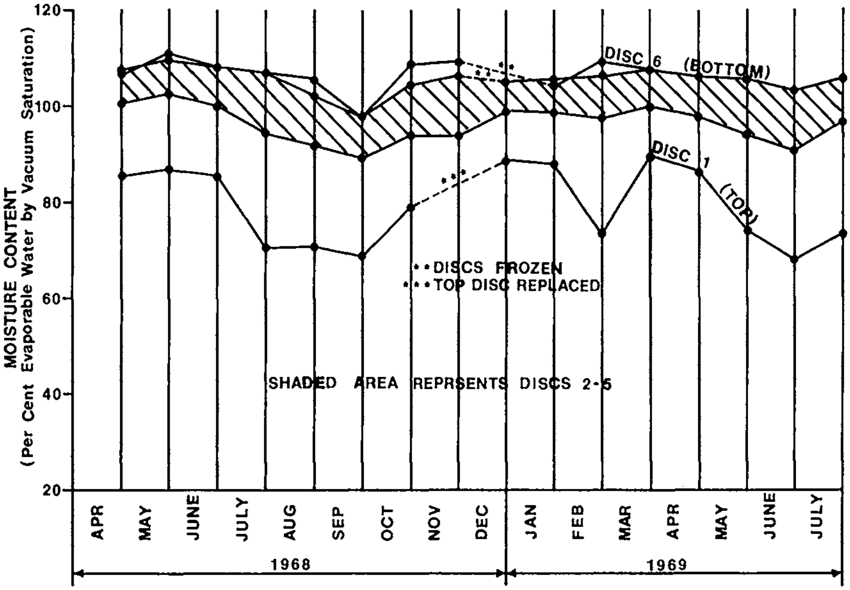

Fig. 16--Moisture content in specimen B of a pavement

Fig. 17--Meltwater from the snow on the parapets keeps the bridge deck wet while the roadway (background) is dry

SP 47-9

Long-Term Freeze-Thaw Durability Of Concrete in Catch Basins, Sidewalks And Pavement Slabs

By

J. Hode Keyser and M. Kushner

Synopsis: The City of Montreal has approximatively 65,000 catch-basins, 1639 miles of concrete sidewalk and 979 miles of concrete pavement. The paper gives the history of their long term freeze-thaw durability.

The first part of the paper deals will catch basins. An information sheet was prepared to describe all possible defects. An examination of the 325 defective units revealed that 90% of defects were in the upper three elements, and 57% of these, were deteriorated due to frost action. An inspection of the manufacturing process had shown that in the manufacture of dry cast catch-basin elements (a) the sequence for adding of admixtures must be controlled (b) a practical test method is needed to determine the air content of no slump fresh concrete (c) the yield of the manufacturer's recommanded dosage of air-entraining agent must be verified.

In the second part, the authors show that the sidewalk scaling problem was solved by applying research findings, revising specifications and by implementing a rigid quality control system. During concreting, each truckload of concrete is tested for air content.

The third part of the paper gives the results of an evaluation of long term variation of the strength of 93 concrete pavement bases. The study revealed that the strength increases at the least 15% the first year and is expected to increase on the average by as much as 36% at the end of 10 years. However the gain in strength is independent of the initial strength and may vary within a wide range.

Keywords: age-strength relation; air entrainment; catch basins; compressive strength; concrete pavements; concrete slabs; concretes; deterioration; freeze-thaw durability; long-time study; sidewalks; tensile strength.

J. Hode Keyser, Professor, Ecole Polytechnique, University of Montreal, formely Chief Engineer, City of Montreal, Control and Research Laboratory.

M. Kushner, Engineer, Chief of Quality Control Section, City of Montreal, Control and Research Laboratory.

INTRODUCTION

Major Research (1)

The city of Montreal had experienced in the late forties as did every other city in Canada, a post-war construction boom. In the rush to meet demands for new housing units, land developers and builders had pressured the City to open new streets at an unprecedented rate.

Prior to this period, all street construction had been done by City crews and contractors using construction methods and according to specifications established in 1923. Because of the great demand for new street construction, the City had no alternative but to let out all the work to private contractors. Of the nine contractors bidding for the work, two were equipped to supply a ready-mixed concrete; the others dry-batcheded on the job-site.

With the increased number of job-sites and rate of production, the City approved in 1953 new specifications for street construction. In particular, all the most recent criteria for a quality concrete had been incorporated.

