ACCEPTANCE OF CONCRETE COMPRESSIVE STRENGTH

Prof. Tibor Kausay Dr. Tamás K. Simon

The new concrete standards give directives regarding the checking if the hardened concrete conforms to the compressive strength requirements of the designed compressive strength class. The acceptance or rejection of conformity is the function of the compressive strength testing methods and the evaluation of the test results. In the paper through examples we show the role of the acceptance probability and the acceptance constant during the evaluation of test results and their significance during the conformity verification procedure.

Keywords: concrete, concrete grade, conformity, continuous manufacturing, continuous testing, identification testing, acceptance probability, acceptance constant, design value

1. INTRODUCTION

According to table 3.1. of MSZ EN 1992-1-1:2005 (Eurocode 2) standard, during the design of concrete structures the mean compressive strength value $f_{cm,cyl}$ is derived from the characteristic compressive strength value $f_{ck,cyl}$ by using the following relationship:

$$f_{cm,cyl} = f_{ck,cyl} + 8 \quad [N/mm^2] \tag{1}$$

This relationship is valid for cylindrical samples of 150 mm diameter, 300 mm high, 28 days of age and cured under water throughout the time (wet cured). Generally the concrete technology tests the conformity of compressive strength on cubes with the sizes of 150 mm, at the age of 28 days which were mix cured (first 7 days under water, 21 days on air).

If we accept that according to the new concrete standard, namely MSZ EN 206-1:2002 European standard and it's roles of application in Hungary MSZ 4798-1:2004 document, until the compressive strength class C50/60:

$f_{c,cube}/f_{c,cyl}$ = 0.97/0.76 is the ratio between the wet cured, cylindrical samples of 150 mm diameter, 300 mm high and cubic samples with the sizes of 150 mm, and

$f_{c,cube}/f_{c,cube,H}$ = 0.92 is the ratio of the compressive strengths of the wet cured and mix cured normal concrete cubic samples with the sizes of 150 mm,

then the connection between the compressive strengths of the mix cured cubic samples with the sizes of 150 mm ($f_{c,cube,H}$) and the wet cured cylindrical samples of 150 mm diameter, 300 mm high ($f_{c,cyl}$) can be expressed as

$$f_{c,cube,H} = 0.97/(0.76 \cdot 0.92) \cdot f_{c,cyl} \sim 1.387 \cdot f_{c,cyl}, \tag{2}$$

which after substituting into the right and left side of relationship (1) will derive to

$f_{cm,cube,H}/1.387 = f_{ck,cube,H}/1.387 + 8$ [N/mm^2], and from here we can arrive to the

$f_{cm,cube,H} = f_{ck,cube,H} + 11.1$ [N/mm^2]

expression. This gives the relation of the mean compressive strength and characteristic compressive strength of the 28 days old sample cubes with edges of 150 mm, mix cured, according to MSZ EN 1992-1-1:2005 until the compressive strength class of C50/60.

So by the approach of MSZ EN 1992-1-1:2005 for example the concrete of C25/30 compressive strength class at the age of 28 days, mix cured, should have a minimum mean compressive strength determined using cubes with 150 mm edges of

$f_{cm,cube,test,H} \geq f_{cm,cube,H} = 33 + 11.1 = 44.1$ [N/mm^2].

Based on the MSZ EN 206-1:2002, and the MSZ 4798-1:2004 Hungarian standards the concrete having the compressive strength class of C25/30 at the age of 28 days, mix cured and the compressive strength is determined on cubes with the sizes of 150 mm will have a mean compressive strength instead of the above calculated $f_{cm,cube,H} = 44.1$ N/mm^2 only $f_{cm,cube,H} = f_{ck,cube,H} + 1.48 \cdot 1.387 \cdot \sigma_{min} = 33 + 1.48 \cdot 1.387 \cdot 3 = 39.2$ N/mm^2. A certain safety margin is given by that between the design compressive strength value of concrete (f_{cd}) and the characteristic value of it defined on standard cylindrical samples with 150 mm diameter, 300 mm height and wet cured ($f_{ck,cyl}$) exists the relation of $f_{cd} = f_{ck,cyl} \cdot \alpha_{cc} / \gamma_c$, where $\gamma_c = 1.5$ is the safety factor of concrete compressive strength in the ultimate limit state and $\alpha_{cc} = 0.85$ is the decrease factor taking into consideration the long term load bearing capacity. Accordingly for example the design compressive strength of a concrete (f_{cd}) defined on standard cylinders which were wet cured is $f_{cd} = 14.2$ N/mm^2.

If it is found during the statical calculation – not taking into consideration the environmental conditions – that the practice would require a concrete having $f_{cd} = 14.2$ N/mm^2 design value, then the designer based on MSZ EN 1992-1-1:2005 will prescribe concrete of C25/30 compressive strength class. To this class, according to the above $f_{cm,cube,H} = 44.1$ N/mm^2 mean compressive strength belongs, considering mix cured standard cubes. At the same time the mixing plant will satisfy the prescription – based on MSZ 4798-1:2004 – with a concrete having a mean compressive strength of $f_{cm,cube,H} = 39.2$ N/mm^2 considering also mix cured standard cubes.

The deviation arises from the different relationship calculation of the characteristic and mean values, which is being further complicated by the unusualness of the acceptance constant (λ_n) given in the new concrete standards.

Generally the hardened concrete is to be characterized by it's compressive strength and body density, in special cases by frost resistance, corrosion resistance, water permeability, resistance against wear etc., and according to these properties, based on MSZ EN 206-1:2002, and the MSZ 4798-1:2004 Hungarian standards should be classified. The 4.3. paragraph of MSZ 4798-1:2004 Hungarian standard deals with the classification of hardened concrete, the testing and requirements are given in paragraph 5.5., the conditions of conformity and the controlling procedures are dealt with in the 8. paragraph.

The concrete satisfies the compressive strength requirements if it complies to paragraph 8.2.1. and appendix A and B of MSZ 4798-1:2004 Hungarian standard regarding the compressive strength and the body density.

During compressive strength testing and evaluation of the test result differentiation must be made between the discrete concrete constitutions sampling and testing procedure, while in the conformity conditions between initial production and testing, the continuous production and testing and the identifying testing procedure.

The evaluation of the continuous production and identifying testing is to be done by the mean value (f_{cm}) and standard deviation (s_n) of the test values.

The characteristic value (f_{ck}) and so the derived compressive strength class is significantly influenced by the acceptance constant (λ_n):

$$f_{ck} = f_{cm} - \lambda_n \cdot s_n \tag{3}$$

2. THE CONTINUOUS PRODUCTION AND TESTING

The continuous production of concrete starts at the time when at least 35 consequently under the same conditions produced concrete test results are available within the period of longer than three month but not more than twelve month, and this is called by the new standards the initial production. From the test results of the initial production the standard deviation must be calculated (σ), which gives a good approximation of the theoretical standard deviation and which under certain circumstances should be taken into consideration during the evaluation of the test results of the continuous production.

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}\left(f_{ci} - f_{cm,test}\right)^2}{n-1}} = \sqrt{\frac{\sum_{i=1}^{n} f_{ci}^2 - n \cdot f_{cm,test}^2}{n-1}}, \quad \text{where } n \geq 35.$$

From here on the smallest value of the σ standard deviation, in the case of wet cured standard cylinders:

- in case of normal concrete (if the compressive strength class is ≤ C50/60): 3 N/mm^2;
- in case of high strength concrete (if the compressive strength class is ≥ C55/67): 5 N/mm^2.

