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ASSESSMENT OF THE RELIABILITY OF STRUCTURAL CONCRETES DURING EXECUTION PHASES

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Abstract. *The quality control of concrete is basically an assessment of compressive strength from which also depends the durability of the material. In the case of important constructions, the control of design prescriptions is not always easy. In addition to the uncertainty factors related to the composition of the material, there are also factors relating to the construction phases. These problems are amplified if the production is on site. These reasons can often suggest to perform, destructive and non-destructive test after the completion of the structure, in order to obtain further information about in-place concrete strength. These investigations, if accompanied by appropriate evaluation procedures, allow to determine the degree of concrete compaction, that if unsatisfactory, makes the material more permeable, less durable and less mechanically efficient. This paper collects the numerical elaboration of resistances measured on cubes made during the concrete placing and on cores extracted after the completion of the structure, for the concrete used in the construction of the "Esaro" Dam facilities (Cosenza, Italy). In addition to the statistical treatment of the sample, aimed to assess the analytical congruence with the homogeneous classes provided in the design, the influence of compaction degree on in place strength value was qualitatively evaluate, with the aid of an analytical methodology.*

1 INTRODUCTION

In new structures, the quality control of concrete, and in particular of the compressive strength, is an essential step for the safety of the structure and its durability, and also plays an important role in the relations between the various professionals involved in the procedure. The operations to be performed in the quality inspections involve both the construction phases, (concrete casting), both a-posteriori “in situ" investigations, in order to verify that the material conforms to that required and specified in the project. This last point is very important in case of controversies about the concrete quality, especially in the case of new projects with strategic importance. However, despite the importance of the problem, both for the safety implications and for the relapses on the regular execution of the construction, concrete is actually one of the few products that is chosen and purchased in accordance with one feature - the compressive strength - that can’t be controlled at the time of purchase and use.

The technical rules [1,2,3] provide indications regarding the implementation of "acceptance tests" of homogeneous mixtures, which have to be controlled after 28 days from the concrete casting. These checks, based on the satisfying of analytical relationships on a statistical basis, are performed on specimens taken during concrete casting, which are properly moulded, compacted and cured in order to develop the so-called "*potential resistance*", that is the upper limit value that a given concrete is capable of developing. If the quality inspection (which is mandatory during the *supervision of works*) is positive, the concrete is “accepted”, i.e. it is considered compliant with the design and law requirements, and no additional verification is neede. In this case, from a strictly legal point of view, both the structural safety and contractual relations between manufacturer and constructor are fully satisfied. Leaving aside the non-compliance due to the negligence or poor check, a negative acceptance control is determined by an inadequate value of the concrete strength.

The factors that can induce a decay of the concrete strength in the acceptance control are related to:

- *Production process*: constituent materials (type of aggregates, cement, etc. ..), production technologies, methods and time of mixing;
- *Transport and installation*: duration and type of transport (in cases when the building site isn’t near the production plant); quantity of water added in the mixture; environmental temperature;
- *Preparation of concrete specimens*: temperature of curing (high values favour the hydration process and reduce resistance), moisture degree [4], executive procedures of the test.

As a consequence of the large number of parameters influencing the resistance value in the different realization phases, the building codes seem to neglect the aspects related to the durability and safety at the serviceability limit state. In fact, the rules, while provide specific requirements relating to the reference life in regard to seismic actions, don’t specify the procedures for guaranteeing that the performance requirements of the materials keep constant in time. The question is even more serious in the case of grand works, that not require a large quantity of concrete, but involve a long duration of the material production and execution phases. It should be noted, in fact, that even if the quality inspections are satisfied (i.e. the concrete supply is compliant with specific exposure conditions, consistency and resistance classes, prescriptions about maximum aggregate size and cement) it is not authomatically guaranteed that in the actual structure in-place will be the same as the prescribed one. There are two other operations involving concrete casting, whose performances are the responsibility of the builder and that can affect significantly the behaviour of the entire structure during the service life.

