Quality Control of Pavements in the Netherlands

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A brief historical review of the main elements of the development of quality control in road construction in the Netherlands is given. In this development, the continuing deliberation on technical specifications and methods of construction between the State Road Laboratory and committees of experts from contractors' organizations plays an essential part. The general principles of the nonstatistical quality control systems applied since 1968 as well as the statistical system developed during the past few years are explained based on 10 years' experience in the quality control of more than 250 road works. In the Netherlands, the separation between the responsibility for daily production control exercised by the contractor and the acceptance control exercised by the engineer after completion of the job is of great importance. Acceptance control concerns layer thickness, strength of soil cement, and density and bitumen content of asphalt mixtures on the one hand and skid resistance and roughness of the road surface on the other. Finally, issues of costs and benefits for jobs of inferior quality and the payment deductions required in such cases are discussed.

In the Netherlands, during the period from 1960 to 1965, a start was made in several major road contracts in using a general method of pavement quality control. This method ultimately led to an adequate system accepted by both the national highway authority and the contractors' organization. On the basis of the great quantities of data accumulated during these years, contract conditions connected with penalty clauses were introduced for the first time in 1966 as an experiment on some jobs. The conditions and the specifications were completed during the following 2 years and were drawn up in a definite version in 1968.

Since that time, these developments have been stimulated on the one hand by a lack of sufficiently skilled supervisory staff on the part of the highway authority and on the other hand mainly by ever-increasing mechanization and automation and the increase in magnitude of most of the jobs. The highway authority and the contractors became convinced that the method of unilateral quality control by the engineer, usually based only on testing of a relatively limited number of selectively taken samples, was no longer justified and needed to be changed. Although these conditions have not fundamentally changed since 1968, an alternative system was proposed in 1975 based on statistical principles and on the sampling and testing experience gained over a 10-year period.

CONSULTATION BETWEEN HIGHWAY AUTHORITY AND CONTRACTORS

Before the system of quality control incorporating reduced-payment clauses was introduced in 1968, thorough deliberation took place between the State Road Laboratory (SRL), representing the government, and a committee of contractors' representatives. In the Netherlands, the State Road Laboratory is a central institute of the national authority that is responsible for (a) formulation of the quality specifications, (b) structural design of the constructions and the composition of the mixtures, and (c) directions on quality control and on the execution of that control as far as it concerns the national (primary) roads. This centralization has resulted in a high level of uniformity in road construction specifications and effective consultation with the representative committee of the contractors' organization.

The system of quality control used since 1968 and now revised has been accepted in general terms by the contractors' organization and has been recognized as being reasonable, fair, and effective in reaching the desired quality level.

PRINCIPLES OF NONSTATISTICAL QUALITY CONTROL SYSTEM

The nonstatistical system of quality control is based on a consistent separation between daily production control by the contractor and limited acceptance control by the highway authority after completion of the work. To ensure a correct mix design, the contract prescribes that the contractor is to carry out a preliminary investigation of the strength (and, therefore, the needed cement content) of the sand cement base as well as the composition and the Marshall stability of the asphalt mixtures (the job mix design). The results of the preliminary tests are compared with the results of similar tests conducted by the State Road Laboratory. In this way, clear agreement is reached between the authority and the contractor on the design and the characteristics of the mixtures before the work starts.

Production Control by the Contractor

The contract prescribes that the contractor must maintain thorough, daily production control of the composition and the properties of the mixtures (the specifications are the same as they are for acceptance control testing). Therefore, a well-equipped on-site laboratory with skilled personnel must be available to the contractor.

The contractors have decided over time to make more use of statistical methods in managing the quality of production, especially in the execution of big jobs. For that reason, they use the so-called control charts, which aid in adjusting mixing, compacting, and finishing methods.