The result of continuous production can be evaluated by at least 15 consequent sampling and testing within a maximum period of 12 month. The samples are to be taken continuously during the production but not more frequently than one sample out of every 25 m^3.

In case of continuous production one sample may only be one test cylinder or cube. At the beginning of continuous production, until 15 samples are not yet available the number of samples should be complemented with the samples taken at the end period of the initial production.

For the evaluation of the results of continuous production must be given at least 15 test results, the average of the at least 15 test results, and using the following expression must be calculated the standard deviation of the at least 15 test results:

$$s_n = \sqrt{\frac{\sum_{i=1}^{n}\left(f_{ci} - f_{cm,test}\right)^2}{n-1}} = \sqrt{\frac{\sum_{i=1}^{n} f_{ci}^2 - n \cdot f_{cm,test}^2}{n-1}}, \quad \text{where } n \geq 15.$$

During the continuous production the concrete satisfies the requirements of the compressive strength class (conformity) if the following conditions are fulfilled at the same time:

1. condition in case of all compressive strength class according to table 14. of MSZ 4798-1:2004 Hungarian standard in case of wet cured standard cylinders:

$$f_{cm,test} \geq f_{cm} = f_{ck} + 1.48 \cdot \sigma$$

where σ is the standard deviation calculated from the initial production, based on the test results of at least 35 sample and 1.48 is the value of the acceptance constant ($\lambda_{n=15}$)

(table 6.). The smallest value of standard deviation to be taken into consideration in case of wet cured standard cylinders:

- in case of normal concrete (if the compressive strength class is ≤ C50/60): 3 N/mm^2;
- in case of high strength concrete (if the compressive strength class is ≥ C55/67): 5 N/mm^2;
- further on for all types of concrete: $0.63 \cdot \sigma \leq s_n \leq 1.37 \cdot \sigma$;
  that is in case of samples from continuous production the s_n experienced standard deviation determined on a minimum of 15 samples may not be less than 0.63 times the σ theoretical standard deviation determined from the minimum of 35 samples of the initial production and may not be more then 1.37 times of the same σ value.

If the above requirement of the standard regarding the standard deviation is satisfied then the standard deviation σ determined during the initial production may be used in the period of continuous production for the compliance checking of conformity.

If the above requirement of the standard regarding the standard deviation is not satisfied, then based on the test results of the latest at least 35 samples (since continuous production is assumed, at least 35 test samples) a new value for standard deviation σ must be calculated.

If the manufacturer is unable to prove the value of standard deviation for the initial production period, then for wet cured standard cylinders we must calculate with the value of $\sigma \geq 6$ N/mm^2 (8.2.1.3. paragraph of MSZ 4798-1:2004 Hungarian standard).

2. condition according to table 14. of MSZ 4798-1:2004 Hungarian standard in case of wet cured standard test cylinders:

- in case of normal concrete (if the compressive strength class is ≤ C50/60): $f_{ci} \geq f_{ck} - 4$ [N/mm^2];
- in case of high strength concrete (if the compressive strength class is ≥ C55/67): $f_{ci} \geq 0.9 f_{ck}$.

The MSZ EN 1992-1-1:2005 and the MSZ EN 206-1:2002 standards set up conformity for the compressive strength of concrete based on compressive strength test results of cylinders having a diameter of 150 mm and a height of 300 mm which were kept under water through the time of 28 days. Due to this reason in case of evaluating compressive strength results of cubes – having sizes of 150 mm and wet or mix cured – we do not make mistakes if we calculate the individual result values to the compressive strength of the wet cured standard cylinders and evaluate these values by taking into consideration the conditions of conformity.

According to paragraph 5.5.1.2. and N2. topic of MSZ 4798-1:2004 Hungarian standard until the compressive strength class of C50/60 the ratio of the compressive strengths of the standard cylinder and cube if wet cured according to expression (2) is $f_{c,cube,H}/f_{c,cyl} = 0.97/(0.76 \cdot 0.92) \sim 1.387$.

Implicitly using the exchange rate given in the national application document's NAD 3.2. note in MSZ 4798-1:2004 standard and dividing by this factor the measured compressive strength of a cube with the sizes of 150 mm mix cured, we can get to the compressive strength of a standard cylinder with 150 mm in diameter and 300 mm height which was wet cured as can be seen in the numerical example.

A further condition of conformity is that the fresh concrete test samples which are prepared for compressive strength testing may not alter in their body density more then ± 2 % from the designed density of the concrete.

For the evaluation of compressive strength test results in case of continuous production a numerical example is given in *Table 1*.

Table 1: Numerical example for the evaluation of compressive strength test results in case of continuous production

Sign of sample (1 sample = 1 specimen)	Sample cube $f_{ci,cube,test,H}$	Sample cylinder $f_{ci,cyl,test}$	*2. condition* $f_{ci,cyl,test} \geq f_{ck,cyl} - 4$
1.	47.1	34.0	34.0 > 21.0
2.	45.4	32.7	32.7 > 21.0
3.	44.3	31.9	31.9 > 21.0
4.	47.9	34.5	34.5 > 21.0
5.	49.3	35.5	35.5 > 21.0
6.	44.8	32.3	32.3 > 21.0
7.	45.0	32.4	32.4 > 21.0
8.	46.9	33.8	33.8 > 21.0
9.	48.8	35.2	35.2 > 21.0
10.	44.9	32.4	32.4 > 21.0
11.	46.7	33.7	33.7 > 21.0
12.	44.5	32.1	32.1 > 21.0
13.	44.0	31.7	31.7 > 21.0
14.	46.2	33.3	33.3 > 21.0
15.	44.8	32.3	32.3 > 21.0
	$f_{cm,cyl,test}$ =	**33.2**	mean
	s_{15} =	1.21	standard deviation
	s_{min} =	3.0	standard deviation at least
	σ_{35} =	1.77 → **3.0**	= σ_{min} from initial production
	$0.63 \cdot \sigma_{min} = 1.89 < s_{min} = 3.0 < 4.11 = 1.37 \cdot \sigma_{min}$		
	$f_{ck,cyl,test} = f_{cm,cyl,test} - 1.48 \cdot \sigma_{min} = 33.2 - 4.4 =$ **28.8**		
	1. condition		
	$f_{ck,cyl,test}$ =	$28.8 > 25 = f_{ck,cyl}$	
	$f_{cm,cyl,test}$ =	$33.2 > 29.4 = f_{cm,cyl} = f_{ck,cyl} + 1.48 \cdot \sigma_{min}$	
Compressive strength class: **C25/30**		Unit: N/mm^2	

3. THE ACCEPTANCE CONSTANT

In Table 14. of the new concrete standards MSZ EN 206-1:2002 and MSZ 4798-1:2004 for the 1. criteria of compressive strength conformity of continuous production the acceptance constant is the λ_n value, by which multiplying the standard deviation s_n, or σ and so obtaining $\lambda_n \cdot s_n$, or $\lambda_n \cdot \sigma$ respectively (lead value). By subtracting these from the mean compressive strength value f_{cm} we arrive to the characteristic strength f_{ck} of concrete. The sign of λ_n in case of t distribution: t_n.

