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Feasibility Analysis of NDT Methods Using to Estimate the Concrete Strength as Part of Urban Regeneration

Kürşat Esat Alyamaç[1], Merve Açıkgenç Ulaş[2]*, Yavuzhan Taş[3], Ehsan Ghafari[4]
[1]Fırat University, Faculty of Engineering, School of Civil Engineering, Elazig, TURKEY
[2]Fırat University, Faculty of Architecture, School of Architecture, Elazig, TURKEY
[3]Ministry of Transport, 8th Regional Directorate of Highways, Elazig, TURKEY
[4]Purdue University, Faculty of Engineering, School of Civil Engineering, West Lafayette, USA
*merveacikgenc@firat.edu.tr

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Abstract

Most of the countries are placed in a seismic zone which has high activity and has extremely experienced large-scale losses due to several destructive earthquakes such as Turkey. Therefore, governments are seriously trying to produce the projects that will significantly reduce the earthquake effects. The most important part of these projects is urban regeneration. Within the context of urban regeneration activities, renewal of the buildings which have low earthquake-resistant is targeted. While the earthquake resistance level of a building is decided, one of the important steps is the determination of the strength of the building materials. There are many standard NDT methods that will be able to be used to determine the compressive strength. However, it is necessary to choose the appropriate methods in order to quickly and reliably estimate the strength properties of the materials. The purpose of this study is to determine the optimum NDT method for the urban regeneration. So, feasibility analysis was carried out for the standard NDT methods, and the performance of these methods was evaluated based on the cost and the accuracy. The result is the requirement new NDT method which is the practical and efficient for the large-scale projects such as urban regeneration.

Keywords: NDT, Compressive Strength, Urban Regeneration, In-Place Test, Earthquake.

Kentsel Dönüşüm Sürecinde Beton Dayanımının Tahmini İçin Kullanılan Hasarsız Deney Metotlarının Fizibilite Analizi

Özet

Dünya ülkelerinin çoğu, yüksek aktivite gösteren ve Türkiye gibi birçok yıkıcı deprem nedeniyle büyük çapta kayıplar yaşayan bir sismik bölgeye yerleşmiştir. Bu nedenle hükümetler, deprem etkilerini önemli ölçüde azaltacak projeler üretmek için ciddiyetle çalışmaktadırlar. Bu projelerin en önemli olanı kentsel dönüşümdür. Kentsel dönüşüm faaliyetleri bağlamında, depreme dayanıklı olmayan binaların yenilenmesi hedeflenmektedir. Bir binanın depreme dayanıklılık seviyesi belirlenirken, önemli adımlardan birisi yapı malzemelerinin dayanımının belirlenmesidir. Basınç dayanımını belirlemek için kullanılabilecek birçok standart hasarsız deney yöntemi mevcuttur. Bununla birlikte, malzemelerin mukavemet özelliklerini hızlı ve güvenilir bir şekilde hesaplamak için uygun yöntemleri seçmek gereklidir. Bu çalışmanın amacı kentsel dönüşüm için uygun hasarsız deney yöntemini belirlemektir. Böylece, standart hasarsız deney yöntemleri için fizibilite analizi gerçekleştirilmiş ve bu yöntemlerin performansı maliyet ve doğruluğa dayalı olarak değerlendirilmiştir. Sonuç, kentsel yenilenme gibi büyük ölçekli projeler için pratik ve verimli olan yeni hasarsız deney yönteminin gerekliliğidir.

Anahtar Kelimeler: Hasarsız Deney Yöntemleri, Basınç Dayanımı, Kentsel Dönüşüm, Yerinde Test, Deprem.

