QUALITY ASSURANCE IN THE MANUFACTURE OF CONCRETE PAVING BLOCKS IN FRANCE

by A. SANCHEZ

Head of Civil Engineering Section, Quality Depart. CERIB

B.P. 42 - F 28230 EPERNON

SUMMARY

After a brief historical account of the paving block standardization and certification in France, the standard NF P 98.303 "Concrete paving blocks" is presented. The specifications and the level of performance selected for the geometrical, physical, mechanical and appearance characteristics are justified.

The standard drafters have endeavoured to give definitions without any ambiguity and reproducible test procedures thanks to the use of characteristic values for expressing the performance levels. Moreover, the acceptance of batches delivered is based on different sampling plans according as the works hold the NF certification or not.

In the second part of the report, the organization settled in works which hold the mark and the methods of the quality assurance are described. The sampling and the tests carried out at every stage of the manufacturing process within the framework of the internal control are detailed. The guarantee about the validity of the test results and the measures taken by the firm for juridically an permanently proving the paving block quality are also reported. The costs of non-quality can be limited by the data processing and their integration in the manufacturing process.

The NF mark functions with a checking of the internal control by an external organism. The task of such organism, the organization of the checking together with the assistance inferred are detailed. The procedure for the attribution of the mark and the identification of paving blocks which hold the mark are also dealt with.

1 - Chronology of the standardization and certification of paving blocks in France

The decision taken by the French Federation of the Concrete Industry to draw up for a maximum number of products standards or specifications defining the required qualities and test methods for checking them date from 1951. Parallel to this, a certified qualification resting on the National Mark NF or the professional label QualiFIB has been progressively laid down.

As far as concrete paving blocks are concerned, the main stages are as follows :

1975 : publication of the professional specifications and settling of label "paving blocks",

1980 : first edition of the officially authorized standard NF P 98.303 "concrete paving blocks" and creation of the mark NF,

1983 : second edition of standard NF P 98.303.

2 - NF P 98.303 - Concrete paving blocks

2.1 - Specifications and behaviour of paving blocks in their environment

During its service life, a pavement made of concrete paving blocks is subjected to stresses such as :

- stresses due to traffic,
- climatic stresses.

Moreover, a modification of the appearance is liable to take place owing to the effect of dirty marks and stains.

2.1.1 - Stresses due to traffic

The concrete paving blocks are during the service life subjected to the action of the rolling load vertical and horizontal component and therefore subjected to a multidirectional state of stress. The results of a recent study (1) show that a pavement made of paving blocks has, against the rolling load vertical component, a behaviour in the areas near the loading point similar to a plate with a rigidity reduced owing to the presence of joints (fig. 1). With the plate effect the paving blocks are subjected to a flexural tensile load in the direction of their cross section (fig. 3).

The figure 2 which has been obtained in this study illustrates the state of strain recorded for the central paving load (under the load). It appears that the tensile strength is the characteristic which reproduces at best the behaviour of paving blocks against vertical loads.

The same study also shows that, against the horizontal component of the rolling load, the transmission of loads was characterized in the paving blocks by the growth of shearing and bending stresses and that tight dimensional tolerances ensure a better resistance to horizontal loads for paving blocks.