If values of f_{cm}; s_n; and λ_n are given than the characteristic compressive strength can be calculated using formula (3):

$$f_{ck} = f_{cm} - \lambda_n \cdot s_n.$$

In the new concrete standards (MSZ EN 206-1:2002 and MSZ 4798-1:2004) in the 1. criteria for the conformity of continuous production for n = 15 samples the given lead value $\lambda_{n=15}$ = 1.48. This is practically taking the role of the *Student's* factor used by the previously valid Hungarian standard (MSZ 4720-2:1980). The value of this *Student's* factor depend on the number of samples and it was in all cases at least 1.645 but in case of small sample number this was significantly higher. The change of the standard – at least in this point – is by no question in the favour of the producer since the smaller the multiplicator of the 1. criteria, the easier to satisfy the condition. In order to understand the reasons which explain the value $\lambda_{n=15}$ = 1.48 of the acceptance constant (and the values given in the previous standard) it is useful to think over the principles of concrete classification by compressive strength. We must indicate that for the acceptance constant values given in both the previous standard and the 1.48 are mathematical statistically absolutely correct, but – and this is the real reason for the difference – under totally different circumstances. In our explanation we mainly lean on the papers of Taerwe (1986) and Zäschke (1994).

The requirement to be able to classify the concrete into compressive strength classes is that if we would be able to examine the total amount of the used concrete (such being able to determine the distribution of the compressive strength), 95% of the so obtained results (typical value) should reach the predetermined f_{ck} characteristic strength. We may also say that the 5% quantile of the distribution of the compressive strength ($f_{ck,test}$) is bigger or equal to f_{ck} ($f_{ck} \leq f_{ck,test}$).

To the typical value of the compressive strength values of concrete belong that portion, which do not reach the f_{ck} threshold value. The portion of the strength values below the f_{ck} is usually denoted by p, the value of which is between 0 and 1 (many case expressed in percentages). The $f_{ck} \leq f_{ck,test}$ requirement we can express with the help of this portion in the form of $p \leq 5\%$.

Would we know the value of p, our task would be simple, since if $p \leq 5\%$ we would accept the sample and reject in other cases. Naturally we never know the value of p (since for that we would have to examine the total concrete lot as a sample), therefore we need different statistical methods. In all applied method is common the assumption of normal (Gaussian) distribution of the obtained compressive strength values. Further we assume that the test results follow a normal distribution with an unknown expected value μ and σ standard deviation. In this case the 5% quantile of the distribution can be determined by the $f_{ck,test} = \mu - 1.645 \cdot \sigma$ formula.

The *Student's* factors in the earlier Hungarian standard MSZ 4720-2:1980 are explained by elementary mathematical facts. If we know the standard deviation σ of the compressive strength, then the average of the test results $f_{cm,test}$ will give the undistorted estimation of the expected value μ and such $f_{cm,test}$ - $1.645 \cdot \sigma$ is a natural estimation of the 5% quantile. In the standard the condition $f_{ck} \leq f_{cm,test} - 1.645 \cdot \sigma$ expresses exactly that the estimated value of the 5% quantile ($f_{ck,test}$) must remain above the prescribed strength limit which is (f_{ck}).

In case we do not know the standard deviation, then the situation is slightly more complicated since it has to be also estimated. For such a case the

$$\frac{f_{cm} - \mu}{\sigma_n} \sqrt{\frac{n}{n-1}}$$

quantity will follow the so called *Student*-type *t*-distribution with n - 1 freedom and the value of the 5% quantile can be estimated by taking the value of the *t*-distribution from table.

Based on the available data the methods given in MSZ 4720-2:1980 in case of both known and unknown standard deviation estimated the value of $f_{ck,test}$ empirical parameter which was to be matched to the critical prescribed characteristic value f_{ck}. Due to the symmetry of the used probability distributions the property of the so obtained method is that if the manufacturer produced concrete of just „critically good" (that is $p = 5\%$) then the concrete was accepted with a probability of around 50%. Shall we introduce the *A(p)* acceptance probability of the concrete having p characteristic strength, - which would show that with what probability will we accept a concrete having a p portion of the strength values below f_{ck} – then it's meaning is $A(0.05) \approx 0.5$.

The new Hungarian standards MSZ EN 206-1:2002 and MSZ 4798-1:2004 wish to ensure the compressive strength acceptance of the concrete in such a way, which is part of a more widely understood quality control system.

In case of any acceptance, criteria can be interpreted for a concrete with a given p characteristic value and a corresponding $A(p)$ acceptance probability. If we plot $A(p)$ as a function of p then we obtain the acceptance curve (*Fig. 1.*).

The base of the acceptance decision of the new concrete standards (MSZ EN 206-1:2002 and MSZ 4798-1:2004) is the next train of thoughts (Taerwe, 1986, Zäschke, 1994): we would like a quality control system which satisfies for all p characteristic values the criteria of

$$p \cdot A(p) \leq 5\%$$

the uppermost curve (*Fig. 1.*). Further we can state that the criteria system in the new concrete standard satisfies this criteria in the upper curve of fig. 1., since for example:

if	$p = 0.05$	then	$A(p) \leq 1.0$
if	$p = 0.07$	then	$A(p) \leq 0.7$
if	$p = 0.10$	then	$A(p) \leq 0.5$
if	$p = 0.25$	then	$A(p) \leq 0.2$

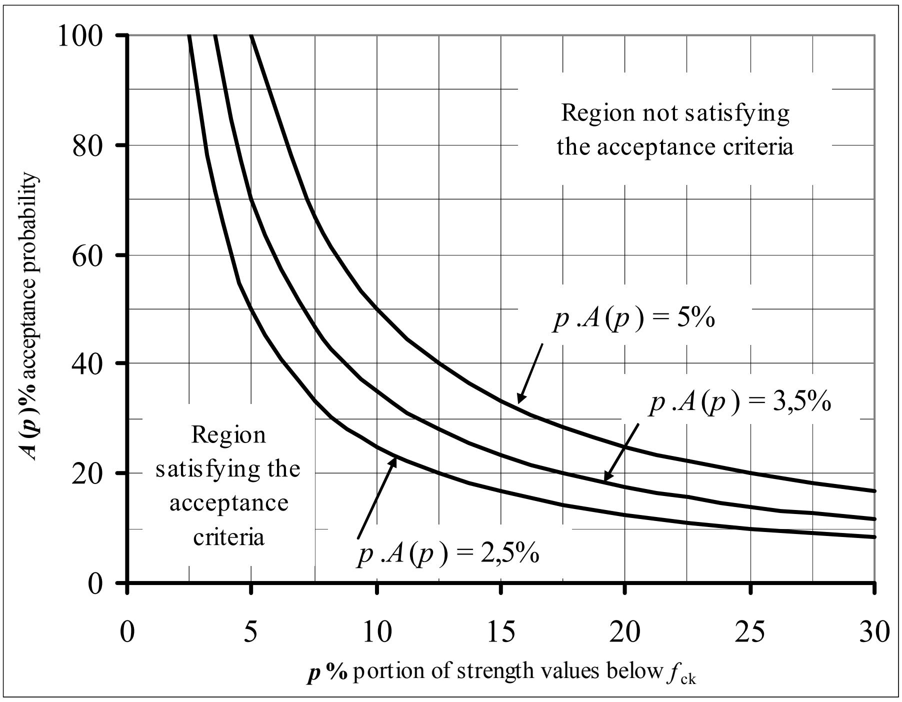

Fig. 1: Acceptance curves

Any acceptance criteria can be taken as a kind of filter: retains the unacceptable samples and lets pass the acceptable ones. Let us assume that we are testing such a material – e.g. rebar – the conformity of which can be checked before application and we are testing it continuously. The confirming lot is being used while the nonconforming lots are substituted by perfect quality ones. In this case obviously the quality of the total used lot will be better due to the filtering of the acceptance criteria. The $p \cdot A(p) \leq 5\%$ criteria ensures that the p value of the filtered lot would remain below 5%. It is important to emphasize on the point that even in this case a *continuous* (and not random) *testing* is to be assumed.