These are:

- Concrete *placing* (intended as the jet and compaction of in-place concrete) that induces a reduction of in situ strength compared to that of the specimens used in quality inspecttions [5]. In this sense, some of the proposals in the literature show how to quantify the effects of compaction on acquired resistance by in situ destructive tests [6];
- *Aging*. Temperature and time of aging significantly influence the final resistance of specimens. The routine control doesn't always provide consistent results for productions that continue for long periods of time.

In this paper, statistical processing of data collected during the realization phases of the works in support of the Esaro Dam (Calabria, Southern Italy) is presented. Numerical processing based on the resistance values collected by the tests carried out on samples taken during the executive phase, both by the Company and by the Building Supervisor (i.e. the person in charge of the control of materials on behalf of the client, hereinafter "BS"), allows to perform some remarks on the limits on the quality control of concrete for major works. These controls, by the heterogeneity of the mixtures and strength classes provided are made complex.

These operations, made during realization stages, may be useful if in the future the structural safety must be evaluated (typical is the case of existing buildings or infrastructure [7,8,9,10]. In such cases the features in time of concrete must be evaluated, especially for structures that do not have control or monitoring systems for the static capacity in time [11,12,13].

For a better understanding of the reflections produced by this note, a brief summary and critical framework of quality control in the standards are described. For this purpose in the next section there is an overview of the main indications contained in the Italian and European standards.

2 ITALIAN AND EUROPEAN RULES (REGULATORY FRAMEWORK)

2.1 Quality Inspections

As indicated by NTC2008[1], BS has the obligation to verify, during construction and concrete casting, at the end of 28 days from the execution, that the characteristic "*potential*" compressive strength of the concrete (hereinafter indicated with the abbreviation $R_{ck,pot}$) is higher than the characteristic resistance of project ($R_{ck,d}$):

$$R_{ck,pot} \geq R_{ck,d} \tag{1}$$

The characteristic "potential" value is defined as the experimental strength (determined by compression tests) of cubic specimens taken by PS during the control of the concrete supply.

The acceptance of the quantity of concrete is subsequent at the satisfaction of the inequations indicated, respectively, for the control of type A (*§11.1.5.1* - NTC2008[1]) or Type B *(§11.2.5.1* - NTC2008), by adopting the one or the other depending on the amount of homogeneous mixture employed in the realization of the work. For both types the smallest resistance (R_1) between all the specimens must firstly satisfy the following inequation:

$$R_1 \geq R_{ck,pot} - 3.5 \tag{2}$$

In particular, the control of type A, is based on a simplified verification (Eq. 3) and is adoptable only for structures with less than *1500* m^3 of homogeneous concrete, by taking a sample every *100* m^3 of casting and however a minimum of *3* samples (then *6* specimens, because one sample is equal to two specimens).

$$R_{ck,pot} \leq R_{cm,pot} - 3.5 \tag{3}$$

where $R_{cm,pot}$ is the average resistance of the samples (expressed in MPa).

If the amount of homogeneous mixture exceeds 1500 m^3, it is required to adopt control of type B, which is a purely statistical control, in which the correlation between the characteristic and average value is defined by the following equation:

$$R_{ck,pot} \leq R_{cm,pot} - 1.4 \cdot \sigma_{pot} \tag{4}$$

With σ_{pot} standard deviation of the resistance values evaluated on the cubes.
The number of samples to evaluate the mean value $R_{cm,pot}$ and the standard deviation σ_{pot} must be greater than or at least equal to *15* (*30* cubes). Furthermore, it should check that the coefficient of variation (CV) usually called *Relative Standard Deviation*, given by the ratio between standard deviation and average resistance, must not exceed the limit value of *0.3*. If CV exceeds the threshold value of *0.15*, BS must perform more accurate controls. Specifically, if CV is greater than *15%* is necessary to carry out the evaluation of the concrete strength by non-destructive in-situ tests (rebound-hammer or ultrasonic pulse velocity) and destructive tests (extraction of samples by core drilling).