1. Introduction

The most popular performance measure which is used by design engineers to estimate the actual strength of concrete is the compressive strength, which is usually measured by breaking cylindrical or cubic specimens in a compression-testing machine. The compressive strength results can be used for the quality control, the formwork stripping times, the curing times, the fault diagnosis on the existing reinforced concrete/masonry structures, the research works, and the in-place testing of concrete/mortar strength. Specifically, it is critical to estimate the in-place compressive strength of concrete, mortar and rock to establish the safety of the concrete and the masonry buildings. Because, most of the countries in the world are frequently exposed to the destructive earthquakes. After these earthquakes and tragedies, millions of buildings were severely damaged or collapsed [1-7]. To figure out this problem, the governments have been trying to renew the buildings by using urban regeneration/transformation policy or post-earthquake rehabilitation and reconstruction before the earthquakes [8, 9], for instance, Turkey is one of these countries. Urban regeneration was regulated with the Law: "The Regeneration of the Areas under Disaster Risk (Law No: 6306)" in Turkey in May 2012. Decreasing the risk before the disasters, which are especially earthquakes, is aimed at this law [10]. Minimizing the risk before the earthquakes means that hundreds of thousands of existing buildings, which have low earthquake resistance or insufficient resistance, should be renewed. First of all, earthquake resistance of these buildings, namely safety, must be determined. The in-situ strength of concrete, mortar and rock is an important part to establish the safety of the buildings [11].

Urban regeneration projects where the buildings have been rebuilt include not only a building but also at least dozens of buildings. Although the earthquake resistance of these buildings, which are usually reinforced concrete or masonry buildings, are estimated to be weak or inadequate, this problem still legally needs to be proven. For this reason, it is necessary to estimate the in-place compressive strength of the concrete in the buildings. Standard non-destructive (NDT) methods and drilling core method are usually used together to estimate the strength properties of the concrete. However, since the number of buildings is very high, the cost of determining the strength of the concrete is greatly increasing. In addition, a considerable amount of time is lost. It is critical to determine the concrete strength quick and reliable so that urban regeneration projects continue economically and rapidly.

Many standard NDT methods, such as UPV, rebound hammer, and penetration tests, are presently used to estimate the strength of the concrete. In this paper, the most preferred standard NDT methods are evaluated in terms of cost, reliability and practicality, and a feasibility analysis is carried out considering carefully requirements and expectations. The purpose of this study by the feasibility analysis is to provide the possibility of comparing the NDT methods for the researchers and engineers. So, they will be able to determine the most effective method for their projects at the earliest convenience. Consequently, a practical graphic-based method is proposed to choose the NDT methods to be used in urban regeneration projects.

2. NDT Methods

There are many NDT techniques used to determine the concrete strength. The most known of these can be listed as follows:

- Rebound Number (Schmidt Hammer Test) [12, 13]
- Ultrasonic Pulse Velocity [12, 14]
- Penetration Resistance (Probe and Pin Tests) [12, 15]
- Pullout Test [12, 16]
- Break-off Number [12, 17]
- Maturity Method [12, 18]
- Cast-in-place Cylinders [12, 19]
- PNT-G Test [20]
- Drilling Resistance [21]
- Nail Penetration [22]
- Twist-off Test [23]

For the feasibility analysis, the NDT methods just used in the standard, current, and for existing buildings have been taken into consideration, and their characteristics have been clearly presented.

2.1. Rebound number test

The rebound number test is technically a test for surface hardness, and it approximately provides for establishing relationship between the rebound hammer number and the compressive strength of concrete. The Rebound Hammer has been around since the late 1940s and today is a commonly utilized method for estimating the in-place compressive strength of the concrete. Basic operation of the rebound hammer test is illustrated in Fig. 1. Schmidt Hammer is usually used for this test [24].

The tests can be carried out in horizontal, vertically upward, downward or any intermediate angled positions. The rebound hummer is simple to use, and a large number of readings may be obtained in a relatively minimum amount of time. This method is non-destructive and characteristically more economical than other NDT methods. However, with these advantages come disadvantages related to technical limitations on accuracy, and the need for exact calibration and correlation with cores for assessment of an existing structure [25]. The surface texture, moisture content, and carbonation significantly affect the rebound (R) number of the tests.