With the ever increasing number of miles of sidewalk and pavement, and because of improved snow and ice removal operations, the City was experiencing for the first time in 1954 a major scaling problem.

An investigation later revealed that scaling was attributed to several factors; a greater proportion of sidewalk concrete was now being exposed to a greater number of freeze-thaw cycles, the concrete of the late forties was not air-entrained, and the quality of the materials was not adequately controlled.

In 1956, specifications were again revised, inspectors had been trained, sampling and testing frequences were established and statistical quality control was slowly being introduced. By 1960, the Control and Research Laboratory was inspecting, sampling and testing all materials.

From field data gathered over the years, from laboratory experiments, and experiences, the authors have reported their findings concerning the long term freeze-thaw durability of concrete in catch-basin elements, sidewalks and pavements.

CONCRETE CATCH-BASINS

Identification Of The Problem

Because of the soaring cost of repairs, the Roads Department and the Laboratory collected and compiled information during two years regarding catch basins to determine the number of concrete elements that had to be replaced due to concrete deterioration. A sample of 324 defective catch-basins was examined for causes. Although concrete deterioration was of prime importance, other factors were also considered. An information sheet was prepared on which are described all or at least most of the defects that could be encountered in this type of catch-basin (Figure 1).

In the City of Montreal, on the 979 miles of pavement and 1639 miles of sidewalk, there are approximately 65,000 catch-basins. This is equivalent to 74 miles of 24 inch diameter concrete pipe. The depth of a standard catch-basin is about 72 inches.

Catch-basins are repaired by contractors during and at the end of the 5 year guarantee period. All other catch-basins are repaired by the City. The cost of supplying and installing a new unit under contract is about $160.00. The cost to repair one is $350.00.

Table I shows the assembly, location and total number of defectives found in the 325 units inspected.

From the Table I, 90% of repairs were found to be in the upper three elements which receive most of the impact and are most frequently exposed to freeze and thaw. Only 172 of the 608 elements were judged deteriorated. A closer examination revealed that 57% of these were deteriorated due to frost action, i.e. 16% of the total.

Determination Of Factors Causing Defects

Since no identification of elements was reported, it was not possible to determine their exact age or to identify them with a particular manufacturer. It can be presumed however, that between the years 1945 and 1953, a large number of these catch-basins was manufactured without entrained air. It is nevertheless certain that all were at least five years and older.

The laboratory decided, in view of these findings, to investigate the quality of concrete currently used in the manufacture of catch-basin elements. Specimens were cut and cored from elements and tested for compressive strength and resistance to freeze and thaw. The results are shown in Table III and Table IV.

The results show (Table IV) that the air-entrained concrete was not sufficiently durable to resist long term freeze and thaw. From Table IV, although the average compressive strength was good, the "σ" value was high as expected. Cores obtained from elements manufactured by the dry-cast process and depending on the type of machine used, showed a high within batch variation. The core obtained from the upper third of an element which during fabrication was pressed by the making of the joint tested higher in compression than a core obtained from the bottom third.

Inspection of the manufacturing process revealed certain anomalies: (1) Producer "A" did not follow the sequence recommended for the addition of admixtures during the mixing cycle. All admixtures were added at the same time; (2) Producer "B" added only $\frac{1}{2}$ of the recommended dosage of air-entraining agent per sac of cement; (3) Producer A's process was found to be satisfactory. Because a test for air with an air meter in a no slump concrete is difficult and almost impossible to perform, the manufacturer did not know if in fact air was incorporated into the concrete.

At one of the plants, three test batches of concrete were mixed using one, two and three times the manufacturer's recommended dosage of air-entraining agent. A measure of the entrained-air in specimens obtained from three elements showed them to contain 7.3, 9.6 and 10.6% of air respectively. For a 3/8 in. aggregates, the specifications requirement for air content is $9\frac{1}{2}$%. The mix was adjusted to comply with specifications for air-content and minimum compressive strength.

Conclusion

The durability of concrete used in the fabrication of catch-basins was below expectations; the following recommendation was made; In the manufacture of dry-cast catch-basin elements, a greater effort should be made to determine and control the quantity of air-entraining agent required to obtain the desired air-content. The manufacturer should strictly follow the recommended sequence for the adding of admixtures.

