Beam | 20/10/2014 | 41.7 |
| 1968 | Office Building | Compression Test | SU05 / 36-38-CTP5 Beam | 20/10/2014 | 49.7 |
| 1968 | Office Building | Compression Test | SU05 / 36-CP5 Column | 20/10/2014 | 67.2 |
| 1968 | Office Building | Compression Test | SU-06/27-CP6 Column | 20/10/2014 | 57.5 |
| 1968 | Office Building | Compression Test | SU06 / 28-30-CTP6 Beam | 20/10/2014 | 57.3 |
| 1968 | Office Building | Compression Test | SU06 / 31-33-CTP7 Beam | 20/10/2014 | 40.9 |
| 1968 | Office Building | Compression Test | SU07 / 13-CP8 Column | 20/10/2014 | 41.3 |
| 1968 | Office Building | Compression Test | SU07 / 23-CP7 Column | 20/10/2014 | 59.8 |
| 1968 | Office Building | Compression Test | SU07 / 24-26-CTP8 Beam | 20/10/2014 | 46.8 |
| 1968 | Office Building | Compression Test | SU09 / 05-CP10 Column | 20/10/2014 | 36.8 |
| 1968 | Office Building | Compression Test | SU09 / 06-08-CTP10 Beam | 20/10/2014 | 31.7 |
| 1968 | Office Building | Compression Test | SU09 / 06-CP9 Column | 20/10/2014 | 51.3 |
| 1968 | Office Building | Compression Test | SU09 / 07-09-CTP9 Beam | 20/10/2014 | 38.8 |
| 1968 | Office Building | Compression Test | SUP04 / 40-CP4 Column | 20/10/2014 | 44.3 |
| 1967 | Workshop Building | Compression Test | OF01 / 100-CP1 Column | 20/10/2014 | 72.3 |
| 1967 | Workshop Building | Compression Test | OF01 / 98-100-CTP1 Beam | 20/10/2014 | 50.5 |
| 1967 | Workshop Building | Compression Test | OF03 / 90-92-CTP2 Beam | 20/10/2014 | 45.5 |
| 1967 | Workshop Building | Compression Test | OF03 / 76-CP2 Column | 20/10/2014 | 54.7 |
| 1967 | Workshop Building | Compression Test | OF04 / 62-30-CP3 Column | 20/10/2014 | 30.2 |
| 1967 | Workshop Building | Compression Test | OF05 / 62-26-CP5 Column | 20/10/2014 | 40.5 |
| 1967 | Workshop Building | Compression Test | OF05 / 62-26 / 64-26-CTP3 Beam | 20/10/2014 | 24.2 |
| 1967 | Workshop Building | Compression Test | OF05 / 62-28-CP4 Column | 20/10/2014 | 35.2 |
| 1967 | Workshop Building | Compression Test | OF05 / 64-28 / 62-28-CTP4 Beam | 20/10/2014 | 41.4 |
| 1967 | Workshop Building | Compression Test | OF06 / 1-CTP5 Beam | 20/10/2014 | 35.2 |
| 1967 | Workshop Building | Compression Test | OF06-CP6 Column | 20/10/2014 | 40.3 |
| 1967 | Workshop Building | Compression Test | OF07-CP7 Column | 20/10/2014 | 54.6 |
| 1967 | Workshop Building | Compression Test | OF07-CTP6 Column | 20/10/2014 | 34.4 |
| 1967 | Workshop Building | Compression Test | OF08-CP8 Column | 20/10/2014 | 58.3 |
| 1967 | Workshop Building | Compression Test | OF08-CTP7 Column | 20/10/2014 | 31.8 |
| 1967 | Workshop Building | Compression Test | OF09-1 04/06-CTP8 Beam | 20/10/2014 | 30.6 |
| 1967 | Workshop Building | Compression Test | OF10 / 02-26-CP9 Column | 20/10/2014 | 35.6 |
| 1967 | Workshop Building | Compression Test | OF10-1 06/08-CTP9 Beam | 20/10/2014 | 27.6 |

| Construction years | Construction Site | Test Type | Structural element | Test Date | Compressive strength (MPa) |
|---|---|---|---|---|---|
| 1967 | Workshop Building | Compression Test | OF12-1 20 / 18CTP10 Beam | 20/10/2014 | 32.1 |
| 1967 | Workshop Building | Compression Test | OF12 / 02-18-CP10 Column | 20/10/2014 | 37.1 |
| 1967 | North Building | Compression Test | FN04-CP1 Column | 20/10/2014 | 37.3 |
| 1967 | North Building | Compression Test | FN04-CP2 Column | 20/10/2014 | 27.4 |
| 1967 | North Building | Compression Test | FN04-CST1 Beam | 20/10/2014 | 42.4 |