As noted above, the rules state that the conglomerate is identified by its characteristic resistance (potential if verified by means of samples taken during casting), ie compression strength at below which is located only *5%* of all measurements.
However, in correspondence of the fractile of *5%* , the value of the multiplying factor of the standard deviation is equal to *1.64*, while for a value equal to *1.4* (indicated by the standard) the fractile is equal to *8%* [14]. This means that a positive acceptance of control implies that only *92%* of the values are greater than the characteristic value $R_{ck,pot}$. An important issue, always for type B controls, and thus for great quantities of conglomerate, is the possibility to perform accurate statistical analysis. The interpretation of the experimental results can be carried out by identifying the more appropriate law of the statistical approach (without necessarily to use the normal distribution as in the past).
In this case the minimum resistance of sampling (R_1) must be greater than the value corresponding to the lower fractile of *1%* ($R_{ck,pot\,-1\%}$).

$$R_1 \geq R_{ck,pot-1\%} \tag{5}$$

Therefore, the technical standard forces that *99%* of all the resistance of the sample is greater than the minimum resistance R_1.

2.2 Quality control of in-situ concrete strength

If the mechanical strength of the samples taken during the concrete casting doesn't satisfy Eq. 1, or in cases where there's doubt about the validity of the acceptance tests, BS or the *Static Tester* must carry out the assessment of the characteristic compressive strength of in situ concrete (also called "*structural*" strength $R_{ck,strutt}$) by executing experimental investigations based on core drilling and non-destructive tests.

The core drilling is the most commonly used destructive method. It is based on in the extraction of specimens of cylindrical shape. The specimens has *non-standard* size (ie having a *slenderness* λ - defined as ratio between height H and diameter D - equal to 1) if compression concrete strength value must be compared to the characteristic "cubic" strength of project or potential ($R_{ck,d}$ o $R_{ck,pot}$), while it has *standard* size (with λ equal to 2) when the comparison is in terms of the characteristic "cylindrical" resistance of project or potential ($f_{ck,d}$ o $f_{ck,pot}$).

For assessing of the *structural* strength (in situ), with reference to the cylindrical value $f_{ck,strutt}$ the indications contained in the main technical rules [15] provide two cases:

1. Evaluation of the average value in situ $f_{cm,strutt}$, when the number of cores is less than 15. In order to verify the conformity of the material in place, this value must be greater than *85%* of the average cylindrical value of design f_{cm}, according to the following relations:

$$f_{cm,strutt} \geq 0.85 \cdot (0.83 \cdot R_{ck,d} + 8) \quad (6)$$

2. Also evaluation of the characteristic value if the number of cores is greater than *15*. This kind of control is purely statistical and it is based on the correlation between characteristic and average value by the following equation:

$$f_{ck,strutt} = f_{cm,strutt} - 1.48 \cdot \sigma_{strutt} \quad (7)$$

where σ_{strutt} is the standard deviation of mechanical strengths of the cores. For this additional parameter, therefore, the acceptance control is to satisfy the following relation:

$$f_{ck,strutt} \geq 0.85 \cdot (0.83 \cdot R_{ck,d}) \quad (8)$$

With regard to the comparison between "structural" and "potential" strength, the NTC2008 *(§ 11.2.6*) clearly explain that the value $R_{cm,strutt}$ is generally less than the average value of the resistance $R_{cm,pot}$ of samples taken during concrete casting and preserved in optimal laboratory conditions (*20°C* e φ*>95%*).

At the end of the overview about acceptance tests, is reported below the casuistry on the possible responsabilities attributable to professionals when *Eqs. 6* and *8* are simultaneously satisfied and not satisfied:

1. *Eqs. 6 and 8 satisfied*: the strength of the in situ concrete is acceptable without further verification. It may, however, remain a possible dispute against the supplier if Eq. 1 is not verified.
2. *Eqs. 6 and 8 unsatisfied*: BS or the *static tester* can require the structural strengthening or even the whole demolition. In this case, the overall cost of such actions will be borne by the supplier if the concrete $R_{ck,strutt}$ is greater than *85%* of $R_{ck,pot}$ because the constructor has put in-situ a concrete lacking provided by the supply. If, however, the resistance characteristic of the structure is less than *85%*, the cost is borne also by the company because the concrete already poor, in a wrong way was casted.