Acceptance Control by the Authority

Quality control, as practiced on road projects in the Netherlands, involves the following properties: (a) thickness of the pavement layers; (b) bitumen content of the different types of asphaltic concrete; (c) compaction (percentage of air voids) of asphalt; and (d) compressive strength of sand cement. In the past 10 years, cement concrete has not been used in the construction of motorways in the Netherlands. Because it may be used again in the near future, a system of quality control for cement concrete roads similar to that now used for flexible roads must be developed.

According to the quality control system used since 1968, one test sample is taken from every 2000 m^2 of pavement; each sample consists of two cores 10 cm in diameter drilled out of the finished construction. When testing of the four properties mentioned above leads to the conclusion that the quality is insufficient, penalties are imposed. These penalties are strictly limited to the specific sample and thus to the specific 2000 m^2 of pavement layer from which the sample was taken. The

Table 1. Results of quality control testing of road works in the Netherlands since 1968.

Property	Material	Overall Mean Value	Overall Standard Deviation	Specification or Penalty Limit
Compressive strength, MPa	Sand cement	6.0	2.3	2.0
Relative density (Marshall test), %	Sand asphalt	98.0	2.0	94.5
Air voids, %	Bitumen bound gravel	5.9	1.8	9.5
	Open-textured asphaltic concrete	4.7	1.9	8.5
	Dense asphaltic concrete	3.7	1.65	7.0
Bitumen content,[a] %	Bitumen bound gravel	5.0	0.32	5.0 ± 0.75
	Open-textured asphaltic concrete	5.5	0.31	5.5 ± 0.75
	Dense asphaltic concrete	6.5	0.29	6.5 + 0.75, 6.5 - 0.65
Layer thickness,[b] mm	Sand cement	150	17	120
		400	38	330
	Sand asphalt	120 (130)	18	100
	Open-textured asphaltic concrete	40 (43)	8	30
	Dense asphaltic concrete	40 (43)	6	33
	Total asphaltic concrete (120-mm bitumen bound gravel; 40-mm, open-textured asphaltic concrete; 40-mm dense asphaltic concrete)	200 (216)	20	180

[a]Nominal values.
[b]The layer thicknesses are nominal values, specified as minimum thicknesses. For asphalt mixtures, the prescribed quantities to be worked up are 20 kg/m^2 and 25 kg/m^2 per 10-mm nominal thickness for sand asphalt and all types of asphaltic concrete respectively. These quantities are controlled by a weighbridge and are settled. Because the normal mean densities of sand asphalt and asphaltic concrete are about 1850 kg/m^3 and 2300 kg/m^3 respectively, an extra safety margin of about 8 percent is calculated for each asphalt layer to ensure that minimum (nominal) thicknesses are present everywhere. Mean effective thicknesses are given in parentheses.

Figure 1. Cumulative percentage of road works for which penalties of various magnitudes have been demanded.

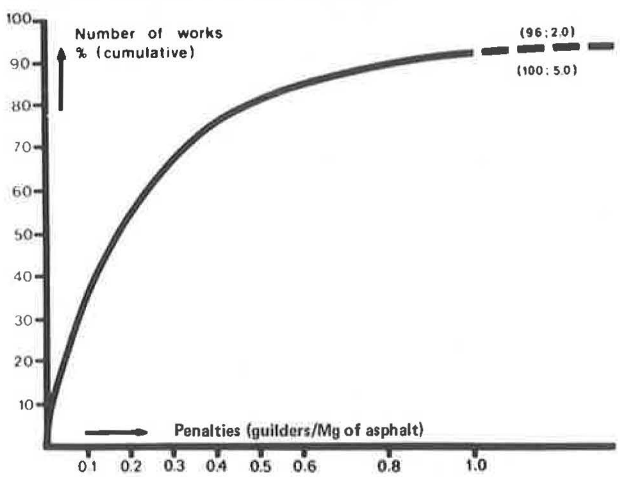
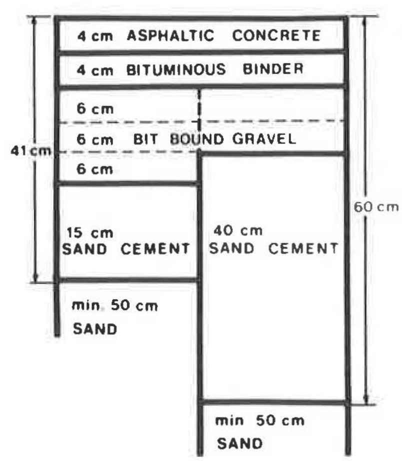