CONCRETE SIDEWALKS

Definition Of Problem

After only several years of service, the poor quality of concrete in sidewalks resulted: (1) in excessive repair costs, and (2) was a constant danger to pedestrians. (2)

Special Research

The City of Montreal Research and Control Laboratory conducted several research projects to find causes and recommend corrective measures to eliminate and reduce to a minimum the scaling of concrete sidewalks.

Among the numerous research projects carried out by the City Laboratory to determine the causes of scaling,were: (1) the construction of 20 experimental sidewalks to determine the relative influence of cement and air content; (2) Laboratory investigation on the relative influence of compressive strength and air-content; (3) The construction of an experimental pavement and sidewalks to investigate the influence of air and waterproof-coating on the durability of concrete.

Experimental Sidewalks

In 1955, 20 sections of experimental sidewalks were built. The object of this investigation was to compare the relative performance of two local cements, A and B, both conforming to ASTM Specification C-150.

Six slabs were built with each type of cement. The concrete of the remaining slabs contained only 1.8 to 2 per cent air. During the 4 winters following the construction, in addition to more than 300 freeze-thaw cycles, each slab was de-iced by salt 100 times. The conclusions of the test were: (1) None of the air-entrained concrete sidewalks had scaled, whereas the others were badly deteriorated; (2) No significant difference in scaling was noticed between slabs made with different cements.

Relative Influence Of Compressive Strength And Air-Content On Durability Of Concrete

Concrete samples of different strength and air-content were subjected to 200 freeze-thaw cycles. Test results, given in Table V indicate the importance of air-content in relation to compressive strength.

Experimental Pavement

In 1955, the concrete pavement around the laboratory was rebuilt. A concrete of 3500 lb per sq.in. compressive strength, 4-in.slump, and 5 to 7 per cent air-content was used. An air test was made for each truckload of concrete. All slabs were built with concrete of this strength, but 3 of the slabs had 5 in. of slump and no air. Two of the three slabs were treated with number 10 motor oil diluted with 10 per cent carbon tetrachloride.

Only a year later, the surfaces of the slabs with no entrained-air and no waterproof coating were scaled. The slabs with water proof coating deteriorated gradually. A recent inspection (9 years after construction) of the 550 slabs indicates that none of the air-entrained concrete slabs were scaled whereas the three non-air entrained slabs suffered severe deterioration.

Tests On Surface Treatment Materials

The purpose of this study was to compare the efficiency of different commercial waterproofing products in protecting sidewalks and other exposed concrete surfaces (such as catch-basins) against scaling. In all, six materials from different sources were tested, i.e. one silicone solution, two types of bituminous materials, and three linseed oils from different sources. Triplicate samples were made for each product with the same concrete, they were then coated with different materials according to the manufacturer's recommendations and subjected to 200 freeze-thaw cycles.

Observations following the test clearly indicated that after 200 freeze-thaw cycles the samples coated with linseed oil were practically unaffected, the samples coated with bituminous materials have partially deteriorated, and the samples coated with silicone material, like the untreated samples, were badly scaled.

Conclusive results indicate that a good air-entrained concrete does not require any additional protection against scaling. There is however one indication that may or may not be conclusive. That new fresh concrete for sidewalks which is poured in the late fall should be protected with a surface treatment.

Specification Requirements

The result of controlled experiments to study the effects of freeze and thaw on the durability of concrete has shown that durable sidewalks could be built if the quality of materials is controlled, concrete is air-entrained and construction is supervised. In addition, the City included in its specification a stipulation whereby the contractor must guarantee all materials and workmanship for a period of five years.

Although the City's specifications are of the end result type, the Laboratory nevertheless exercises a rigid quality control over all materials supplied and used in the construction of sidewalks.

Materials and concrete mix-designs must be approved before the commencement of works. During the construction, materials are sampled and tested according to established frequencies for compliance with specifications, concrete plants are inspected, weights verified, concrete deliveries checked, and the pouring, finishing and curing of concrete supervised.

During concreting each truck load of concrete is tested for air-content. The slump test is made and at least 3 samples of 3 cylinders are taken per pour or per day for strength tests.

Conclusion

Figure 2 illustrates the end results. As indicated by the two surveys, the scaling of sidewalks after a 5 year period was reduced from 22 per cent in 1959 to less than 0.5 per cent in 1966.

CONCRETE PAVEMENTS

Introduction

The design of a rigid pavement is based on the modulus of reaction of the subgrade, the concrete strength and the anticipated traffic conditions. The purpose of this investigation is to evaluate the long term variation in the strength of concrete base.