2.3 Concrete laying

The care in concrete casting is an aspect that greatly affects the durability of the material, and as noted at the end of the previous paragraph, is one of the causes of legal challenges that arise during acceptance tests. In RC structures built with ordinary concrete (excluding the self-compacting concrete), the structural resistance R_{strutt} (average or characteristic value), that is determined on drilled cores, is less than the resistance measured on test specimens (cubic or cylindrical) taken during the casting phases. Thus, indicating, respectively, with $R_{C,pot}$ the mechanical strength of a cubic specimen, $f_{C,pot}$, the cylindrical strength of specimen (both taken by jets) and f_{core} the resistance of a sample extracted by a RC element of the structure by core drilling:

$$0.83R_{C,pot} = f_{C,pot} \geq f_{core} \quad (9)$$

The differences not only by the factors relating to the operations of drill are caused (such as the damage on the sample induced by core drilling), but especially to the incomplete compaction of the concrete than the highest obtained for samples taken during the cast.

The correlation between R_{CI} and f_{core} is strictly dependent on the care taken during the concrete casting. This care can be measured by the following parameter, called "*compaction degree*" g_c [5]:

$$g_c = \frac{m_V}{m_{VO}} \tag{10}$$

where m_{V0} is the density of the specimen and m_V is the density of the drilled core.

For an ordinary structural work, considering homogeneous classes of material, if the structural concrete has been compacted with the same care with which it has been the concrete of the specimen, the degree of compaction is unitary: $g_c=1$. The density m_V will, instead, less than m_{v0}, and consequently $g_c<1$, if the efficacy of the compaction of the core is lower than that of the specimen. By means of experimental tests on concretes having different consistency classes and resistances, the same author has evaluated the influence of g_c on the percentage decrease of the concrete mechanical strength ΔR_g inside the structure than the value of the corresponding specimen:

$$\Delta R_g = \frac{f_{C,pot} - f_{core}}{f_{C,pot}} \cong (1 - g_c)500 \tag{11}$$

It represents a linear relationship between ΔR_g and g_c valid in the range $0.90 < g_c < 1$ relative to concrete for structural uses.

The uniaxial compression test allows to derive the compression strength of the cylindrical core. The value is strongly dependent on various parameters associated with the test mode that make it substantially different from the effective resistance of the in situ concrete.
Guidelines on how to perform the test and the processing of the results obtained are the [16,17,18]. These documents take as reference the compressive strength measured on a "standard" core ($\lambda = 2$). It is possible, however, to take samples having *non-standard* size provided that, the value of the relative strength $f_{c,nst}$ is reported (by appropriate corrective coefficients) to a resistance associated with an equivalent sample of *standard* size:

$$f_{core} = F_{mc} F_d \left(F_{H/D} F_{dia} F_r f_{c,nst} \right) \tag{12}$$

$F_{H/D}$, F_{dia} and F_r are respectively the corrective coefficients which take account of the effects induced by the variability of λ, D and when the reinforcement bars are inside the core ("*internal*" or "*form*" factors). F_{mc} and F_d are correction factors to take account of, respectively, the storage conditions of the specimens before of the compression test and the damage induced by drilling core ("passive" factors).

The effects of these factors on the strength value and the different proposals to assess numerically the coefficients can be found in numerous research studies in the literature [19,20,21,22,23,24,25,26,27,28,29,30].

The numerical variability of the strength (f_{core}) is therefore intrinsic. It is to be intended as a sum of the variability of independent parameters relating to the execution method of the experimental test, the quality of the material, geometrical characteristics of the samples and the damage caused by the drilling core. With good approximation, the overall variability is between a minimum of *3.2%* [27] to a maximum of *6.0%* [31].