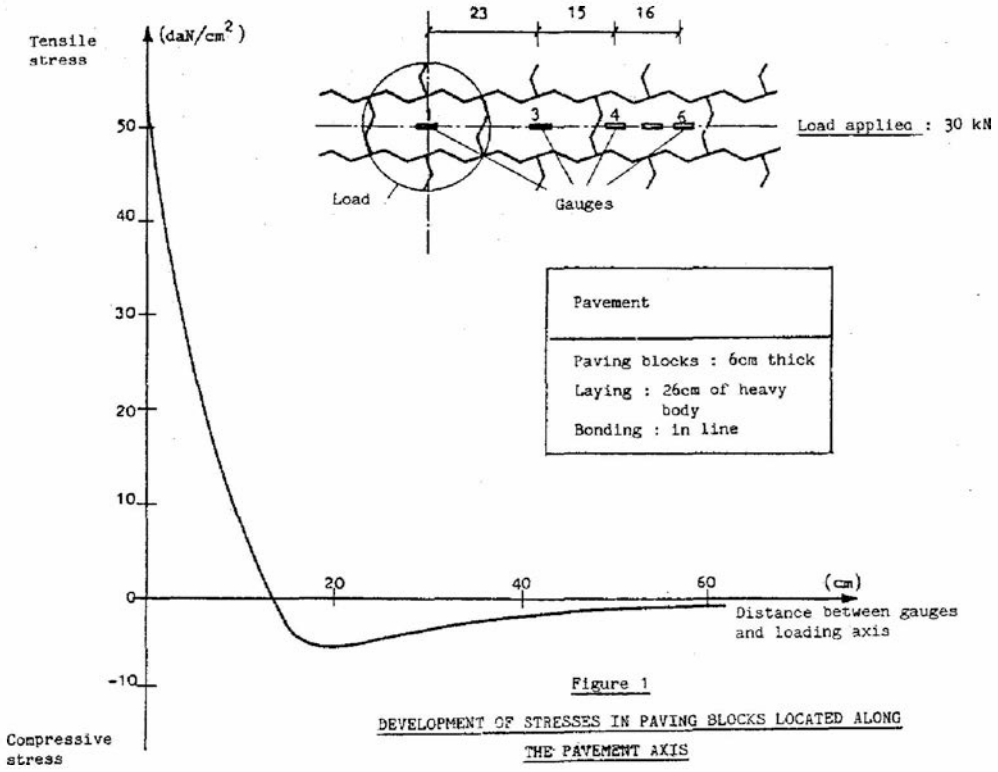
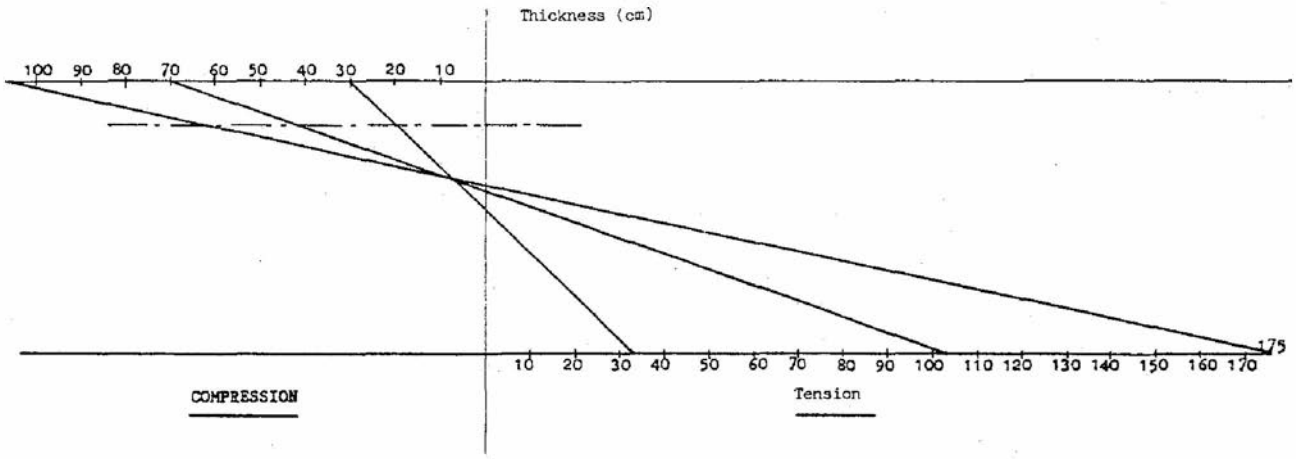
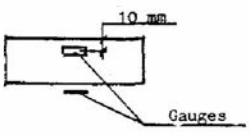


Figure 1

DEVELOPMENT OF STRESSES IN PAVING BLOCKS LOCATED ALONG THE PAVEMENT AXIS





Pavement \ Load in kN	10	20	30
Paving blocks : 6cm thick Laying : 26cm of heavy body Bonding : in line	33/20	103/42	175/63

Figure 2

DIAGRAM OF CENTRAL PAVING BLOCK STRAIN

(immediately under load)