Figure 2. Standard construction for motorways in the Netherlands.



penalty per sample varies roughly in practice between 1000 and 10 000 guilders (1 guilder = \$0.40) per 2000 m^2 and per property (e.g., the compressive strength of the sand cement subbase or the density of the asphaltic concrete top layer) of a layer. This system is essentially not a real statistical method because it is based on judging the quality of individual samples and implementing the test results on penalties. In practice, however, the number of samples is normally so great (i.e., 50 from a total controlled surface of 100 000 m^2) that random testing may be justified.

The test results indicate that in most cases the number of samples of an insufficient level of quality (expressed in percentages of the total number of samples) is approximately equal to the number that transgress the specification limits, as calculated theoretically from the mean value and the standard deviation. Moreover, the system allows that 2 percent of the number of samples may give results below the specification limits without incurring a penalty. Higher percentages lead to reduced payments.

Results

The most important results of the quality control of more than 250 road construction jobs since 1968 are summarized in Table 1 and Figure 1 and in the table below (on the average, 1 Mg of asphalt in the Netherlands costs 50 guilders):

Highest Penalty (guilders per megagram of asphalt)	Percentage of Controlled Projects (cumulative)	Highest Penalty (guilders per megagram of asphalt)	Percentage of Controlled Projects (cumulative)
0	9	1.0	91
0.1	35	2.0	96
0.2	54	3.0	98
0.3	67	4.0	99
0.4	77	5.0	100
0.5	80		

These projects covered areas of at least 50 000 m^2; most of them measured 100 000 to 200 000 m^2 and some still more. The majority of the works thus had lengths of 10 to 20 km with a mean lane width of about 10 m.

The decision on whether the quality of work on a project is good or poor does not depend on any one property because every work is judged according to the results of testing for at least three or four properties: layer thickness, strength of soil cement (if present), and density and bitumen content of asphalt mixtures. Moreover, this testing deals with at least three or four different layers: sand cement (15 to 40 cm) or sand asphalt (10 to 12 cm), bitumen-bound gravel (12 to 24 cm), open-textured asphaltic concrete (4 to 8 cm), and dense asphaltic concrete (4 cm) (Figure 2).

In summary, the whole system is generally a combination of about 10 different quality control subsystems; the risks are thus spread over all parts of the construction. Therefore, if a penalty of 1 percent has to be imposed for insufficient strength of the sand cement and if no penalties are imposed for the other properties and layers, the overall reduced payment is limited to about 0.2 percent of the total value of the construction. Thus, when the total reduced-payment penalty for a job is very high, one can conclude that the quality of the work as a whole is poor.

PRINCIPLES OF THE NEW STATISTICAL QUALITY CONTROL SYSTEM

The nonstatistical method of quality control applied in the Netherlands since 1968 has some drawbacks. According to modern theory, these drawbacks can be overcome by using statistics. In a statistical testing system, the interpretation of test results on the basis of mean values and standard deviations takes the place of interpretation based on testing of individual samples.

In recent years, such a completely statistical system of quality control has been developed on the basis of the results of tests conducted on the 250 road projects controlled for quality in the past 10 years (Table 1). This system must be such that, for projects of an acceptable quality level, only small, incidental penalties can occur. To achieve this, a contractor's risk of 0.05 is generally chosen, which means for the contractor a 95 percent chance of approval (or acceptance) of the work or a 95 percent chance of incurring no penalties.