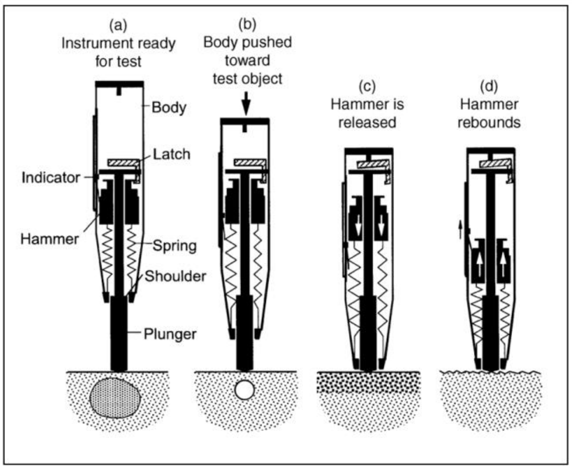

Figure 1. Operation of the rebound hammer as schematic [12].

The advantages and limitations of the rebound hammer test should be recognized and figured on if the rebound hammer will be used for a large-scale project about existing buildings.

2.2. Ultrasonic Pulse Velocity (UPV) Test

Pulses of the waves are produced by an acoustical transducer that is kept in contact with one surface of the concrete under evaluation. After traversing through the concrete, the pulses are gotten and altered into electrical energy by a second transducer placed a distance (L) from the transmitting transducer. The transit time (T) is directly measured electronically. The pulse velocity (V) is calculated by dividing L by T. The operational principle of modern testing equipment is illustrated in Fig. 2 [14].

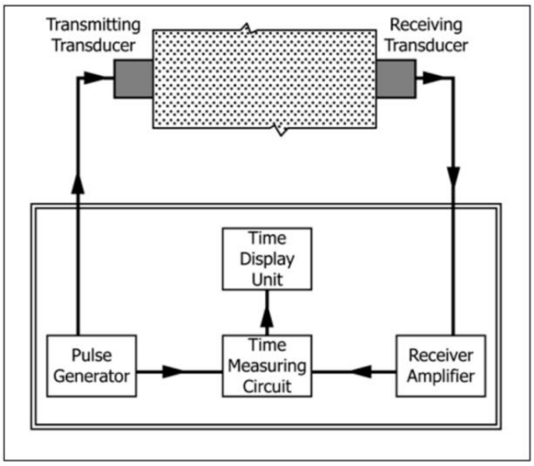

Figure 2. Schematic diagram of the pulse velocity test [14].

UPV can be utilized for the following properties [26]:

- Estimation of the relationship between the strength and the pulse velocity.
- Estimation of uniformity of the concrete.
- Assessment of alters obtaining with time in the common properties of the concrete.

There are three possible configurations where the transducers can be settled as illustrated in Fig. 3. These are direct transmission (Fig. 4a), semi-direct transmission (Fig. 4b), and indirect (surface) transmission (Fig. 4c). Indirect transmission should be used when only one face of the concrete is available. These configurations provide significant advantages for estimation of the in-place strength of the concrete [25].

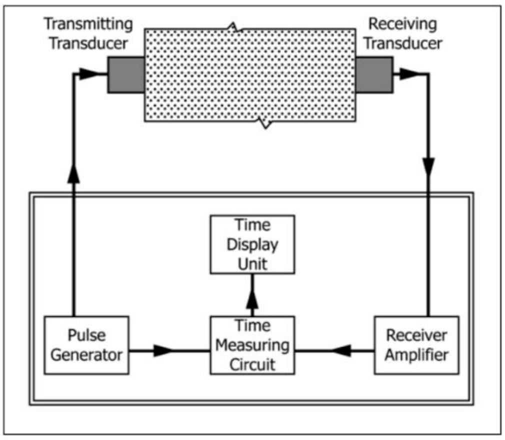

Figure 3. Configration of the UPV test application [25].