Figure 13

GAUGE ARRANGEMENT - SCHEMATIC RUPTURE

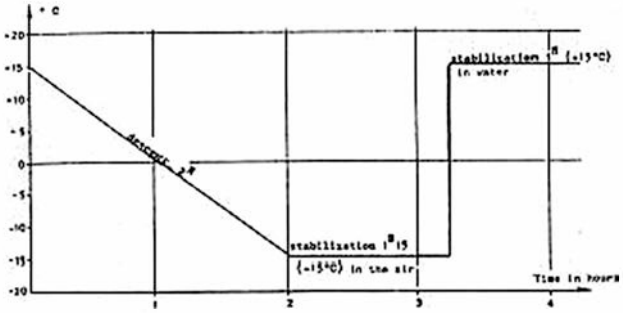


Figure 4

THEORETICAL FREEZING-THAWING CYCLE

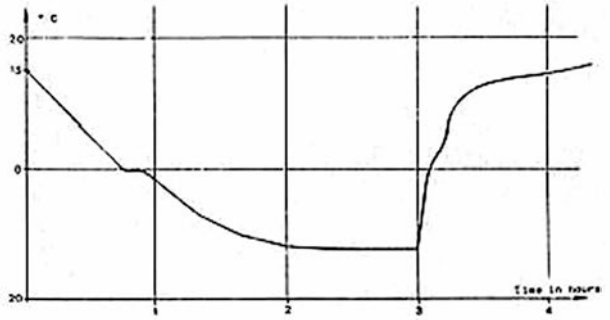


Figure 5

REAL FREEZING-THAWING CYCLE FOR 8 PAVING BLOCKS

Weight : 27,4 kg. (gradient of + 15 à -12° C : 0,5° c/mn)



Figure 6

WEATHERING AFTER FREEZING-THAWING TEST

(55 cycles)

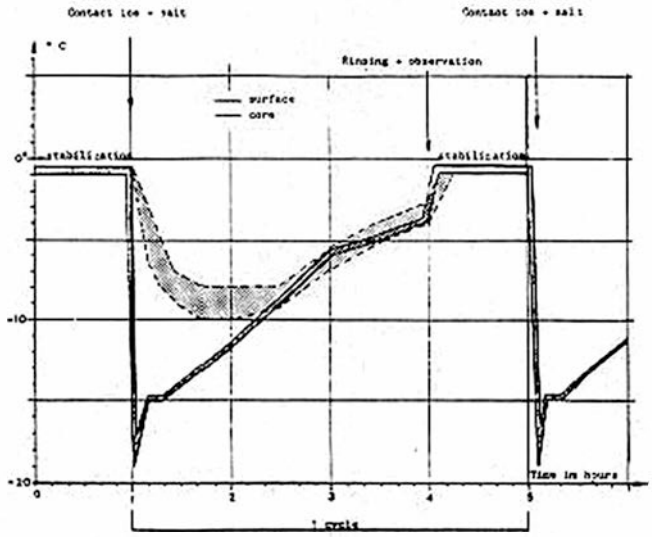


Figure 7

DIAGRAM OF TEMPERATURES ATTAINED DURING THE DE-ICING TESTS



Figure 8

TEST PROCEDURE FOR THE DE-ICING TEST



Figure 9

WEATHERING AFTER 25 CYCLES OF DE-ICING SALTS

(paving block n° 17 : A = 4,6% - n° 19 : A = 6,6%)

2.1.2 - Climatic stresses

They show themselves :
- either in the form of sudden temperature changes,
- or by the effects of frost and the use of de-icing salts.

Thermal expansion and contraction is essentially bound to temperature differences between summer and winter or even between day and night. For manufactured concrete paving blocks, the resulting stresses are negligible owing to their small dimensions and the presence of multiple joints.

On the other hand, the effects of frost and de-icing salts should be a matter of concerne and affect the paving block durability. The most unfavourable conditions are met for highly porous or badly compacted concretes facilitating the penetration of water. The use of de-icing salts increases the risks of damage caused by a sudden surface cooling (surface thermal shock) and also by a multiplication of freezing-thawing cycles (accelerated ageing).

This has been confirmed by a study (2) from which it appears that a threshold of coefficent of absorption of water attaining 6 % measured in accordance with RILEM method CPC 11.1 can characterize a good behaviour for at least 55 freezing-thawing cycles (fig. 1, 5 and 6) or at least 25 abrupt thawing cycles (fig. 7, 8 and 9) for concrete paving blocks with a splitting strength higher than 3,2 MPa (see procedure § 2.2).

2.1.3 - Action of dirty marks and stains

As far as dirty marks and stains are concerned, here also the material porosity is the only parameter which conditions the possibility of a subsequent cleaning due to a lesser penetration (3).