In case of concrete obviously the nonconforming deliveries cannot be substituted with perfect quality ones since by the time the nonconformity is realized the material was long before used. The $p \cdot A(p) \leq 5\%$ criteria will only have sense if the continuous tracking of the usage location of the material is assumed and the part of the structure where the nonconforming material is applied would be post reinforced or by any other means we achieve that it would be practically perfect. (That is the non conforming transports will be transformed to confirming ones afterwards.)

If the concrete which is poured is *continuously* being checked and the non conform parts are afterwards transformed to „perfect”, then the $p{\cdot}A(p) \leq 5\%$ criteria really ensures that in the completed structure the amount of concrete below the f_{ck} compressive strength value (prescribed characteristic value) will be below 5%.

In Table 14. of the new concrete standards (MSZ EN 206-1:2002 and MSZ 4798-1:2004) in the 1st criteria of compressive strength acceptance in case of continuous production the $\lambda_{n=15} = 1.48$ value for the acceptance constant belonging to $n = 15$ samples was determined by *assuming such a continuous control and post reinforcing* quality control system. The quality control system obtained this way will surely satisfy the $p{\cdot}A(p) \leq 5\%$ criteria by a significant safety margin (Zäschke, 1994). It will allow for example that if a mixing plant is producing „critically good” concrete, that is concrete with a portion of the strength values below the f_{ck} $p = 5\%$ then the probability of the acceptance $A(0.05)$ is to be 1.0 (the top curve of *Fig. 1.* where $A(0.05) = 1.0$). The quality control system provided by the $\lambda_{n=15} = 1.48$ constant $A(0.05) \approx 0.7$, meaning that if the produced concrete is „critically good”, then the criteria system will accept it with a probability of about 0.7 (the middle curve of *Fig. 1.* where $A(0.05) = 0.7$). This probability value is significantly smaller then 1.0 which is required by the $p\,A(p) \leq 5\%$ basic criteria, but remarkably more then 0.5 which is ensured by MSZ 4720-2:1980 (the bottom curve of *Fig. 1.* where $A(0.05) = 0.5$). The reason for the safety margin is partly that the $\lambda_{n=15} = 1.48$ acceptance constant is calculated by such a model, which allows a weak correlation between the test results (If we measure a lot, then between the results obtained close in time will be some correlation.). Would we assume that the test results are absolutely independent, then for the $\lambda_{n=15} = 1.48$ value we would obtain 1.318. The values of λ_n acceptance constants are belonging to an offered *OC* curve, and were determined by numerical simulation based on random numbers (Taerwe, 1986). The values of λ_n acceptance constants are in *Table 6.*.

By comparing the old MSZ 4720-2:1980 and the new MSZ EN 206-1:2002 and MSZ 4798-1:2004 Hungarian standards, we can see that the old one wants by a randomly sampling acceptance criteria while the new ones want by continuous testing and post repair possibility ensuring acceptance criteria to become a part of the quality control system. The problem with MSZ EN 206-1:2002 and MSZ 4798-1:2004 standards is that, they contain only the acceptance criteria but the requirement of continuous testing and post repair is missing.

Until now we have dealt with only the 1st, compressive strength criteria of the new standards (MSZ EN 206-1:2002 and MSZ 4798-1:2004) which we could do because according to the practice and simulation tests the 2nd criteria has almost no influence on the criteria system (Zäschke, 1994).

4. IDENTIFICATION TESTING OF COMPRESSIVE STRENGTH

The identification testing of the compressive strength of concrete is to be carried out — according to Annex B of MSZ 4798-1:2004 Hungarian standard — if we want to know that:

- the fresh concrete belongs to the same lot for which the producer certified the conformance of the characteristic strength;
- the fresh concrete conforms with the strength class or other properties which are warranted by the producer, if the producer did not carry out tests for the confirmation certification;
- the hardened concrete in the structure is conforming to the compressive strength class which is warranteed by the producer.

According to our understanding *identification testing* is done by an *independent laboratory*, if its task is not the conformance testing of initial or continuous production (it was carried out by the producer or by an other laboratory), but – by the order of either the producer or the client – the task is only the determination of that the compressive strength class of the concrete is according to the one which is certified by the producer. Same, identification type testing can be done by the client or the contractor in his own laboratory. It is advisable to agree with the producer in the circumstances of the tests and to carry out the tests in his presence. Initial or continuous testing may only be carried out by the producer or his trustee, and based on the result the producer – if necessary by using a qualifying body – issues the conformance statement. The reliability of the conformance statement is checked through identification testing by the customer or his trustee.

In the number of samples „*n*" and the location where the sampling is done the interested parties (prescriber, client, producer) must agree previously in writing.

The result of the hand over procedure of concrete, the acceptance or rejection of the lot depend on the result of the *identification test*. From the point of the safety of our structures it can be appreciated if in this procedure differently from the basic idea of the new standards the risk of the two handing over parties is the same, in other words if the acceptance probability A = 50% of the concrete having p = 5 % portion of the strength values below the f_{ck}, and the results of the compressive strength tests are evaluated to this acceptance criteria ($p\ A(p)$ = 2.5 %). Our offer is not opposing the new standards, it is stricter and leads to the increase of the safety of concrete and reinforced concrete structures and the application does not require the finding of the non conforming concrete or post reinforcement. The procedure can be applied by separate agreement of the interested parties.

The mathematical statistical base of the offered conformity criteria of the identification test is not strange neither to the new (MSZ EN 206-1:2002 and MSZ 4798-1:2004) nor to the old (MSZ 4719:1982 and MSZ 4720-2:1980) Hungarian standards and may be summarized as follows:

- during identification testing of concrete we make no difference if the concrete is produced by production quality control or not;
- based on the mean value, the standard deviation of the compressive strength and the number of samples is the conformity of the concrete determined;
- we assume that the test results follow the normal distribution;
- the characteristic value is ordered to the 5% underfalling portion level based on normal distribution in such a way that in the handing over procedure the acceptance probability of the critically conforming concrete is about 50-50%, the acceptance criteria is to be $p{\cdot}A(p)$ = 2.5 % against the order of MSZ EN 206-1:2002 and MSZ 4798-1:2004 Hungarian standards, according to which in case of continuous production the acceptance-rejection probability for critically conforming concrete is around 70-30% and the acceptance criteria $p\ A(p)$ = 3.5 % (Taerwe, 1986);
- the characteristic value in case of more then 40 samples is determined by using the $f_{ck} = f_{cm} - 1.645{\cdot}\sigma$ formula and in case of less samples (n) the $f_{ck} = f_{cm} - t_n{\cdot}s_n$ formula is to be used, where σ is the theoretical standard deviation, s_n is the empirical standard deviation, t_n is the *Student's* factor (Stange et al., 1966) as a function of the number n of the samples;
- assume that until the compressive strength class C50/60 the mixed cured sample cubes with 150 mm edge length and the 150 mm in diameter and 300 mm in height under water cured cylindrical samples compressive strength have a relation of the following formula $f_{ci,cube,H} = 1.387{\cdot}f_{ci,cyl}$, which is also valid for the prescribed standard deviation values, that is $\sigma_{cube,H} = 1.387{\cdot}\sigma_{cyl}$ and $s_{cube,H} = 1.387{\cdot}s_{cyl}$;
- the sample may be of only one piece;
- the procedure may also be used in case of wet cured (under water) standard cubes and

cylinders.