The system is now applied in the following way: From n samples taken at random, the physical properties (layer thickness, bitumen content, compaction, density, and compressive strength) are determined. From the n results, mean values ($\bar{x}$) and standard deviation (s) are calculated according to the following well-known formulas:

$$\bar{x} = \Sigma x_i/n \quad (1)$$

and

$$s = \sqrt{\Sigma(\bar{x} - x_i)^2/(n-1)} \quad (2)$$

On the basis of these values, $(R_{max} - \bar{x})/s$ or $|\bar{x} - R_{min}|/s$ is calculated, where R is the quality (or penalty) limit, either a maximum or a minimum. If this critical value is equal to or greater than the quality number (Q), the amount of the penalty imposed depends on the level of the critical value. Q values can be calculated with the help of statistical formulas that are not dealt with in this paper. Fixed values for Q for the various properties given in Table 1 are given below:

Property	Quality Number
Compressive strength	1.40
Relative density	1.40
Air voids	1.60
Bitumen content	1.60
Layer thickness	
Sand cement	1.40
Sand asphalt	1.40
Open-textured asphaltic concrete	1.40
Dense asphaltic concrete	1.40
Total asphaltic concrete	1.40

Random Samples

In the new system, 40 samples are drilled per job—always at random—over a maximum lot size of 200 000 m^2. When the lot is bigger than 200 000 m^2, it is divided into two equal lots and 20 test samples are taken from each lot. Because of the effort involved in the testing method, determination of bitumen content is limited to only 20 samples.

Statistical quality control is generally too expensive for use on lots smaller than 20 000 m^2. In this case, more frequent and thorough supervision and inspection by the engineer during production can ensure sufficient quality control.

Quality Criteria

As mentioned above, test results for the 250 jobs controlled nonstatistically since 1968 have been worked up statistically; i.e., the mean value ($\bar{x}$) and the standard deviation (s) have been calculated for every controlled property. Overall mean $\bar{\bar{x}}$ and $\bar{s}$ values for all the jobs have been determined from these data and are used to deduce the criteria for R and Q. Thus, the deduction is fully based on the test results acquired in practice on all 250 large jobs (both the good and the bad). The mean values $\bar{\bar{x}}$ ($\sim\mu$) and s ($\sim\sigma$) are thus defined as being representative of a standard job (Table 1). The penalty system is only applied for three layer thicknesses: (a) the total thickness of all asphaltic concrete layers together; (b) the thickness of the base of sand cement or sand asphalt, which is central to the structural design of the pavement; and (c) the thickness of the wearing course, which is highly important for the durability of the surfacing.

Penalties

Based mainly on experience with the nonstatistical quality control system since 1968, the following relations have been determined between the magnitude of penalties (K) and the number of test results (B) [B = percentage defective of the total percentage of samples (n)] that is below the fixed penalty limit (R) as calculated from the mean value ($\bar{x}$) and standard deviations: K = 0.3B - 1.0 for bitumen content and percentage of air voids for asphaltic concrete, and K = 0.3B - 2.0 for layer thicknesses, relative density of sand asphalt, and compressive strength of sand cement.

TRIAL USE OF THE STATISTICAL SYSTEM

It was agreed in deliberations between the State Road Laboratory and the committee representing the road contractors' organization that, during 1976 and 1977, between 10 and 20 road construction jobs should be judged according to both the traditional nonstatistical system and the new statistical system of quality control and that the comparative results should be thoroughly discussed. This might possibly lead to adjustments of the statistical system. (A method for taking extreme values into account had already been proposed.)

CONTROL OF SURFACE CHARACTERISTICS

Surface properties, roughness, and skid resistance are an important part of acceptance control. Testing for roughness and skid resistance is not done according to fully statistical procedures because it is not easy to express traffic safety in terms of statistical figures. However, to limit the number of measurements, at first only 30 percent of the road length is controlled for roughness and skid resistance. The sections to be measured are chosen at random. When the results of these limited measurements and the appearance of the road surface indicate insufficient quality, especially insufficient skid resistance, more measurements are carried out and, if necessary, the whole surface of the finished work is controlled.