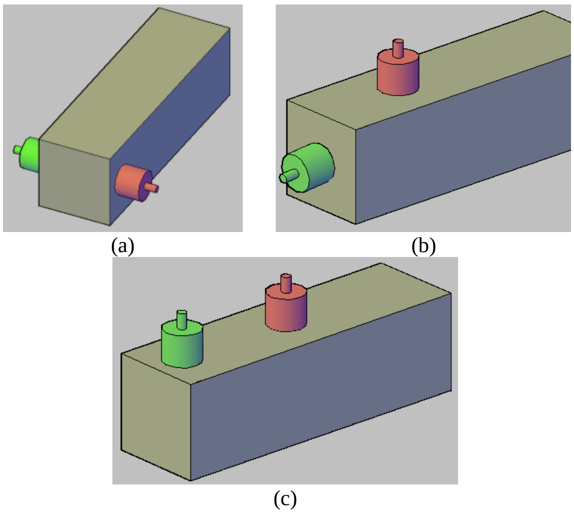

Figure 4. a) Direct transmission, b) semi-direct transmission, and c) indirect (surface) transmission

UPV method adequately provides the examination of relationship between the compressive strength and the pulse velocity of the sample, but the test results of UPV are affected by moisture content, properties of aggregates, cracks, voids. The usability of UPV test is much more limited to predict the compressive strength of concrete, mainly owing to steel reinforcement bars in concrete because the pulse velocity through steel is about 40% greater than through concrete. These limitations should be considered before preferred the UPV method [27, 28].

2.3. Pin Penetration Test

Nasser and Al-Manaseer described an NDT in which a new production hammer that forces a steel pin into the concrete is used to estimate the when it is safe to remove the concrete forms [29]. The apparatus occurs a spring-loaded hammer which may follow a pin of 3.56mm diameter and 30.5mm length with the tip machined [15].

The spring is forced by pressing the hammer against the surface of the concrete, and is released by a trigger causing the pin and the attached shaft and hammer to strike the surface of the concrete with energy of about 108 Nm. After cleaning, the hole depth generated is measured with a dial gauge device (Fig. 5) [28]. There is an acceptable correlation between the pin penetration and the compressive strength of the concrete. Pin penetration (depth of the blind hole in the concrete element) test which requires less energy than the Windsor probe test. The pin test, although easy in concept, has technical disadvantages. The pin penetrates only a small depth into the concrete, and thus, the results can be seriously infected by the properties of the concrete at the surface.

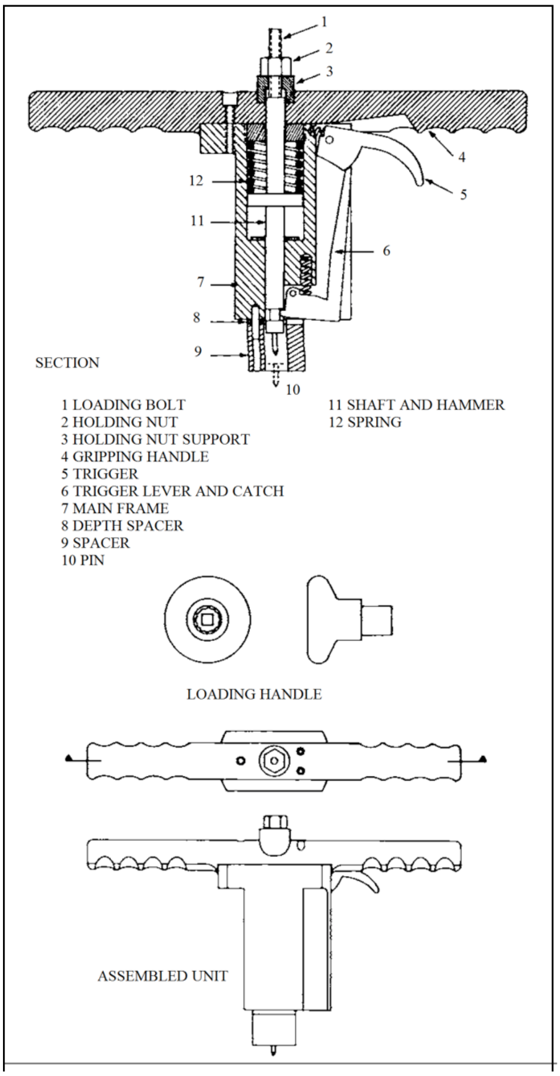

Figure 5. Configuration of the pin penetration test application [29].