The concrete is conforming the designed compressive strength class if the next criteria are simultaneously satisfied:

1. criteria:

$f_{cm,cyl,test} \geq f_{cm,cyl} = f_{ck,cyl} + t_n \cdot s_n$

where the value of s_n may not be smaller then the value in *Table 2.* the smallest allowed standard deviation (s_{min});

t_n is the *Student's* factor belonging to 5% underfalling portion level and n sample number with a freedom of $n - 1$, at 50% acceptance probability, the values of which are in *Table 6.*.

2. criteria:

in case of ≤ C50/60 compressive strength class normal concrete:

$f_{ci,cyl} \geq f_{ck,cyl} - 4$ [N/mm^2];

in case of ≥ C55/67 compressive strength class concrete: $f_{ci,cyl} \geq 0.9 \cdot f_{ck,cyl}$.

The further requirement of conformity statement is that the individual body density of the *fresh concrete* samples prepared for compressive strength tests may not alter more then ± 1.5 % from the designed value. (This requirement is 0.5% less then the loose value given in MSZ 4798-1:2004 Hungarian standard and it is according to 15 liter/m^3 air content.)

The number of samples, the *Student's* factors, and the smallest permitted values of the standard deviations for the offered compressive strength identification test of sample cubes are given in *Table 2.*.

Table 2: The sample number, the *Student's* factor, and the smallest permitted values of the standard deviations for compressive strength identification test using the *Student's* factor (offer)

Concrete properties	Without conformity statement	With conformity statement			
	Unique (not serial) production, in all cases	In case of serial production			
Compressive strength class		C8/10 – C16/20		C20/25 – C50/60	C55/67 – C100/115
Concrete designed components		Designed concrete, prescribed concrete and prescribed industrial concrete		Designed concrete and prescribed concrete	
Exposure class		XN(H), X0b(H), X0v(H)	Other classes	All exposure classes	
Number of samples, at least, n	-	200 m^3	150 m^3	100 m^3	50 m^3
	-	at least 1 of each concrete volume, but at least 1 of each lot			
	3	3	6	9	9
The *Student's* factor t_n belonging to the 5% underfalling portion level, by 50 % acceptance probability, in the function of n required sample number (Stange et al., 1966)					
t_n, if the freedom n-1	2.920	2.920	2.015	1.860	1.860
Smallest allowed value of standard deviation, in case of wet (under water) cured, standard cylinders, s_{min}, N/mm^2	6	2	3	3	5

An example is given for qualification of concrete based on 9 samples (9 standard cubes) identification test results, according to the offered acceptance criteria (*Table 3.*)

Table 3: Numerical example for the evaluation of compressive strength test results in case of identification testing procedure using *Student's* factor (offer)

Sign of sample (1 sample = 1 test specimen)	Sample cube $f_{ci,cube,test,H}$	Sample cylinder $f_{ci,cyl,test}$	*2. criteria* $f_{ci,cyl,test} \geq f_{ck,cyl} - 4$
1.	48,7	35.1	35.1 > 21.0
2.	47.7	34.4	34.4 > 21.0
3.	44.5	32.1	32.1 > 21.0
4.	46.6	33.6	33.6 > 21.0
5.	45.8	33.0	33.0 > 21.0
6.	47.6	34.3	34.3 > 21.0
7.	43.1	31.1	31.1 > 21.0
8.	43.8	31.6	31.6 > 21.0
9.	46.2	33.3	33.3 > 21.0
	$f_{cm,cyl,test}$ =	**33.2**	Mean value
	s_9 =	1.37	Standard deviation
	s_{min} =	**3.0**	Minimum Standard deviation
	t_9 =	1.86	*Student's* factor
$f_{ck,cyl,test} = f_{cm,cyl,test} - t_9 \cdot s_{min} = 33.2 - 5.6 =$ **27.6**			
1. criteria $f_{ck,cyl,test} = 27.6 > 25.0 = f_{ck,cyl}$; $f_{cm,cyl,test} = 33.2 > 30.6 = f_{cm,cyl} = f_{ck,cyl} + t_9 \cdot s_{min}$			
Compressive strength class: **C25/30**		Unit: N/mm^2	

A numerical example is given in *Table 4.* in which for comparison, the evaluation of the compressive strength test results given in *Table 3.* is done in case of having conformity statement, by the standard identifying testing method. In *Table 5.* we have prepared such a numerical example, in which the evaluation of the compressive strength test results given in *Table 3.* is done – also for comparison – according to the „old" (MSZ 4719:1982 and MSZ 4720-2:1980) Hungarian standards.

In *Table 6.* we give *Student's* factors belonging to the 5% underfalling portion level by 5% acceptance probability (Stange et al., 1966). The *Student's* factors in *Table 6.* are the distribution of $N(0.1)$ t-distribution – belonging to the one side 5% underfalling portion level – $t_{95\%,f}$ is the statistical variable (quantile of $p = 0.05$ value, threshold value, if the number of samples is n, and n-1 is the freedom of the t-distribution). These values differ in a certain amount from the *Student's* factors given in MSZ 4720-2:1980 Hungarian standard, because those were determined by approximation (Owen, 1962; Palotás, 1979, 9.93.4. point; Szalai, 1982, 2.8.5. point). If $n \rightarrow \infty$, then the *Student's* t-distribution tends to the *Gaussian* normal distribution (*Fig. 2.*).

