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COOPERATIVE TEST PROGRAM FOR PRECAST CONCRETE PAVING ELEMENTS

by G.G. Litvan, Cameron MacInnis, and P.E. Grattan-Bellew

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SOMMAIRE

Des dalles de pavage en béton sont mises à l'essai afin d'atteindre les trois objectifs suivants: 1) évaluer le degré requis de résistance au gel-dégel dans les diverses régions climatiques du Canada; 2) estimer la valeur des méthodes d'essai courantes; 3) déterminer l'efficacité des produits commerciaux. Les résultats ont prouvé que la quantité de sel utilisée pour la même superficie à différents endroits varie énormément (3 kg à Saskatoon, 277 kg à Ottawa), que la teneur en eau, sans tenir compte de la saison, est près de la saturation (humidité relative de 87 %), que ni le cycle gel-dégel normal ni les essais courants d'écaillage par le sel ne donnent de résultats représentatifs et que tous les produits commerciaux, à une exception près, sont jugés résistants.

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Cooperative Test Program for Precast Concrete Paving Elements

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ABSTRACT: Concrete paving slabs were tested to achieve the following three objectives: (1) assess the degree of freeze-thaw durability required in the various climatic regions of Canada, (2) assess the merit of standard testing methods, and (3) evaluate the adequacy of commercial products. Results indicated that: the amount of salt used for the same area at the various sites differs greatly (3 kg in Saskatoon, 277 kg in Ottawa); the moisture content, regardless of the season, is close to saturation (relative humidity 87 percent); neither the standard cyclical freezing-thawing nor the standard salt-scaling tests yield representative results; all the commercial products, with one exception, could be judged durable.

KEY WORDS: concrete, precast concrete, pressed concrete, paving slabs, building materials, durability, freezing and thawing, salt scaling, alkali-aggregate reactivity

For satisfactory service in Canada, precast concrete paving slabs are required to have a very high degree of resistance against the action of freezing and thawing in the presence of deicing salts. To satisfy this requirement, manufacturers of such products face a difficult task.

Matters are made more complicated by the diverse conditions prevailing in the various regions of the country: the relatively temperate Atlantic Provinces; the dry, cold Prairie Provinces; and the variable but severe climate around the Great Lakes. Obviously, not the same durability is required in the various regions.

Not only are these requirements ill defined but there is no agreement concerning the testing method. Because of these uncertainties, the adequacy of the slabs now manufactured cannot be evaluated.

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The pertinent Canadian Standards Association (CSA) Standard for Precast Concrete Paving Slabs (CSA A231.1-1972) states, "The manufacturer shall satisfy the purchaser either by proven field performance, or the laboratory salt-scaling test, that the paving slabs have adequate durability." Field performance is considered to be satisfactory if no objectionable deterioration occurs after 3 years of exposure. The laboratory salt-scaling test consists of exposing the specimen, with a salt solution ponded on the surface, to repeated cycles of freezing and thawing (CSA A231.1).

At the request of the National Precast Concrete Association, the National Research Council (NRC), in cooperation with the University of Windsor, initiated the present project in 1972 with the following objectives:

1. assess the degree of freeze-thaw resistance necessary for good performance in the various climatic regions of Canada,
2. evaluate the merit of the various methods for testing the freeze-thaw resistance of precast concrete elements, and
3. evaluate the adequacy of the products of manufacturers in various regions of Canada.

Materials

In the summer of 1972, seven manufacturers supplied 144 precast paving slabs from their current production. These were either "wet pressed" using Fielding machines, or "dry impacted" using a Rino machine, or cast in molds. In addition, for purposes of comparison, 40 slabs were cast in molds at NRC. There were altogether ten different types of slabs, each nominally 762 by 610 by 51 mm (30 by 24 by 2 in.). They were coded with letters from A to J. Slabs A, D, E, and H were cast and air entrained; B, C, G, I, and J were wet pressed; and Slab F dry pressed.

Field Exposure

The specimen slabs were exposed at four sites: Halifax, Nova Scotia, at the Nova Scotia Technical College; Saskatoon, Saskatchewan, at the exposure site of the Prairie Regional Laboratory of the NRC of Canada; Windsor, Ontario, at the University of Windsor Campus; and in Ottawa on the NRC grounds.