2.4. Windsor Probe Test

The probe-penetration technique requires the use of a specially designed gun to run the steel probe into the concrete [15]. (This test system is commonly known as the Windsor Probe Test, as seen in Fig. 6).

Figure 6. Windsor Probe Test equipments.

The Windsor probe test, like the rebound hammer test, is a hardness tester, and its inventors maintain that the penetration of the probe shows the exact compressive strength in a localized area is not certainly true [30]. Nevertheless, the probe penetration does refer to the some property of the concrete, so it has been possible to improve empirical correlations between the compressive strength and the probe penetration [25]. Schematically, failure of the concrete during Windsor probe penetration test is illustrated in Fig 7.

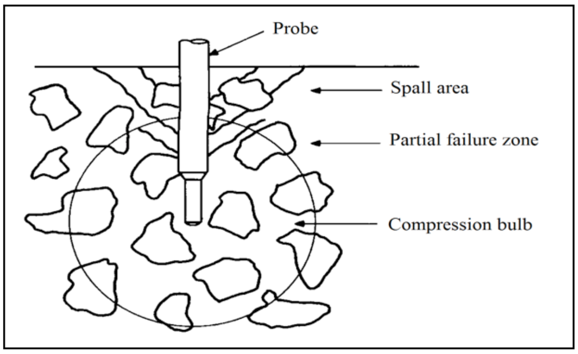

Figure 7. Failure of the concrete during Windsor test schematically [28].

The advantages of the Windsor probe test are [25, 28, 31]:

• The test is adequately fast, and the result is obtained immediately provided an appropriate curve with good correlation is ready for use.

• The correlation with the concrete compressive strength is changed by a relatively small number of variables.

• Application is only required to one surface.

The limitations of the Windsor probe test are [25, 28, 31]:

• The test damages an about 8 mm blind hole in the sample in which the probe penetrated and, in elder concrete, this zone around the point of the penetration is usually broken.

• The least distance from a test location to any edges of the concrete sample or between two tests location is of the order of 150 mm to 200 mm.

• The distance from reinforcement can also be affected the depth of the penetration, especially if the distance is less than about 100 mm.

• The least thickness of the sample, that can be tested, is about three times the estimated depth of steel probe penetration.

• The costs of the operations are really high.

Although the PR method has some advantages, it is particularly sensitive to characteristics of aggregate and minimum member thickness, which can be tested. The advantages and limitations of the Windsor probe test should be recognized and taken into account if this test will be utilized for the existing buildings.

3. Urban Regeneration and the In-Place Test

Turkey connects the tectonic plates that are including the Eurasian, Arabian, and African and the Anatolian plates [32] and Turkey has a high seismic activity because of its location. Many destructive earthquakes occurred in the past two decades in Turkey and the social and economic damages were really huge [33]. So, Turkey is really important model to evaluate for the urban regeneration.

The Turkish earthquake knowledge and data regarding urban projects are seriously little and limited. In urban areas, risks related not only community services and infrastructure but also housing [34]. Erzincan earthquake which occurred in 1992 supplied valuable data to understand the dangerous of the building stock which has not been enough earthquake resistance. However, unfortunately, this experience was not enough to protect from the disasters which were occurred in Kocaeli (1999), Bingol (2003), Van (2011) et al [7].

Critical amount of Turkey's building stock does not comply with either the design codes or standards, and specifications that were efficient at the time of their built, or the ever more stringent modern design code applied today. It is not practicable to perform reliable estimates of seismic losses due to aforementioned complexities. However, researches based on the scenario earthquakes possible to Istanbul harshly predict 30.000 – 40.000 heavily damaged structures and eleven billion in direct losses due to damage to buildings [33]. The building stock which has low earthquake resistance is a very serious problem threatening many countries like Turkey. To solve this problem, governments are trying to produce efficient urban generation projects.