Special Studies

The pavements built in Montreal are almost all of the composite type, i.e. 6-10" of concrete base overlayed with 3" of bituminous mixture. The concrete base rests directly on the compacted subgrade.

Prior to 1955, no air-entrainment was required in the concrete. A series of cores obtained for pavement evaluation purposes indicates that 20 years after construction nearly all the concrete in the pavement base was completely desintegrated.

From 1955 to 1970, the quality characteristics of the concrete used in the construction of new and reconstructed pavements had to satisfy specifications requirements:
3000 psi-minimum compressive strength, 525 lb-minimum cement content, 3 in-maximum slump, 5-7% entrained-air, $1\frac{1}{2}$ in-maximum crushed aggregate. Inspection at the plant, sampling and testing of ingredients and concrete assured conformance with specifications. Core samples were obtained for acceptance purposes.

A fourteen year temperature record shows that an average of 60 freeze-thaw cycles occurs per year and the length of a frost period is about 190 days. The critical depth of frost penetration in Montreal is approximately 6 feet.

The study covers 93 pavements varying in age from 1 to 10 years (3).

The relative data consists of:

a) Results of tests for concrete strength of samples obtained for control purposes immediately after construction, and

b) Results of tests for concrete strength of samples obtained several years after construction for pavement evaluation (R_{va}). The pavement's age, initial strength, strength at time of evaluation and increase in strength are summarized on Table VI.

The statistical analysis of the data is shown in Table VII. The mean, standard deviation, standard error, minimum and maximum value, and range were calculated for the four pavement characteristics: age initial strength, strength at time of evaluation and change in strength. The initial strengths vary between 2755 lb and 5250 lb.

The two analyses made were: a) An analysis of results of a group of 93 pavements ranging in age from one to 10 years.

On figure 3 is shown the relation between age of the concrete base and the increase in strength expressed in per cent of the initial strength. A coefficient of correlation of 0.67 was obtained for a linear relation. There is an appreciable scatter, and the standard error of increase in strength is 13%.

A third degree polynomial was also fitted to the two dimensional data as shown on figure 4. The coefficient of correlation 0.68, and standard error 12.9 are almost equal to the values obtained for a linear relation.

In general, the concrete strength increases rapidly, especially during the first years, and continues to increase even after 10 years of age.

b) Analysis of 60 pavements at the age of 10 years.

This analysis, by eliminating the age factor, was made to study the nature and the variations in the change in strength.

The histogram of figure 5a shows the distribution of the initial average concrete compressive strength for the 61 pavements at an age of 10 years. The average, standard deviation, and coefficient of variation are respectively 3814 lb, 417 lb and 10.9%. By ACI standards, the uniformity of the concrete is very good.

The concrete strength of these pavements after ten years of age is shown of figure 5b. The average strength, standard deviation, and coefficient of variation (5194 lb, 757 lb, 14.5%) have all increased. The statistics indicate that the increase in strength is not uniform.

On figure 6 is shown the relation between the initial strength and the strength after 10 years. The coefficient of correlation is 0.65 and the standard error is 582/lb in.

The linear relation can be expressed as:

$$R_{10\ years} = 714 + 1.175\ R_{Init.}$$

Figure 7 is a histogram of the increase in strength after 10 years. The average gain is 36.4% with a standard deviation of 16.2%. The maximum values are respectively 65 and 3%.

To find a relation between increase in strength and initial strength, linear and polynimial regressions were studied. The results are whown on figure 8.

In can be concluded that there is no relation since in both cases the coefficients of correlation are .005 and .226.

Conclusions

The study of the compressive strength results of the 93 pavements built according to City of Montreal specifications within the last 10 years permits us to make the following conclusions:

1. The strength of the concrete in pavement bases increases by at the least 15% the first year, and is expected to increase on the average by as much as 36% at the end of 10 years.

2. The minimum and maximum gain in strength after ten years is between 3.2% and 94%. An interesting study could be made to identify the factors causing such a large variability.

3. The gain in strength is independent of the initial strength.

REFERENCES

1. Hode Keyser, J., Scaling of Concrete by Frost Action, Performance of Concrete, University of Toronto Press, 1968.

2. Chauret, E. L'Air dans le béton, L'Ingénieur, hiver 1959.

3. Hode Keyser, J. Etude des chaussées mixtes rapport no: 3 Accroissement de la résistance du béton de fondation avec le temps Unpublished report 1973