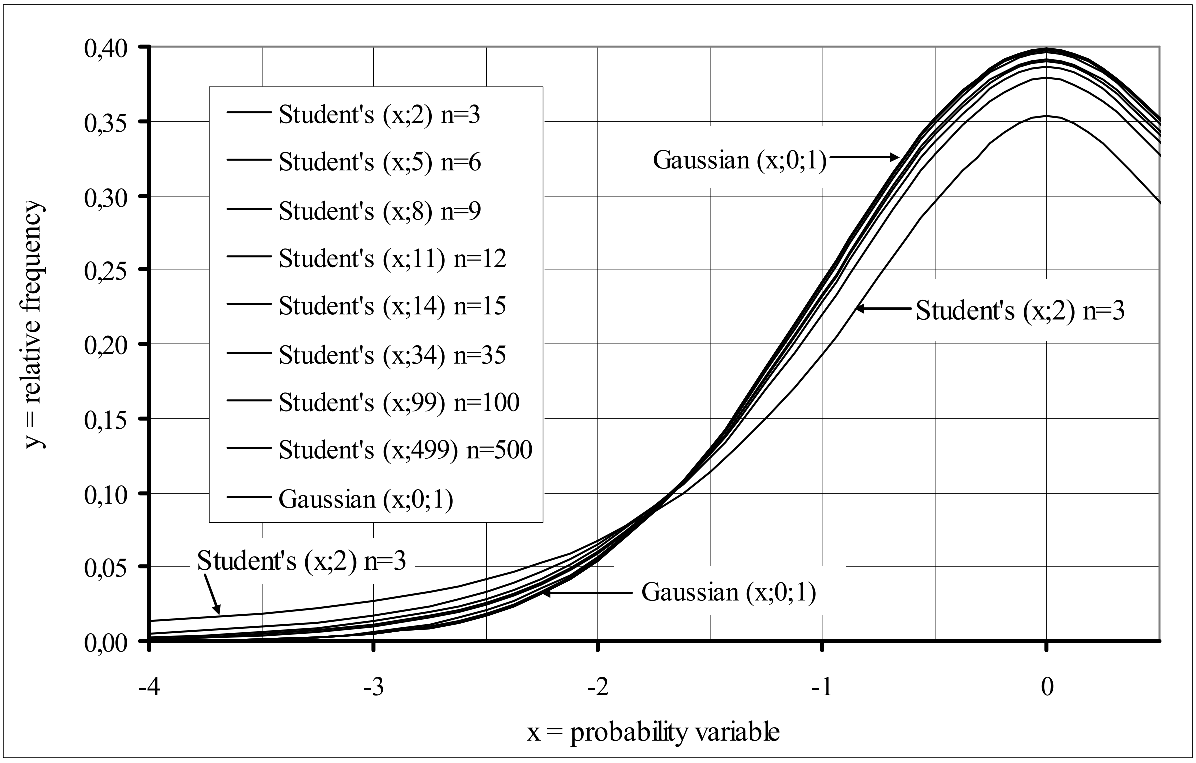

Fig 2: Standardised frequency curves of Gaussian and Student's distributions

Table 4: Numerical example for the evaluation of the compressive strength test results given in *Table 3.* is done in case of having conformity statement, by the standard identifying testing method.

Sign of sample (1 sample = 1 test specimen)	Sample cube $f_{ci,cube,test,H}$	Sample cylinder $f_{ci,cyl,test}$	*2. criteria* $f_{ci,cyl,test} \geq f_{ck,cyl} - 4$
1.	48.7	35.1	35.1 > 21.0
2.	47.7	34.4	34.4 > 21.0
3.	44.5	32.1	32.1 > 21.0
4.	46.6	33.6	33.6 > 21.0
5.	45.8	33.0	33.0 > 21.0
6.	47.6	34.3	34.3 > 21.0
7.	43.1	31.1	31.1 > 21.0
8.	43.8	31.6	31.6 > 21.0
9.	46.2	33.3	33.3 > 21.0
	$f_{cm,cyl,test} =$	**33.2**	mean value
	$f_{ck,cyl,test} = f_{cm,cyl,test} - 4 =$	**29.2**	
1. criteria $f_{ck,cyl,test} = 29.2 > 25.0 = f_{ck,cyl}$ $f_{cm,cyl,test} = 33.2 > 29.0 = f_{cm,cyl} = f_{ck,cyl} + 4$			
Compressive strength class: **C25/30**		Unit: N/mm^2	

Table 5: Numerical example, in which the evaluation of the compressive strength test results given in *Table 3.* is done according to the „old" (MSZ 4719:1982 and MSZ 4720-2:1980) Hungarian standards.

Sign of sample (1 sample = 1 test specimen)	Sample cube $f_{ci,cube,test,H}$	
1.	48.7	Evaluation according to the MSZ 4719:1982, the MSZ 4720-2:1980, and the MÉASZ ME-04.19:1995 Hungarian regulations
2.	47.7	
3.	44.5	
4.	46.6	
5.	45.8	
6.	47.6	
7.	43.1	
8.	43.8	
9.	46.2	
$R_{m,cube,test}$ =	**46.0**	mean value
s_9 =	1.89	Standard deviation
$s_{min,cube}$ =	**2.0**	Minimum standard deviation, MSZ 4720-2:1980
t_9 =	1.82	MÉASZ ME-04.19:1995 → Table 4.18.
k_R =	1.24	MÉASZ ME-04.19:1995 → Formula 4.61.
$R_{k,cube,test}$ =	**41.5**	$= 46.0 - 4.5 = R_{m,cube,test} - k_R \cdot t_9 \cdot s_{min}$
Criteria $R_{k,cube,test} = 41.5 > 40.0 = R_{k,cube}$ $R_{k,cube} = 40.0 \rightarrow 35.0 = R_{k,cyl}$		
Compressive strength class: **C35**		Unit: N/mm^2

Table 6: Acceptance constants

Number of samples n	Freedom in case of *Student's*-distribution n - 1	*Student's* factor t_n	*Taerwe* factor λ_n
	(Stange et al., 1966)		(Taerwe, 1986)
2	1	6.314	
3	2	2.920	2.67
4	3	2.353	2.20
5	4	2.132	1.99
6	5	2.015	1.87
7	6	1.943	1.77
8	7	1.895	1.72
9	8	1.860	1.67
10	9	1.833	1.62
11	10	1.812	1.58
12	11	1.796	1.55
13	12	1.782	1.52
14	13	1.771	1.50
15	14	1.761	*1.48*
20	19	1.729	
30	29	1.699	
	∞	*1.645*	

5. CONCLUSIONS

According to the new concrete standards in the initial and continuous stage of production the concrete is being tested by the producer, and based on the test results of the continuously produced material issues the conformity statement for a characteristic value which is determined by a 70-30 % probability of acceptance-rejection. The reliability of the conformity statement is checked by the client through identification testing procedure. The result of the continuous and identification testing is significantly influenced by the evaluation method of the characteristic strength value, in which the value of the acceptance constant has the major role. From the point of the safety of our structures it could be appreciable if the risk of the producer and the client during the hand over procedure would be 50-50%.

6. ACKNOWLEDGEMENT

The authors would like to express their gratitude to *dr Zoltán Megyesi mathematician*, who gave valuable help in the mathematical understanding of the acceptance criteria of the new concrete standards.

7. THESAURUS

Portion of the strength values below the f_{ck} (underfalling portion) (Anteil der Festigkeitswerte unterhalb von f_{ck}). The portion of the material in the total material volume (lot) which does not satisfy the conformity (acceptance) criteria. It is the characteristic value of x statistical variable. Sign: p.

Lead value (Vorhaltemass). It is the product of the acceptance constant and the standard deviation (e.g. $\lambda_n \cdot s_n$, or $t_n \cdot s_n$), by subtracting it from the mean compressive strength value f_{cm} the result will be the characteristic value, in other words it is the difference between the characteristic and mean values of the compressive strength.

Acceptance constant (Annahmekonstant). A multiplicator, by which first multiplying the standard deviation of the compressive strength test results and afterwards subtracting this product from the mean value of the compressive strength results, we obtain the characteristic strength. It's sign is generally: λ_n, and in case of the t-distribution: t_n (*Student's*-factor), where n is the number of samples.

Acceptance characteristic (curve) (Annahmekennlinie). A curve, which shows the acceptance probability $A(p)$ in the function of the underfalling portion p. The function is: $p \cdot A(p)$ = constant (*Fig. 1*).

Acceptance probability (Annahmewarscheinlichkeit). The probability of the acceptance of a concrete volume (lot) having p underfalling portion. Sign: $A(p)$.

Continuous production (stetige Herstellung). The production which follows initial production, lasting for at least 15 consequent compressive strength test result of without intermission under the same circumstances produced concrete, where the duration of the production time period is maximum 12 month before the last test is carried out.