Urban regeneration is a first step in the rebuilding of a part of the cities, and that it has been designed as a governments-assisted urban regeneration strategy. The origin of the conversation of urban regeneration within the Turkish planning literature was an extension of government programs that were formed by efforts to secure a place in the 1980s world order [35]. Disaster risk resulted from the destructive earthquakes has become the main theme of the urban regeneration in Turkey, especially, in the last decade, and has soon become the primary reason for the application of urban regeneration projects with the Law on the 6306, "Regeneration of Areas under the Risk of Disasters', which was accepted on 16.05.12. This has added to the "legality" of urban regeneration projects that will be implemented all over the country with a quick and public model of rebuilding [36].

One of the most important parts of the existing urban regeneration projects is to determine earthquake risk levels of the buildings. When the risk levels of the buildings are determined, one of the basic steps is estimation of the compressive strength of the concrete. Determination of the strength of the concrete by just using the core drilling method is expensive, difficult and time-consuming. Therefore, as far as possible, the destructive methods should be used as minimum and NDT methods usually should be used. Even so, it is not easy to select the most suitable one/more from many NDT methods. Accordingly, in this study, a feasibility analysis was carried out for NDT methods in line with the urban regeneration requirements.

For the urban regeneration projects, estimation of the in-place strength of the concrete is the topic of discussion, because all NDT is unsuitable for determination of the in-place concrete strength. Thus, also any NDT may not be suitable for urban generation projects.

Since the 1900s, there has been an ongoing investigation of the in-place strength of the concrete [37]. Although there are many in-place test methods, very few of them are standard [38, 39]. The standard methods have many advantages such as comparability with the previous works, experience, and easy reachability to the test equipment.

4. Feasibility Analysis of the NDT Methods

Feasibility analyses are originally formed by social scientist. In this study, the feasibility studies made is one of the first examples of its kind, and these methods will hopefully be more commonly performed in the future researches. A feasibility analysis estimates and observes an economic opportunity based on certain theory and estimations that have been put forward in the process of starting a new project [40]. Feasibility analyses aim to decide whether a business opportunity is possible, practical, and workable [41]. A number of the factors are considered and assessed in a feasibility analysis to calculate the most effective results.

Within the framework of urban regeneration projects, to determine the in-place strength of the concrete, priority expectations from the NDT methods are listed below:

- Economy (cost of the operation)
- Time (minimum labor and test time)
- Accuracy (more than 90%, if possible)

The critical issue for the project is that the cost of the operation should be more economical than the cost of the test equipment. The approximate cost of the operations and test equipment are presented in Table 1.

Table 1. Cost information for the NDTs

NDT Methods	Operation Cost ($)	Equipment Cost ($)
Rebound Hammer	Only labor	$300.00

Table 1. Cost information for the NDTs

NDT Methods	Operation Cost ($)	Equipment Cost ($)
UPV	Only labor	$4000.00
Pin Penetration	$10/each	$5000.00
Windsor Probe	$18/each	$5500.00

In order to be able to apply the tests in Table 1, there must be no plaster or coating on the surfaces of the concrete elements. If it is present, it has to be removed from the concrete surface. So, it is assumed that the labor that is for removing the coating will be in equal amounts, $100, for all the tests.

At least three tests should be performed to determine the compressive strength of the concrete. These three tests are accepted as a set. In order to compare NDT methods, a certain number of tests must be taken into account in feasibility analysis. Windsor probe test is taken as reference to determine this numerical value. This value is the test number that makes the cost of the operation equal to the cost of the equipment. The number of the tests = 5500 / 18 ≅ 305.

Two parameters were used for feasibility analysis. The first is based on cost; the second is based on the benefit. The parameters of the analysis are explained in Table 2.