Stainless steel studs, cemented in the slabs with epoxy cement prior to exposure, facilitated length change measurements in the field with a Huggenberger gage. The slabs were placed on a 50 mm deep sand base in random sequence with their top surface being approximately level with the surrounding ground. With the exception of the Saskatoon site, the slabs formed sections of existing walkways that were subjected to considerable pedestrian traffic.

During the winter the walkways were cleaned of snow and salted when icing conditions prevailed. The amount of salt (NaCl) applied was recorded (Table 1).

The results, though incomplete, clearly show the vast differences that exist with respect to climatic conditions among the various Canadian geographic regions. The ratio of the quantities of salt applied at Saskatoon, Windsor, Halifax and Ottawa is 1:15:26:101. Although salt consumption cannot be accepted as the sole measure of severity, it is certainly one of the major factors. It is a well known fact that, in the presence of deicing salts, damage due to frost action is increased. The relatively cold but changeable Ottawa climate is the most damaging from the salt scaling point of view, an indication consistent with field experience.

In addition to the NRC site, ten slabs were exposed in Ottawa on a city street, forming the curbside section of the sidewalk at a bus stop. Unfortunately, after the first winter exposure, the city paved the street and the specimens were lost. Even in this short period of time, however, the slabs suffered much deterioration as can be seen in the photograph taken in March (Fig. 1). The combined effect of the mechanical damage inflicted by the snow-clearing equipment, the buses, and the frequent splashing of brine must have caused the failure of the slabs. The sharply differing performance of the same type of slabs at two locations in Ottawa underlines the importance of the local environment as well as the material when evaluating durability. It is quite common to classify a material in itself as durable without specifying the limiting environmental conditions.

Adsorption Isotherm

To establish the relationship between moisture content and relative humidity, two specimens (100 by 100 mm-base) were cut from each type of slab and exposed to carefully controlled humidities in a glove box. The relative humidity was continuously monitored with an Aminco hygrometer; the variation was less than ±1 percentage point. Change in moisture content was determined inside the glove box. Time required to reach equilibrium at a given humidity level was approximately 22 weeks.

TABLE 1—*Yearly salt consumption, kg, at the exposure sites.*

	1972–1973	1973–1974	1974–1975	1975–1976	1976–1977	Total
Halifax	20.9	8.2	...[a]	19.1	23.6	71.8
Windsor	8.2	...[a]	16.3	10.0	8.2	42.7
Ottawa	72.6	61.3	25.0	74.9	43.1	276.9
Saskatoon	0.0	2.7	0.0	0.0	0.0	2.7

[a]Not available.

FIG. 1—*Photograph of concrete slab.*

The isotherms shown in Fig. 2 exhibit marked hysteresis. The first adsorption path (Points 1, 2, and 3) was not retraced in the second path (Points 5, 6, and 7). Similar deviation was found with respect to other points. The total uptake varies from 3.15 (Specimen C) to 5.45 weight percent (Specimen H), the average for the ten types being 4.1 percent.

Moisture Content of Exposed Specimens

To obtain information on the moisture content of the exposed slabs, specimens of each type were cut (with 100 by 100 mm base), the sides covered with an epoxy coating and placed on a 50 mm thick sand bed in the field in the same general area as the slabs. The variation of moisture content was determined by weighing at periodic intervals, at least twice a year. Four specimens of each type were exposed; the averages of the weight changes are shown in Fig. 3. The values were corrected for weight loss due to spalling. A portion of the epoxy coating and in some instances chips of the concrete fell off, mainly during the first year. In spite of the