2.1.4 - Recapitulation of specifications retained according to the different stresses

Refering to what has been said before, the relevance of specifications retained for characterizing the fitness of paving blocks is given hereunder :

	STRESS			
SPECIFICATIONS	Rolling load	Frost/ De-icing salts	Dirty marks stains	Wear
Tensile strength	Yes	Yes		
Absorption of water.....		Yes	Yes	
Dimensional tolerances.....	Yes			
Wear resistance				Yes

As appears from the table, the service life of paving blocks is essentially dependent on the tensile strength, the porosity and the wear. Such considerations imply that paving blocks which are delivered shall have a defectless appearance.
These criteria are concretely and measurably interpreted in the standard NF P 98.303 "Concrete paving blocks" (4). The standard determines the general characteristics of concrete paving blocks based on usual aggregates and tests for checking them.

2.1.5 - Excerpt from standard NF P 98.303

Tests	Specifications
Rupture by splitting	$\geqslant$ 4,0 MPa for the 0,05 fractile and no result < 3,2 MPa.
Absorption of water	$\leqslant$ 5,4 % for the 0,05 fractile and no result > 5,7 %.
Abrasive wear	maximum individual width $\leqslant$ 25 mm.
Checking of dimensions	$\pm$ 3 mm for total thickness $\pm$ 2 mm for length and width batter < 2 mm (or 2 %)
Checking of appearance and structure	no crack, deformation, pulling out, anomalous heterogeneity.

2.2 - Test procedure

The test procedure has been selected taking into account two essential reasons :
- the reference tests worked out had to be in agreement with the experimental findings about the behaviour of pavements made of paving blocks.
- the tests should, as far as possible, be effectively carried out in the laboratories of relevant works for a continuous control.This is why the measurement of the concrete tensile strength through the tensile splitting test (ISO 4.108) and of the porosity through the test of absorption of water (RILEM CPC 11.1) have been selected.

2.2.1 - Test of absorption of water
(see detail in standard NF P 98.303)

It has been shown by experience that precautions had to be taken as regards the equipment which is used and also during the test in order to limit the errors of interpretation which can lead to erroneous results. In particular, it is recommended in the standard to check the stove suitability before using it in order to determine the maximum number and mass of paving blocks to be introduced. It has been shown that an insufficient ventilation associated with a high number of paving blocks led to the oven saturation ; the paving blocks had then a constant mass but not a dry condition.

A minimum 3 days long immersion and drying time is also specified. For each paving block, the coefficient of absorption of water A is given in percent by :

$$A\ \% = \frac{M1 - M2}{M2} \times 100$$

M1 : humid mass (considered as constant).
M2 : dry mass (considered as constant).

2.2.2 - Splitting test
(see detail in standard NF P 98.303)

The load is applied on the paving block longitudinal axis by means of two steel rollers. The modulus of rupture T is calculated by the formula :

$$T = 0{,}637 \times \frac{P}{S} \text{ with :}$$

T : modulus of rupture, MPa
P : rupture load, N
S : test piece cross-section at rupture, mm2.

2.2.3 - Abrasion test
(see detail in standard NF P 98.303) :

The test consists in making a mark by sand blasting upon the paving block external face by means of a 70 mm wide drum which is 200 mm in diameter and revolves on a horizontal spindle (75 RPM). The drum is in contact with the paving block face under a pressure equal to the weight of the counterweight (13,70 daN). The abrasive output is 0,22 dm3/s and the test lasts 60 seconds (fig. 10) (5).

The drum and the sand have well defined characteristics and are controlled at regular intervals. The test result is expressed by the maximum print length in mm.

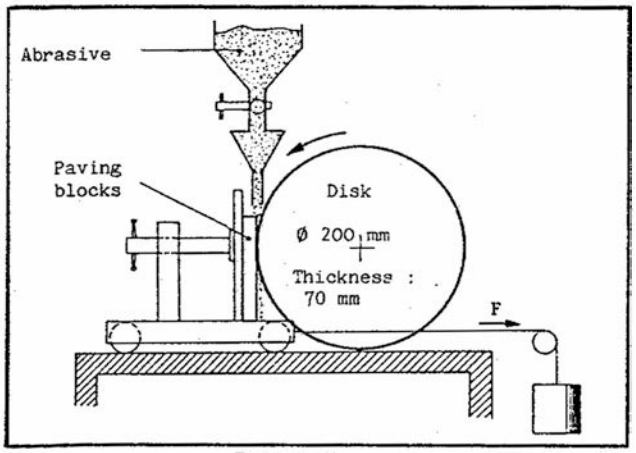


Figure 10

SCHEMA OF ABRASION TESTING MACHINE

2.3 - Statistical guarantee

The standard "concrete paving blocks" introduces the notion of characteristic values in order to clearly define the guarantee of the production conformity for users. The admissible values for splitting rupture and the absorption of water are defined by a fractile of "p" order and a boundary (6).