Initial production (Erstherstellung). The initial production is lasting for at least 35 consequent compressive strength test result of without intermission under the same circumstances produced concrete, where the duration of the production time period is longer than three monthes but maximum 12 monthes before the last test is carried out.

Quantile (Quantil). Mathematical statistical variable x_p belonging to the p underfalling portion, a threshold value, characteristic value (e.g. $f_{ck,test}$). The 5% quantile of the distribution may be determined by using the formula: $f_{ck,test} = \mu - 1.645 \cdot \sigma$.

Verification of conformity (conformity statement) (Konformitätsbestätigung). A statement – usually by involving a verifying body – about that the concrete conforms to standard requirement (e.g. a compressive strength class).

Declaration of conformity (Konformitätserklärung). A based on the continuous or initial testing a statement by the producer about that the concrete is conform to a standard requirement (e.g. compressive strength class).

Sample (Probe). A certain enough quantity of concrete separated for the production of one or more specimens for compressive (or other) tests representing the general quality of the material.

Normal distribution, Gaussian distribution (Normalverteilung). A distribution of the compressive strength test results which can be expressed by their statistical expected value (μ) and standard deviation (σ), of which the frequency distribution function is expressed as:

$$p(x) = \frac{1}{\sigma \cdot \sqrt{2\pi}} \cdot e^{-\frac{(x-\mu)^2}{2\sigma^2}}$$

Compressive strength (Druckfestigkeit). The highest stress level, expressed in N/mm^2, by which during the compressive strength test of concrete sample cylinder or cube fails.

Mean compressive strength (mittlere Druckfestigkeit). The average of the individual compressive strength test results.

Identity test of compressive strength (Identitätsprüfung für Druckfestigkeit). By involving an independent laboratory or by the laboratory of the client (mostly by involving the producer also) a test carried out during the hand over procedure for the determination if the concrete is conforming to the compressive strength class which was stated by the producer.

Continuous test of compressive strength (stetige Druckfestigkeitsprüfung). Concrete compressive strength test and evaluation of the results during the period of continuous production. During continuous testing the evaluation should be and may be done by the mean value and the standard deviation which was determined by the initial testing period. Continuous testing may be carried out by the producer or its trustee within intermediate quality control checking.

Characteristic value of compressive strength (charakteristischer Druckfestigkeitswert). That compressive strength value below which maximum 5% of the evaluated compressive strength test results of the concrete fall. It can be a prescribed (f_{ck}) or an empirical ($f_{ck,test}$) value.

Initial test of compressive strength (Erstprüfung für Druckfestigkeit). Concrete compressive strength test and evaluation of the results during the period of initial production. During initial testing the evaluation should be done by the mean value and the standard deviation must be given. Initial testing may be carried out by the producer or its trustee within intermediate quality control checking.

Standard deviation of compressive strength (Standardabweichung der Druckfestigkeit). It is the fluctuation of the individual compressive strength values, determined by the square root of the expected value of the square of the difference between the individual and mean value of the compressive strength. From the test results can be determined the empirical standard deviation (s_n) which is close to the value of (σ) the theoretical standard deviation.

Compressive strength class (Druckfestigkeitsklasse). The requirement for the compressive strength of concrete which is to be given by the prescribed characteristic compressive strength value of the 28 days old, cured under standard circumstances, 150 mm in diameter and 300 mm height cylinders ($f_{ck,cyl}$) and 150 mm edge length cubes ($f_{ck,cube}$).

Operating characteristic (OC curve) (Operationscharakteristik). The operation characteristics of the conformance criteria system. It is an operational characteristic curve showing the probability $L(p,n,c)$ of that the together evaluated n specimen just c or less are nonconform, in the function of p, which is the underfalling portion of the concrete. The value of c is a so called decisive number in the n test results it is the maximum number of results which may not be conforming, i.e. in our case $0.05 \cdot n$. To give the values of the *OC curve,* instead of the binominal distribution usually the more easily hadleable *Poisson* distribution is used (Felix et al., 1964):

$$L(p,n,c) = \sum_{x=0}^{c} \frac{(n \cdot p)^x}{x!} \cdot e^{-n \cdot p}$$

Poisson distribution (Poisson-Verteilung). It's density function is:

$$p(x) = \frac{(n \cdot p)^x}{x!} \cdot e^{-n \cdot p}$$

The *Poisson* distribution is giving a better and better approximation of the binominal distribution as n increases and p decreases.

Student's factor (Student-Koeffizient). The $N(0.1)$ distributed t-distribution's – belonging to one side 5% underlaying portion – $t_{95\%,f}$ statistical variable (the quantil of p = 0.05, it's threshold value).

t-distribution (Student's distribution) (t-Verteilung). A distribution, which is similar to the *Gaussian* normal distribution, and which is also a function of n, the sample number. It's density function is:

$$p(x) = \frac{1}{\sqrt{(n-1)\pi}} \cdot \frac{\Gamma\left(\frac{n}{2}\right)}{\Gamma\left(\frac{n-1}{2}\right)} \cdot \frac{1}{\left(\frac{x^2}{n-1}+1\right)^{\frac{n}{2}}},$$

where Γ is the sign of the gamma function. In our case the freedom of the t-distribution is: $n - 1$. If $n \to \infty$, then the t-distribution tends to the *Gaussian* normal distribution (*Fig. 2.*).

8. MOST IMPORTANT NOTATIONS

$A(p)$	acceptance probability of a concrete having p underfalling portion
C	sign of normal density concrete
f	freedom of *Student's* distribution
f_c	compressive strength of concrete
f_{cd}	compressive strength of concrete – design value
f_{ci}	compressive strength of concrete – individual empirical value
f_{ck}	compressive strength of concrete – prescribed characteristic value
f_{cm}	compressive strength of concrete – prescribed mean value

$f_{cm,test}$	compressive strength of concrete – mean of the empirical values
$f_{c,cube}$	compressive strength of concrete – prescribed value for cubes of 150 mm edges, cured under water until the age of 28 days
$f_{c,cube,H}$	compressive strength of concrete – prescribed value for cubes of 150 mm edges, cured under water until the age of 7 days and in laboratory circumstances until the age of 28 days
$f_{ci,cube,test,H}$	compressive strength of concrete – individual empirical value for cubes of 150 mm edges, cured under water until the age of 7 days and in laboratory circumstances until the age of 28 days
$f_{ck,cube,H}$	compressive strength of concrete – prescribed characteristic value for cubes of 150 mm edges, cured under water until the age of 7 days and in laboratory circumstances until the age of 28 days
$f_{cm,cube,H}$	compressive strength of concrete – prescribed mean value for cubes of 150 mm edges, cured under water until the age of 7 days and in laboratory circumstances until the age of 28 days
$f_{cm,cube,test,H}$	compressive strength of concrete – mean of the empirical values for cubes of 150 mm edges, cured under water until the age of 7 days and in laboratory circumstances until the age of 28 days
$f_{c,cyl}$	compressive strength of concrete – prescribed value for cylinders of 150 mm in diameter and 300 mm in height, cured under water until the age of 28 days
$f_{ci,cyl,test}$	compressive strength of concrete – individual empirical value for cylinders of 150 mm in diameter and 300 mm in height, cured under water until the age of 28 days
$f_{ck,cyl}$	compressive strength of concrete – prescribed characteristic value for cylinders of 150 mm in diameter and 300 mm in height, cured under water until the age of 28 days
$f_{ck,cyl,test}$	compressive strength of concrete – empirical characteristic value for cylinders of 150 mm in diameter and 300 mm in height, cured under water until the age of 28 days
$f_{cm,cyl}$	compressive strength of concrete – prescribed mean value for cylinders of 150 mm in diameter and 300 mm in height, cured under water until the age of 28 days
$f_{cm,cyl,test}$	compressive strength of concrete – mean of the empirical values for cylinders of 150 mm in diameter and 300 mm in height, cured under water until the age of 28 days
$L(p,n,c)$	the distribution function of *Poisson's* distribution
n	the number of samples
p	portion of the strength values below the f_{ck} (underfalling portion)
$p(x)$	statistical density function
$R_{cube,test}$	compressive strength of concrete – individual empirical value for cubes of 150 mm edges, cured under water until the age of 7 days and in laboratory circumstances until the age of 28 days according to MSZ 4720-2:1980 Hungarian standard
$R_{k,cube}$	compressive strength of concrete – prescribed characteristic value for cubes of 150 mm edges, cured under water until the age of 7 days and in laboratory circumstances until the age of 28 days according to MSZ 4720-2:1980 Hungarian standard
$R_{k,cube,test}$	compressive strength of concrete – empirical characteristic value for cubes of 150 mm edges, cured under water until the age of 7 days and in laboratory circumstances until the age of 28 days according to MSZ 4720-2:1980 Hungarian standard