Table 2. Parameters of the feasibility analysis

NDT Methods	CO/CE[a]	T[b]	A[c]	T/A[d]
Rebound Hammer	0.3	3	3	1
UPV	> 0.1	2	2	1
Pin Penetration	0.63	3	2	1
Windsor Probe	1	3	1	3

[a.] CO/CE=(Cost of operation + labor) / cost of the equipment

[b.] T: Application Time (0~15 min: 3, 16~60 min: 2, more than 60 min: 3)

[c.] A: Accuracy (Excellent: 1, Good: 2, Approximate: 3)

[d.] T/A: Time/Accuracy

The rate of CO/CE is developed to consider the cost effect on the choosing of the NDT. The rate of T/A is developed to consider the technical benefit on the selecting of the NDT.

Graphic based feasibility analysis is illustrated in Fig. 8. If it is desired to determine as fast, practical and approximate whether an NDT method is suitable for an urban regeneration project, first, the numerical values of the parameters of this method, CO/CE and T/A, are calculated. And then, these parameters are marked on the graphics, finally; the feasibility region is determined by Fig 8. The RED, YELLOW and GREEN Zones mean the unfeasible, acceptable and feasible NDT methods, respectively.

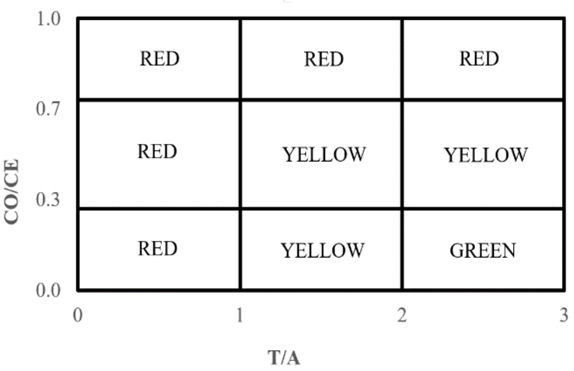

Figure 8. Graphic of the feasibility analysis.

5. Discussion and Results

Graphic based feasibility analysis is performed for the standard NDT methods, and results of the feasibility analysis are given in Table 3.

Table 3. Feasibility result of the NDT method

NDT Methods	Feasibility Zone
Rebound Hammer	YELLOW
UPV	YELLOW
Pin Penetration	YELLOW
Windsor Probe	RED

Rebound hammer, UPV, pin penetration, and Windsor probe tests are in the yellow and red zones, respectively. Existing methods are not feasible but acceptable methods to utilize for the urban regeneration projects. These methods which are in the yellow zone are neither economical nor sufficiently useful. The Windsor probe test is unfeasible because of the cost of the operation. This method is reliable and practical. However, cost of the operation of Windsor Probe test is so high. It is evident how large the economic loss will be, if it is assumed that the test will be used for tens of thousands of buildings in urban regeneration projects.

The proposed method in the current paper is a preliminary and practical method. This feasibility analysis can be used in non-standard NDT methods. However, accuracy must be carefully determined. The most important thing is that these analyses are done by experienced engineers. If every numerical result passes from the engineer's filter, it gains significant value.

6. Conclusion

Urban regeneration has become a strategy to avoid the earthquake damages in many countries like Turkey. Because the target is building stock, the strength of the concrete, which is the most-used material to produce the buildings needed to be determined. A feasibility analysis was carried out for the methods of determining the in-place concrete strength in this study. Following are some of the important conclusions.

- The number of drilled core specimens should be reduced as much as possible while the concrete strength is determined as the number of buildings in urban regeneration projects is too high. Even if it is possible, reliable results should be tried to be obtained without using destructive methods. It can be economically and quickly carried out.
- The efficiency of an NDT method by the help of the graphic based feasibility method can be evaluated with cost, time and accuracy limiters.
- None of the existing methods are in the green zone when the feasibility analysis performed. This conclusion implies that a new feasible NDT method is required.
- Windsor probe test has high accuracy but not economic. So, it can be used for the specific works.
- None of the existing NDT methods can be applied to surface that has coating. Before the NDT is applied, the coating/plaster must be removed. Therefore, a new NDT is required to test the concrete elements without removing the coating, especially for the urban regeneration projects.

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