We shall examine for instance the case of the lower limit, that is to say the case of the splitting rupture ; the other case can be treated in a similar way.
It is generally admitted that the distribution of the rupture strength of paving blocks in a batch is suitably represented by the Gaussian model (see exemple in § 3.2). The model is entirely defined by the mean (m) and the standard deviation (α). However, it may happen for every manufacturing process that the model is defective (for instance excessive standard deviation, multimodal distribution) owing to an anomaly in the manufacturing process (disorder) or in the batching. In order to prevent such risks and as the strength has a direct effect upon the structure durability, it is advisable to specify it by both a fractile of "p" order (Rcp) and by a boundary (B) (fig. 11).

A batch will be in conformity with the specification about the rupture strength when are observed the two following conditions :
- the proportion of paving blocks lower than Rcp (4,0 MPa) shall be lower than p (0,05) : $p' < p$
- the proportion of paving blocks lower than B (3,2 MPa) shall be zero : $p'' = 0$.

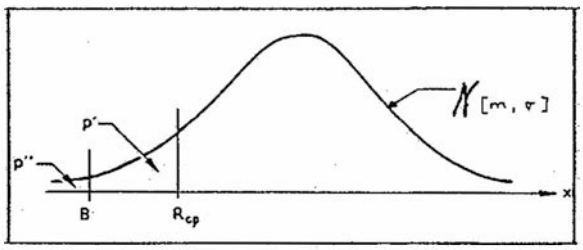


Figure 11

CHARACTERISTIC VALUES

2.4 - Acceptance - Operating characteristic

When the supply comes from a non-certified production, the decision as to the conformity with the specifications is derived from the test results upon the paving block specified characters following a procedure defined under the conditions of acceptance (4). The supply is divided into batches of 20 000 paving blocks maximum, originating from the same making. Two samples of 50 paving blocks each, called n° 1 and 2, are taken on each batch. The originality of this procedure arises from the fact that the acceptance conditions are differently interpreted according as the paving blocks originate from a certified production (holder of mark NF) or not, as controls have already been carried out for certified products.

2.4.1 - Exemple of checking of splitting strength (see detail NF P 98.303)

The checking is carried out on 10 paving blocks taken at random among sample n° 1.

The acceptance is decided upon presentation of a double sampling plan by attributes, being understood that all values lower than the lower boundary lead to declare the batch not in conformity.
Let k1 be the total number of defective paving blocks in the 10 which were taken :

Value of k1		Decision
With mark NF	Absence of mark NF	
$\leqslant 1$	0	Batch declared in conformity
$\geqslant 3$	$\geqslant 2$	Batch declared not in conformity
2	1	New checking on the 10 paving blocks taken at random in sample n° 2

Let k2 be the number of defective paving blocks in the 20 taken in the two samples:

Value of k2		Decision
With mark NF	Absence of mark NF	
2	1	Batch declared in conformity
$\geqslant 3$	$\geqslant 2$	Batch declared not in conformity

The operating characteristic curve of this inspection test is given figure 12. It can be seen that the AOQL (Average outgoing quality limit) is 5 % maximum for a non-certified production. That is to say that, on an average, the inspection tests will lead to the acceptance of 5 % of defective products (which is in conformity with the specifications for the 0,05 fractile).

For the NF productions which have already been controlled by the producer, a higher AOQL has been taken due to the fact that the first control (producer) brings the guarantee of quality, the second one (inspection test) being just carried out as a confirmation.

The producer would be penalized if the inspection test were as severe for certified products as for the other ones. As a matter of fact, every control involves a risk, the producer's risk (called α), to see rejected a good production.

The producer's risk is :
- non NF production : α acceptance
- NF production : α control + α acceptance >> α acceptance.