$R_{m,cube,test}$	compressive strength of concrete – mean of the empirical values for cubes of 150 mm edges, cured under water until the age of 7 days and in laboratory circumstances until the age of 28 days according to MSZ 4720-2:1980 Hungarian standard.
$R_{k,cyl}$	compressive strength of concrete – prescribed characteristic value for cylinders of 150 mm in diameter and 300 mm in height, cured under water until the age of 7 days and in laboratory circumstances until the age of 28 days according to MSZ 4720-2:1980 Hungarian standard
s_{min}	standard deviation of compressive strength of concrete – required minimum value for cylinders of 150 mm in diameter and 300 mm in height, cured under water until the age of 28 days
s_n	standard deviation of compressive strength of concrete – empirical value for cylinders of 150 mm in diameter and 300 mm in height, cured under water until the age of 28 days
t_n	*Student's* factor
x	mathematical statistical variable
α_{cc}	durable strength factor
σ	standard deviation of compressive strength of concrete – theoretical value for cylinders of 150 mm in diameter and 300 mm in height, cured under water until the age of 28 days
σ_{min}	standard deviation of compressive strength of concrete – required minimum value for cylinders of 150 mm in diameter and 300 mm in height, cured under water until the age of 28 days
σ_n	standard deviation of compressive strength of concrete – with unknown probability theoretical value
γ_c	safety factor for concrete
λ_n	underfalling portion factor
μ	probability of expected compressive strength of

9. REFERRED STANDARDS AND CODES

MSZ 4719:1982 „ Concrete (Betonok)" Hungarian standard

MSZ 4720-2:1980 „ The quality control of concrete. General properties (A beton minőségének ellenőrzése. Általános tulajdonságok ellenőrzése)" Hungarian standard

MSZ 4798-1:2004„ Concrete part1. Technical requirements, fulfillment, production and conformity, and the Hungarian NAD for MSZ EN 206-1 (Beton. 1. rész: Műszaki feltételek, teljesítőképesség, készítés és megfelelőség, valamint az MSZ EN 206-1 alkalmazási feltételei Magyarországon)" Hungarian standard

MSZ 15022-1:1986 „Design of loadbearing building structures, Reinforced concrete structures (Építmények teherhordó szerkezeteinek erőtani tervezése. Vasbeton szerkezetek)" Hungarian standard

MSZ EN 206-1:2002 „Concrete part 1. Technical requirements, fulfilment, production and conformity (Beton. 1. rész: Műszaki feltételek, teljesítőképesség, készítés és megfelelőség)" Hungarian standard

MSZ EN 1992-1-1:2005 „Eurocode 2. Design of concrete structures. part 1-1. General and building rooles (Eurocode 2: Betonszerkezetek tervezése. 1-1. rész: Általános és az épületekre vonatkozó szabályok)"

MÉÁSZ ME-04.19:1995 „Production of concrete and reinforced concrete. 6th Topic, testing, quality control, quality certification. Code of practice (Beton és vasbeton készítése. 6. fejezet: Vizsgálat, minőség-ellenőrzés, minőségtanúsítás. Műszaki előírás)" Hungarian code of practice

10. REFERENCES

Felix, M. – Bláha, K. (1964), „Matematikai statisztika a vegyiparban (Mathematical statistics in the chemical industry)”, *Műszaki Könyvkiadó, Budapest*

Owen, D. B. (1962), „Handbook of statistical tables”, *Addison-Wesley Publishing Company, Reading, Massachusetts, Palo Alto – London*

Palotás L. (1979), „Mérnöki szerkezetek anyagtana 1. Általános anyagismeret (Materials of engineering structures, Part 1. General material science)”, *Akadémiai Kiadó, Budapest*

Stange, K. – Henning, H.-J. (1966), „Formeln und Tabellen der mathematischen Statistik”, *Springer-Verlag, Berlin/Heidelberg/New York*

Szalai K. (szerk.) (1982), „A beton minőségellenőrzése (Quality control of concrete)”, *Szabványkiadó, Budapest*

Taerwe, L. (1986), „A General Basis for the Selection of Compliance Criteria”, *IABSE Proceedings P-102/*86*, pp. 113-127, ETH-Hönggerberg, Zürich*

Zäschke, W. (1994), „Conformity Criteria for Compressive Strength of Concrete”, *Concrete Precasting Plant and Technology, 9/1994, pp. 94-100, Bauverlag GmbH, Wiesbaden*

Prof. Tibor KAUSAY (1934), M.Sc civil engineer (1961), specialisation in reinforced concrete (1967), university doctor (1969), candidate of technical sciences (1978), Ph.D. (1997), associate professor of department of Building Materials, Technical University of Budapest (1985), honorary professor at the department of Construction Materials and Engineering Geology, Budapest University of Technology and Economics (2003). Member of the Hungarian Group of *fib* (2000). Gróf Lónyay Menyhért priced, honorary member of the Szabolcs-Szatmár-Bereg county Scientific Organisation of the Hungarian Academy of Sciences (2003). Main research fields: concrete technology, stone industry. Author of about 130 publications.

Dr. Tamás SIMON (1956), M.Sc civil engineer (1983), PhD (2005). Between 1983 and 1990 consultant of VIZITERV Consulting Engineering Company for Water Engineering. For two years, between 1990 and 92 developing and constructing engineer of „kas” Insulation-techniques Developing and Constructing Incorporated Company. Since 1992 senior lecturer of Budapest University of Technology and Economics, Department of Construction Materials and Engineering Geology. Between 2005 and 2006 lecturer of Ybl Miklós College of Technology, Department of Building Materials and Quality Control. Main fields of interest: concrete and reinforced concrete structures, rehabilitation of structures, concrete technology, quality control. Member of the Hungarian Chamber of Engineers and the Hungarian group of *fib*.

PUBLISHED: *CONCRETE STRUCTURES* (Annual Journal of the Hungarian Group of ***fib***, Budapest) 2007. Vol. 8. pp. 54-63.