3 THE CASE STUDY

The Esaro dam is a strategic work made necessary by the growing problems of water supply of the entire territory of the Province of Cosenza. The completion of the dam (to date imminent) will allow an increase in water flow rate of *200* liters per second for the areas between the Tyrrhenian and Ionic coast of Cosenza. In this case, the generic name "dam"

means a collection of works which together with the main structure are fundamental to the enjoyment and the normal functioning of the entire structural system. At the present date, only the support works, necessary for the construction phase of the dam itself, have been completed. The construction of these works began in 2004 and ended in 2012.
These works can be collected in three large sub-categories (Table 1):

Sub-category	Volumes of Concrete *[mc]*	Number of specimens
Sedimentation-Basin	*27255*	*660*
Road	*4088*	*370*
Work for stability	*17118*	*430*
TOTAL	48461	1460

Table 1. Quantities of concrete in place and number of specimen taken during the operations of casting

In particular, within the category "sedimentation basin", the structure of water collection, the retaining structures, walls and boundary of basin are collected; In the "street" falls the entire road of the dam, which provides a bridge and a tunnel of connection; finally, under the category "works of stability", conglomerate volumes associated with "works restraint" (containment structures of the soil to protect the road subject to landslide risk as a result of the digging operations) and the related foundation are collected. The heterogeneity of the works has induced the use of mixtures very different not only for strength classes, but especially for exposure and consistency classes. The importance of the work and the long realization times, led us to adopt systematic control in building site of the mixtures used. To this end, the presence on site of the concrete mixing plant and of the testing laboratory has allowed to a systematic quality control of the material. Different strength classes for each category were used and Tab. 2 reports the number of cubes taken during the jets and crushed by the laboratory in building site and by the official one.

$R_{ck,d}$ *[MPa]*	In building site n. cubes	Official Laboratory n. cubes	Total n. cubes
22	*746*	*278*	*1024*
25	*16*	*42*	*58*
30	---	*312*	*312*
35	*34*	*24*	*58*
40	---	*8*	*8*
TOTAL		1460	

Table 2: Number of cubes taken during the execution stage for different strength classes

4 CONTROL DURING EXECUTION PHASE

The controls of the concrete used for the realization of works in support of the dam, can be divided into two groups:

- *Production controls*. These are based on statistical processing of values obtained by the samples of the various strength classes and by the control of the concrete curing;
- *Laying controls*. These are to assess the compaction degree by statistical approach, in according to specific relations of the literature on issue [5].

In the first group, the numerical processings have concerned samples constituted by cubes. The resistances correspond to values after 28 days by execution of the cast, while as regard to the second group, resistances after, respectively, 3, 7, 21 and 28 days were considered.

4.1 Production controls

On the basis of the volumes of concrete used for the construction of structures (quantity far greater than *1500* m^3), the conformity of the material by assessing the acceptance check of type B was evaluated. In addition, for all the homogeneous classes analyzed statistical elaborations were carried out. The statistical approach allows to process the resistances at *28* days of cubes taken in-situ, in order to identify distribution laws alternatives to the normal one and evaluate main statistical parameters that are representative of every sampling. In particular, for samplings more numerous relating to a $R_{ck,d}$, equal, respectively, to *22*, *25*, *30* and *35 MPa*, significant statistical parameters (mean value μ, standard deviation σ, variance σ^2 and coefficient of variation, *CV* - Table 3) were identified and, furthermore, the normal and lognormal distribution laws were evaluated.

	Samplings			
$R_{ck,d}$ *[MPa]*	22	25	30	35
μ *[MPa]*	*27.71*	*31.24*	*37.09*	*40.21*
σ *[MPa]*	*2.14*	*2.20*	*2.50*	*1.47*
σ^2 *[MPa²]*	*4.60*	*4.83*	*6.25*	*2.16*
CV *[%]*	*7.77*	*7.03*	*6.74*	*3.65*

Table 3. Main statistical parameters of samplings analyzed

It should be noted that the values of *CV* of each sampling are lower than the 15% threshold beyond which the Italian legislation requires more accurate tests (destructive and non-destructive test on samples extracted by structural elements).