It was therefore necessary to reduce acceptance for the NF production in order to get a total producer's risk almost equal in the two cases. It has been taken :
- α acceptance non NF almost equal to 28 % of chances to see a production containing 5 % of defective rejected,
- α acceptance NF almost equal to 8 % of chances to see a peoduction containing 5 % of defective rejected.

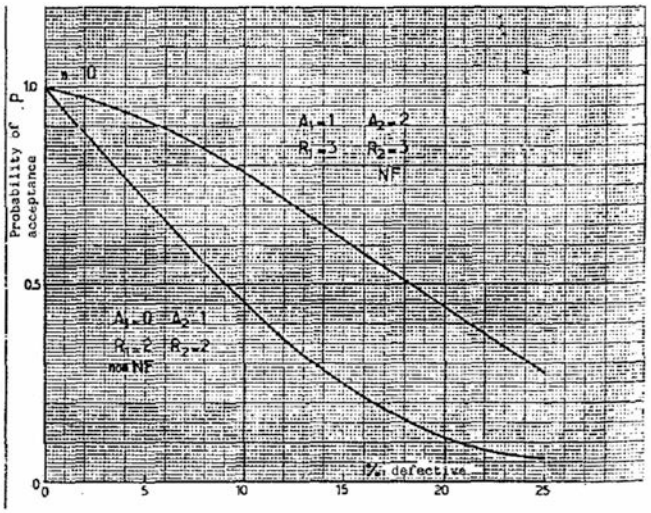


Figure 12

OPERATING CHARACTERISTIC CURVES

3 - Organization and quality assurance in works holders of NF mark

3.1 - Internal control

The internal control defined by the particular statute of NF mark is carried out by the firm and necessitates the installation of a laboratory. This control which takes place at different stages of the manufacturing process is not solely intended so as to be able to meet the requirements of the mark. The aims are multiple and integrated in the firm management (fig. 13).

3.2 - Data processing and integration into the manufacturing process

The tests and their frequencies defined in the table (fig. 13) constitute means for watching and intervention at different stages of the manufacturing process. They enable :
- to be permanently kept informed of the quality of products which are manufactured and sold (regular tests for finished products) (fig. 14),
- The supervision of raw materials and of the manufacturing process (regular tests for raw materials, manufacturing instructions).

The facts reported in this chapter emphasize the importance of an "active" internal control which goes through several phases :

- data processing,
- modification and adjustment based on data,
- reaching of rapid decisions.

	TESTS	FREQUENCIES	REMARKS
Raw materials (register n° 1)	Screen analysis Sand equivalent	Once a week for each category and at each change of origin	Working out of production curve envelopes for 30 results and more
Fresh concrete (register n° 2)	Screen analysis Water content	Once a week for each batching station	Working out of production curve envelopes for 30 results and more
Finished products (register n° 3)	Dimensions	One paving block for 4 000 manufactured with 3 paving blocks minimum by continuous manufacturing post	
	Splitting rupture	One paving block for 4 000 manufactured with 3 paving blocks minimum by continuous manufacturing post	Working out of a histogram by type, all colours mingled, differenciating the greys and statistical calculations if more than 30 results
	Absorption of water	3 paving blocks by manufacturing week and by type manufactured	Working out of a histogram by type, all colours mingled, differenciating the greys and statistical calculations if more than 30 results
	Abrasive wear	Acceptance : one test by concrete receipt Maintenance : on test once a year and for each modification of gravel/sans ratio higher than 7,5 %	

Figure 13 - NF MARK - CONCRETE PAVING BLOCKS - DIAGRAM OF INTERNAL

It has to be outlined that the internal control in particular introduces inside the firm the reflex of holding a dialogue upon the results of measurements wich involves an objective human intercourse often based before on impressions and therefore subjective.

4 - Principle of working of NF mark

4.1 - Checking of internal control

This external control falls within the competence of an independent organism. The CERIB is at present time responsible for this task and therefore this organism also ensures the technical secretariat for the mark.

Actually, this checking takes place by means of unexpected visits, at least twice a year, by a Regional Quality Inspector delegated by CERIB. The object of such visists is essentially the checking of :

- the organization settled by the firm (means in men and equipment) for ensuring the quality of test results,
- register (keeping, frequence and so on ...),
- checking tests are also performed during the visit (appearance, dimensions, rupture).
- the storage yard is also visited by the Inspector (presence of products not in conformity, marking and so on ...).