| 1967 | North Building | Compression Test | FN04-CST2 Beam | 20/10/2014 | 54.7 |
| 1967 | North Building | Compression Test | FN04-CST3 Beam | 20/10/2014 | 52.8 |
| 1967 | Workshop Office | Compression Test | UO03-CP1 Column | 20/10/2014 | 19.2 |
| 1967 | Workshop Office | Compression Test | UO04-CTP3 Beam | 20/10/2014 | 25.8 |
| 1967 | Workshop Office | Compression Test | UO05-CP2 Column | 20/10/2014 | 31.2 |
| 1967 | Workshop Office | Compression Test | UO05-CTP4 Beam | 20/10/2014 | 40.6 |
| 1967 | Workshop Office | Compression Test | UO06-CP3 Column | 20/10/2014 | 18.8 |
| 1967 | Workshop Office | Compression Test | UO06-CTP5 Beam | 20/10/2014 | 38.9 |
| 1930 | Hospital Building | Compression Test | P001 | 20/10/2014 | 13 |
| 1930 | Hospital Building | Compression Test | P002 | 20/10/2014 | 11.8 |
| 1930 | Hospital Building | Compression Test | P003 | 20/10/2014 | 16.3 |
| 1930 | Hospital Building | Compression Test | P004 | 20/10/2014 | 19.8 |
| 1930 | Hospital Building | Compression Test | T1 | 20/10/2014 | 16.3 |
| 1930 | Hospital Building | Compression Test | P1 | 20/10/2014 | 30.4 |
| 1930 | Hospital Building | Compression Test | P2 | 20/10/2014 | 22.2 |
| 1930 | Hospital Building | Compression Test | P9 | 20/10/2014 | 23.8 |
| 1930 | Hospital Building | Compression Test | P10 | 20/10/2014 | 21.6 |
| 1930 | Hospital Building | Compression Test | P201 | 20/10/2014 | 20 |
| 1930 | Hospital Building | Compression Test | P202 | 20/10/2014 | 11.7 |
| 1930 | Hospital Building | Compression Test | P204 | 20/10/2014 | 14.7 |
| 1953 | Car Parking | Compression Test | S04-08 | 2/2/2019 | 63 |
| 1953 | Car Parking | Compression Test | S04-13 | 2/2/2019 | 61.2 |
| 1953 | Car Parking | Compression Test | S04-16 | 2/2/2019 | 30.6 |
| 1953 | Car Parking | Compression Test | S04-01 | 2/2/2019 | 39.2 |
| 1953 | Car Parking | Compression Test | S04-02-B | 2/2/2019 | 24.1 |
| 1953 | Car Parking | Compression Test | S04-17 | 2/2/2019 | 61.9 |
| 1953 | Car Parking | Compression Test | S04-02-A | 2/2/2019 | 35.7 |
| 1953 | Car Parking | Compression Test | S04-15 | 2/2/2019 | 46.2 |
| 1953 | Car Parking | Compression Test | S04-03 | 2/2/2019 | 38.6 |
| 1953 | Car Parking | Compression Test | S04-05 | 2/2/2019 | 56.1 |
| 1953 | Car Parking | Compression Test | S04-04 | 2/2/2019 | 69.5 |
| 1953 | Car Parking | Compression Test | S04-14 | 2/2/2019 | 50.6 |
| 1953 | Car Parking | Compression Test | S04-27 | 2/2/2019 | 37 |
| 1953 | Car Parking | Compression Test | S04-24 | 2/2/2019 | 41.3 |
| 1953 | Car Parking | Compression Test | S04-25 | 2/2/2019 | 51.1 |
| 1953 | Car Parking | Compression Test | S04-32 | 2/2/2019 | 58.1 |
| 1953 | Car Parking | Compression Test | S04-26 | 2/2/2019 | 45.4 |
| 1953 | Car Parking | Compression Test | S04-28 | 2/2/2019 | 55.2 |
| 1953 | Car Parking | Compression Test | S04-20 | 2/2/2019 | 48.3 |
| 1953 | Car Parking | Compression Test | S04-34 | 2/2/2019 | 57.4 |
| 1953 | Car Parking | Compression Test | S04-33 | 2/2/2019 | 48.3 |
| 1953 | Car Parking | Compression Test | S04-19 | 2/2/2019 | 61.1 |
| 1953 | Car Parking | Compression Test | S04-23 | 2/2/2019 | 57.2 |
| 1953 | Car Parking | Compression Test | S04-22 | 2/2/2019 | 38.9 |
| 1953 | Car Parking | Compression Test | S04-21 | 2/2/2019 | 45.1 |
| 1953 | Car Parking | Compression Test | S04-07 | 2/2/2019 | 43.3 |

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