The value of the "*potential*" characteristic strength of each sampling was evaluated by a lognormal distribution law, after a preliminary check in order to ascertain the good correspondence with the distribution of the relative frequencies. The Figure 1 shows the statistical distributions of the most numerous sampling (ie those associated with $R_{ck,d}$ equal to *22* and *30*) while Figure 2 shows the potential characteristic strength at the *5%* fractile of the cumulative lognormal distributions. Also this figure, in the spirit of statistical approach provided by the acceptance tests of type B, shows the value corresponding to the *1%* fractile $R_{ck,pot\ -1\%}$ as representative of the minimum strength of sample taking (ie. sampling).
For these samplings, the defined distribution laws approximate satisfactorily the experimental distribution, while it is interesting to note, that lognormal law, identified as an alternative to that normal, roughly follows the same normal distribution.

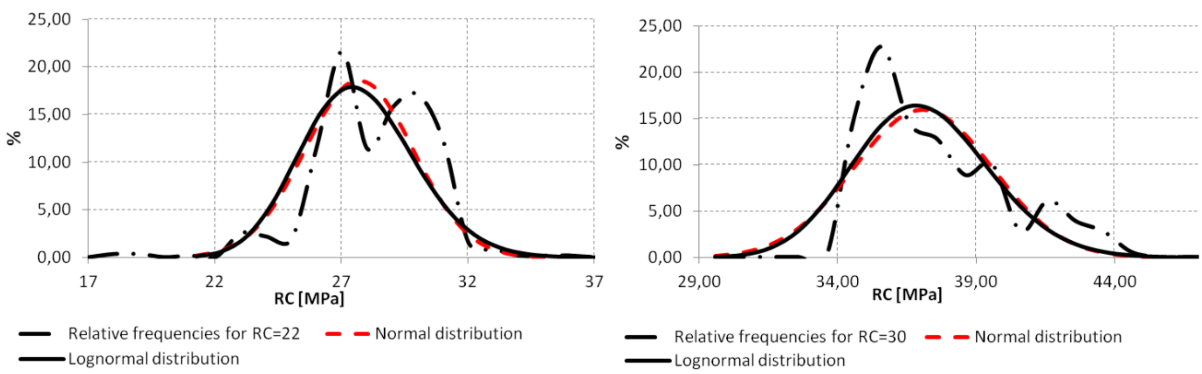

Figure 1: Relative frequencies, normal and lognormal distributions for analyzed samplings .

Instead the lognormal law, used in the calculation of the potential characteristic value $R_{ck,pot}$ (Figure 2) (as intersection with fractile of 5%), provides slightly lower values than those obtained by normal cumulative distribution (with the exception of the sampling associated with $R_{ck,d}$=22 MPa), but in any case values aren't higher than 5%.

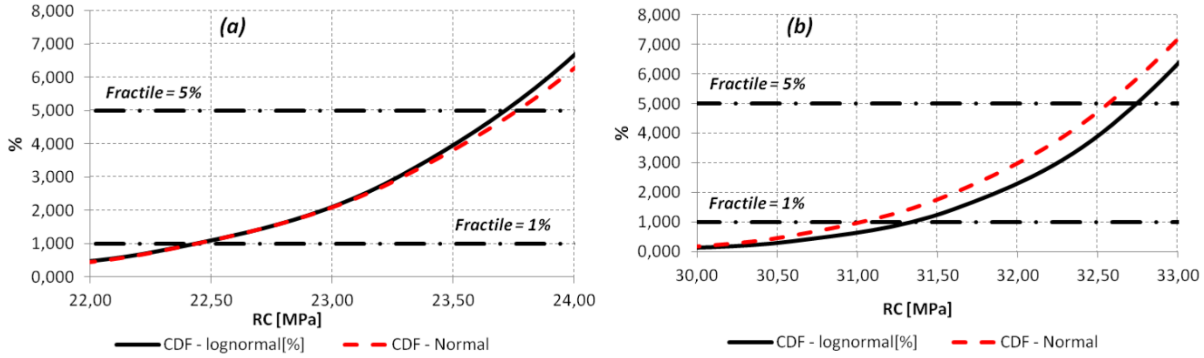

Figure 2. Acceptance control of type B: potential characteristic strength and lower threshold value for sampling associated with project resistance $R_{ck,d}$ equal to 22 (a) and 30 (b)