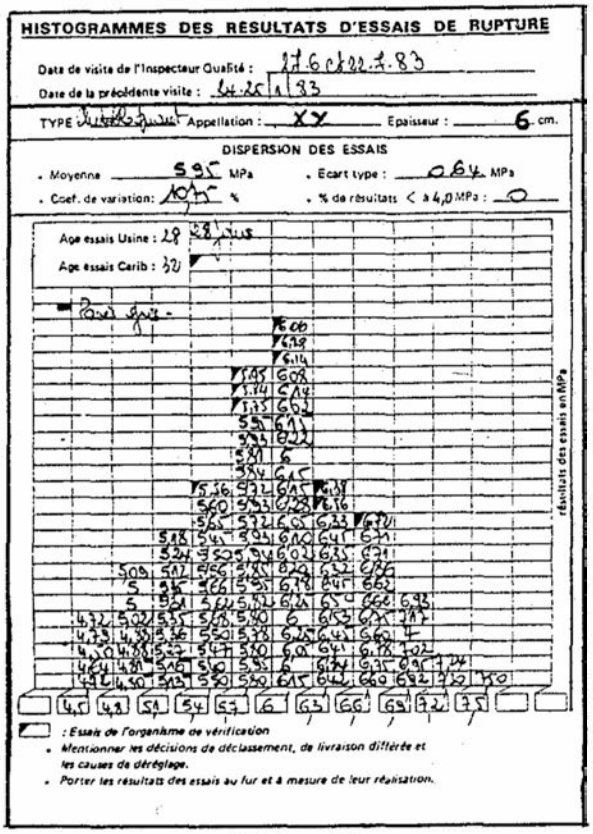


Figure 14

EXEMPLE OF HISTOGRAM FOR RESULTS OF RUPTURE TESTS DRAWN UP BY A FIRM

The tests of absorption of water and of abrasive wear are carried out at the reference laboratory (CERIB) after taking by the Inspector of a batch representative of the production in the storage yard.
CERIB is entitled by the National Test Network to test products for road works.

CERIB also ensures the assistance when the internal control is started. This assistance includes :
- training of laboratory staff by means of professional courses,
- information and spread of useful documents,
- help in the field for settling the internal control,
- advice on how to handle the control results.

4.2 - Procedure for the attribution of the mark

Following the visits described in 4.1 an inspection report is drawn up. It is transmitted to the firm for possible remarks and presented in anonymous form to the Comittee responsible in which are equally represented the users and producers and also experts ensuring the neutrality and the objectivity necessary for taking decisions.

The mark is delivered by the French Standardization Association (AFNOR) which is the approved certifier in the form of an attestation of the right of user expressing the decision of the Particular Committee ; it is sent to the interested firm which is entitled to inform the users of the decision of attribution.

4.3 - Identification of productions holding the mark

The mark is materialized by the impression of the paving block with the following :
- monogram NF,
- identification of works (manufacturer, trade mark),
- date of manufacture,
- number of days fixing the date from which the manufacturer guarantees the splitting strength.

5 % of the paving blocks or 2 paving blocks by package unit are marked.

4.4 - Quality assurance

The quality assurance is defined as "the implementation of a suitable set of pre-established and systematic dispositions intended for giving confidence in the obtainment of the required quality" (7). The implementation of the internal control in the firm comprises regular measures :
- for raw materials,
- during the manufacture,
- for finished products.

All the information which is gathered at different stages of the manufacturing process and noted in registers are compared with the manufacturing instructions in order to detect and correct possible anomalies. With the help of this system, it can be permanently checked that the normal manufacturing process is observed so as to limit the risk of supplying products having an insufficient quality.

Moreover, regular and quite unexpected visits by the inspection organism prove the existence and the continuity of the internal control.

This system is the answer to the above mentioned definition ; it therefore appears that the quality assurance is a resultant of the attribution of the qualification certificate (NF mark).

5 - Conclusion

The quality assurance in the manufacture of concrete paving blocks such as described in this document is a modern and efficient means allowing to comply with a sufficient guarantee to the user's request according to specifications defined in standard NF P 98.303 but it also contributes to a better management of the production as it reduces the costs of non-quality which is a factor of competivity in the present difficult situation.

6 - Bibliography

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