Roughness

Until 1975, roughness was always controlled by using a rolling straightedge 3 m in length. If five or more deviations of >3 mm from the even profile were found per 100-m measuring section, penalties were imposed. When more than a few incidental deviations of >5 mm were found, surface roughness had to be corrected by the contractor by "shaving."

Since 1976, the viagraphe (Figure 3) has been used instead of the rolling straightedge for controlling road-surface roughness. When the so-called percentage of deviation (C_5) is greater than 2, a penalty is required. Deviations greater than 5 mm call for shaving by the responsible contractor. In special cases, when roughness is so bad that correction by shaving will not result in a sufficiently even surface, the contractor is forced by special contract conditions to adjust the surface by constructing an extra 40-mm top layer on the finished surface.

Skid Resistance

Since 1967, it has been required in the Netherlands that, before highways are opened to traffic, new finished pavements must be quality-controlled for skid resistance. This is done by using a standard measuring vehicle with a retarded wheel (86 percent slip) on a wet surface and at a measuring speed of 50 km/h (see Figure 2 in the paper by Elsenaar and van de Fliert elsewhere in this Record). When the measured friction coefficient is lower than 0.56, penalties are imposed. When it is lower than 0.51, the contractor must also correct the surface of the asphaltic concrete by treating it with white spirit and crushing sand. Such a treatment effectively removes the excess bitumen from the surface until a friction coefficient of at least 0.56 is reached. Because this treatment is rather costly, the prospect that it will be required works as a good preventive measure. Slippery sections on new roads are now rare, and normally the finished surface amply meets the specifications on skid resistance.

Figure 3. Viagraphe.

One prescription plays an important role in the acceptance control of skid resistance. For about 10 years, it has been prescribed in Dutch road contracts that asphaltic concrete top layers must be spread with about 2 kg/m^2 of fine chippings 2 to 5 mm in size before the surface is finished by rolling. This treatment effectively prevents the occurrence of the "initial slipperiness" of new asphaltic concrete top layers, which is caused by an excess of bitumen in the surface.

COSTS AND BENEFITS OF QUALITY CONTROL

Neither production control nor acceptance control alone can give 100 percent assurance of the total average quality of the work or prevent exceptional cases of poor quality. Research is, and will continue to be, based on random checks. An exact and ideal match cannot be achieved between optimum quality and the biggest possible profit for the contractor nor between the highest possible level of quality and the lowest possible cost for the governmental authority.

For this reason, the primary object of penalty clauses cannot be to secure adequate compensation for inferior quality. Any theoretical rules drawn up with this end in view would be affected by so many factors (e.g., subsoil, traffic trends, maintenance methods, and weather conditions) that an absolutely exact approach would be impossible. The introduction of an apparently watertight system based on cost-benefit investigation would therefore lead to unfairness to the contractors executing the jobs.

Brouwers of the State Road Laboratory has devoted a special study to the problem of costs and benefits. The conclusion of that study is that the penalties incurred for quality deficiencies under the new quality control system will be less by approximately a factor of 3 than the amount that would theoretically be involved if the effects of these quality deficiencies on the life of the pavement were expressed in loss of value. The following summary of the observations made in Brouwers' research includes findings relating to layer thickness and voids and bitumen content of an asphalt structure. The reduction in the service life of a pavement is calculated on the basis of specific deficiencies in these characteristics.

Layer Thickness

The loss resulting from pavement layers that are too thin can be quantified on the basis of data that relate layer thickness to traffic parameters. Use was made of the thickness design formula applied in the AASHO Road Test, which gives the relation between the number of load repetitions (n)—up to the moment when a specified serviceability index (p) is reached—and thickness expressed as thickness index (D) for a specified wheel load (P) in megagrams. It is possible, by using a thickness design formula, to calculate how many equivalent 10-Mg axle-load repetitions can take place before the point is reached where P equals, for instance, 2.5.