The values of the potential characteristic strength ($R_{ck,pot}$), those corresponding to 1% fractile ($R_{ck,pot\ -1\%}$) (as intersection of the lognormal law with fractile of 1%), the average resistances of sample taking ($R_{cm,pot}$) and the lower resistance of sampling (R_1) are reported in Table 4. It 's clear that for all samplings Eqs. 1, 4 and 5 are respected, although the latter applied improperly (ie not only every 3 samples but on the entire sampling), and furthermore, values exceed the lower threshold ($R_{ck,pot\ -1\%}$) required by statistical control.

Sampling	$R_{ck,pot}$ *[Mpa]* (fractile=5%)	$R_{ck,pot\ -1\%}$ *[MPa]* *(fractile =1%)*	$R_{cm,pot}$ *[Mpa]*	R1 *[MPa]*
$R_{ck,d}$=22 MPa	23.70 *Eq.1, OK!*	22.38	27.71 *Eq. 4,OK!*	22.41 *Eq. 5,OK!*
$R_{ck,d}$=30 MPa	32.58 *Eq. 1, OK!*	31.12	37.09 *Eq. 4, OK!*	33.64 *Eq. 5, OK!*

Table 4. Acceptance tests for the concretes of the case study

4.2 Laying controls

The laying control plays a predominant role in monitoring of conformity of the material. Indeed, it becomes important when is necessary to quantify, especially in the case of great infrastructure projects, the gap in strength between the *potential* material (corresponding to maximum compaction degree) and the *structural* material.

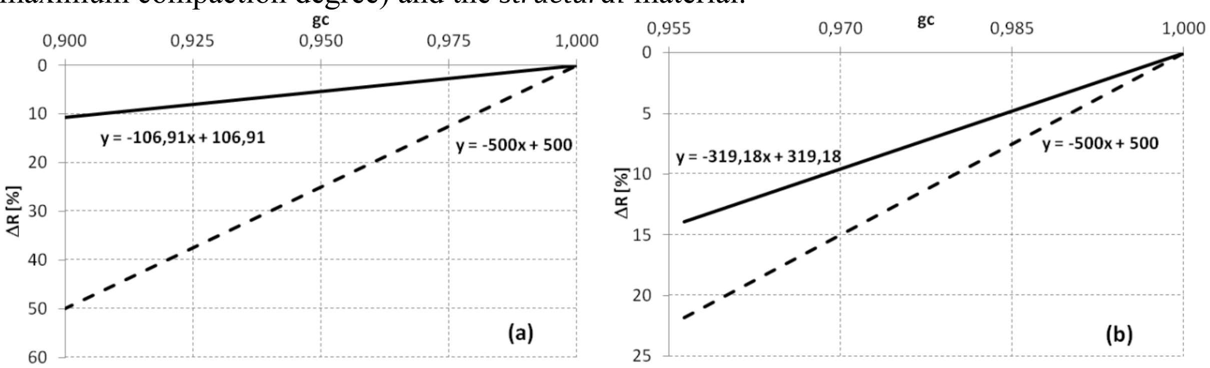

Figure 3. Comparison between percentage reductions of structural strength than the potential values and Collepardi's law [5], as a function of the compaction degree, for sampling associated, respectively, with $R_{ck,}$d=22 MPa (a) and $R_{ck,d}$=30 MPa (b).

The reduction of structural strength than that measured on samples taken during the concrete casting, for the samplings considered until now was evaluated as a function of the compaction degree g_c, according to the approach described in § 1.3. In particular, for each sample $\Delta R=\Delta R(g_c)$ law was identified by expressing it in a form similar to Eq. 11. The results shown in Figure 3 are particularly interesting.

The reductions *ΔR* for the sampling having strength class lower ($R_{ck,d}=22MPa$), are very small than the Collepardi's law (Fig. 3a). In addition, the reductions obtained are about *1/3* than the other sampling analyzed (relating to material having $R_{ck,d}=30MPa$ - Fig. 3b).
Therefore, graphs shows a good compaction of concrete having class equal to *22 MPa* (the reductions are approximately *1/5* of theoretical prevision) and the conservative trend of the Collepardi's law.

In the testing phase, several cores were extracted by core drilling, the reductions of strength as a function of the compaction degree were evaluated for cores relating to strength class $R_{ck,d}=22MPa$. The corresponding values were reported within the $\Delta R[\%]$-g_c format together with the distributions of ΔR for the whole sampling (respectively after 7 and 28 days of curing) and with theoretical trend proposed by Collepardi (Fig. 4).

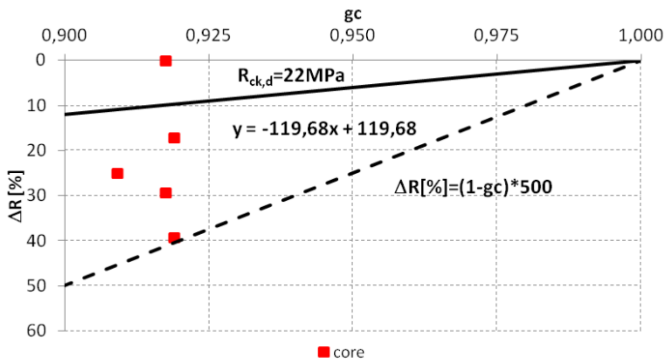

Figure 4. Comparison between percentage reductions of structural strength than the potential values and Collepardi's law [5], as a function of the compaction degree.

The reduction of resistance of the cores are between the performance of sampling and the theoretical one, this suggests that the strength values were influenced, not only by the concrete laying but also by other factors, as for example, those inherent execution of experimental test. In fact, it should be noted that the effect of damage on sample by core drilling was evaluated only by a coefficient based on experimental researches present in literature. Most likely, by reformulating this coefficient, the points obtained will be closer the trend of the theoretical strength reductions.

5 CONCLUSIONS

The current technical rules are based on an approach that aim to achieve a design conforms to the expected durability and the intended use of the structure. They provide, therefore, indications relating to the sizing of the structural elements and to the construction details in order to obtain structures able to mainly support seismic events. These on the effective characteristics of the ground type and geographic location of the structure are calibrated.

The need to preserve the structural safety in time, it isn't, however, extended to the materials commonly used. For this purpose, the rules provide a detailed control of the conformity of "potential" concrete strength, (ie the concrete strength measured on samples taken during the casting operations), compared to the design value. This control can be extended to the “structural" resistance. The assessment allows to resolve any disputes between some professional figures involved in the construction process. In this context is evident that one of the possible causes of discrepancy is caused to poor laying of the concrete. This circumstance is amplified in major works, for the great concrete amount and the prolonged periods of execution.

This study, by data collected during the execution of some structure to support of a dam, provides some remarks on fundamental role of the laying of the concrete. The study highlights how the current rules are particularly restrictive. The statistical results together with specific numerical elaborations have led to consider appropriate the control, not only of the concrete strength, but also of the laying intended as a measure of the durability of the material in time.

It is therefore outlined by the description of the results collected, a systematic procedure based on the measurement of the compaction degree g_c for cubes in-situ packaged. The procedure allows to quantify the reductions of strength in percentage terms of the "structural" value (on site) than the corresponding "potential" value.

The convenience obtained by controlling the compaction degree in the construction phase is unquestionable. Specifically, it may allow a reduction of the drilling cores especially for relatively recent structure in favor of extensive non-destructive investigations. Any changes in concrete performance will be obtained by measurement of the rebound index or ultrasonic pulse velocity.

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