Pavement life can be calculated by assuming a standard traffic density in the first year for the type of road in question and allowing for a constant annual increase. Then the life of a similar pavement of less thickness can be calculated in the same way. It is also possible to calculate, on the basis of a normal distribution, what percentage of the total pavement has a layer thickness greater or smaller than the specified values, if either the average thickness (μ) or the standard deviation (σ) is varied. The reduction in pavement life can thus be calculated in each case and, finally, the loss resulting from having to undertake premature reconstruction and maintenance can be calculated on the basis of comparison with the normal structure. The details of these calculations are not treated here.

Costs determined in this way to compensate for deviations in layer thickness can then be compared with the penalty calculated on the basis of the penalty clauses; the penalty is determined for the same varying average values and standard deviations. Use of this method has resulted in a fairly constant average ratio between costs and benefits of 1:3.

Voids

Calculations of the reduction in pavement service life resulting from excessive voids caused by insufficient compaction can be done on the basis of fatigue tests on asphalt carried out by researchers in various countries. It can be concluded from a study of the published data that a reduction in pavement life of 25 percent for each percentage increase in voids is a cautious, relatively low estimate. Theoretical calculations have now shown that the cost to the highway authority as a result of the reduction in pavement life is on the average five to seven times as large as are the profits that result from penalties imposed because of excessive void percentages. It is also possible to calculate the reduction of the rigidity of asphalt layers because of excessive voids; the resulting effect on the increase in ground pressure (and thereby on the reduction of pavement life if ground pressure is also a decisive factor in the life of the pavement) can then also be calculated.

Bitumen Content

The effects of deviations in bitumen content can be calculated in the same way as can the effects of voids. A study of various published data on the relation between the binder content of asphalt mixtures and pavement service life leads to the conclusion that, for every reduction of 0.3 percent in bitumen content, service life is reduced on average by a factor of 0.75, provided that the bitumen content does not fall to very low values. From these calculations it can be concluded that the costs due to shorter life are on average three to four times as great as the benefits derived from the penalties. The following table gives data on the percentage cost attributable to the reduced service life of pavement and the percentage profit resulting from penalties or allowances imposed on the contractor:

Deficient Property	Cost (%)	Profit (%)	Deficient Property	Cost (%)	Profit (%)
Thickness	100	30 to 40	Bitumen content	100	25 to 35
Density	100	15 to 20	Mean	100	30

The overall cost-benefit conclusion drawn from this study was that costs caused by quality deficiencies are still several times greater than the benefits derived from penalties. Costs and benefits related to the quality control of road construction are therefore far from being in balance.

SUMMARY AND CONCLUSIONS

Since 1968, a uniform, adequate, and fair system of quality control of pavements has been applied in the Netherlands. The system, which has been developed in deliberations between the government and road construction contractors, is characterized by complete daily production control by the contractor and limited, random acceptance control by the highway authority after completion of the work.

According to the current nonstatistical quality control system, one sample per each 2000 m^2 of pavement is tested for layer thickness, strength of soil cement, and density and bitumen content of asphalt. When the quality does not meet specifications, penalties are applied in proportion to the extent of the deviation.

On the basis of experience gained on more than 250 major road works, the system has now been developed into a fully statistical control method. According to this statistical system, from 20 to 40 samples are tested on lots at most 200 000 m^2 in area, and penalties are imposed according to the mathematical formulas discussed in this paper.

Surface characteristics—skid resistance and roughness—are measured at random on 30 percent of the pavement surface. Penalties are applied if test results do not meet the requirements. When the results are below specific safety limits, the surface must be restored at the contractor's expense.

A theoretical study on the decrease in the service life of pavements caused by deficiencies in the thickness, density, and bitumen content of asphalt layers leads to the conclusion that the penalties applied under the quality control system are, on the average, about three times lower than the costs that would theoretically be necessary to compensate for the loss in pavement service life.

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