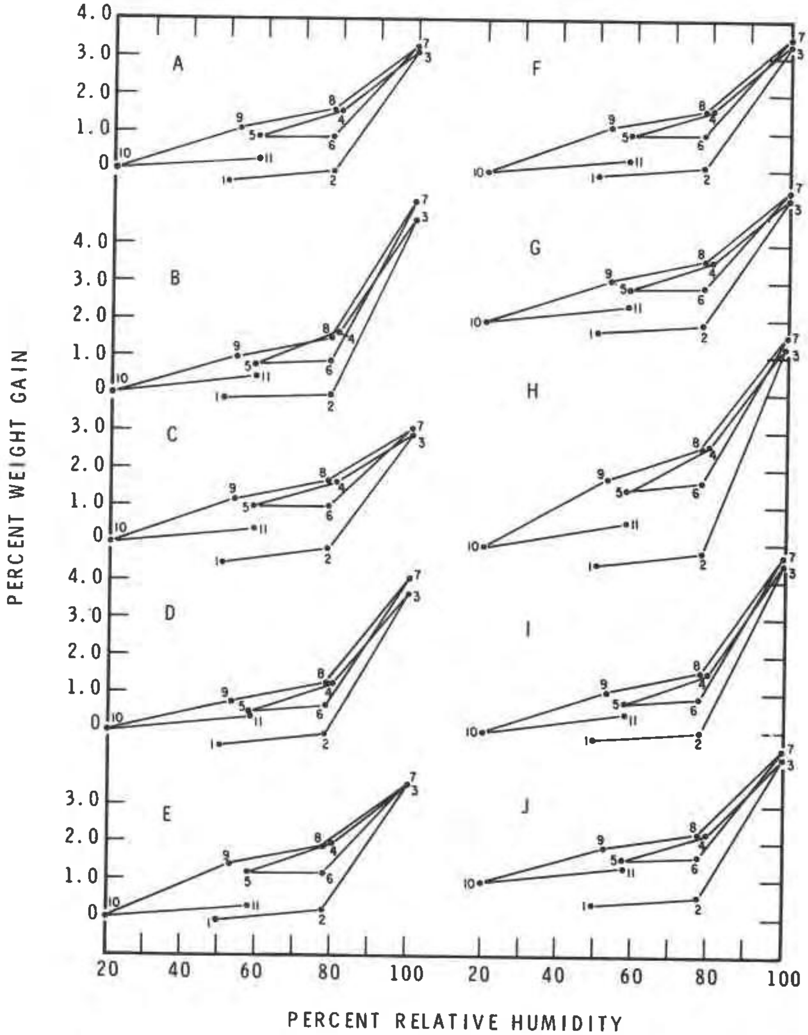

FIG. 2.—*Adsorption isotherm of specimens.*

great care taken, the correction cannot be considered as completely successful and the initial section of the curves may be incorrect.

There is, however, little uncertainty about the later and final section of the curves which indicate essentially no change in moisture content for all ten types of specimens. Because the weight changes could not be monitored continuously, between measurements undetected transitory changes may occur but this is not very probable. From the level reached after 4 years, the average moisture condition to which the specimens are exposed can be

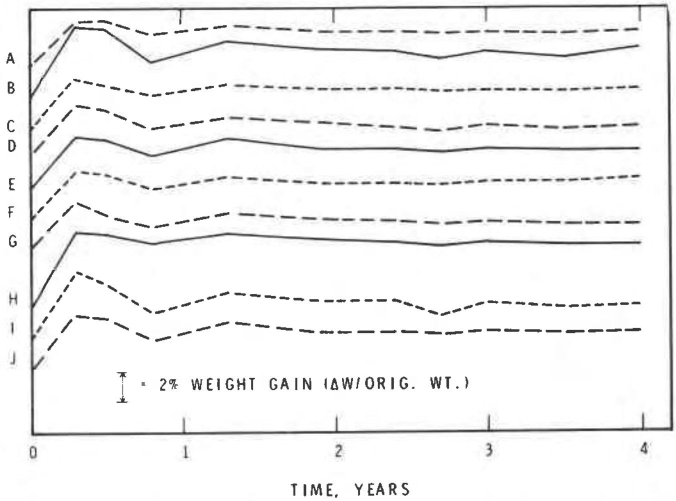

FIG. 3—*Average of moisture content variation of field-exposed specimens.*

estimated with the aid of the adsorption isotherms (Fig. 2). The values of Table 2 indicate that, regardless of the season, the moisture condition is equivalent to a relative humidity of 87 percent.

Cyclical Freezing and Thawing Test

Two specimens, 25 cm long and 7.5 cm wide, were cut from each type of slab and tested in accordance with ASTM Test for Resistance of Concrete to Rapid Freezing and Thawing (C 666 - 77) (freezing in air, thawing in water). The apparatus and procedure conformed to the standard; after

TABLE 2—*Moisture gain, after 4 years of exposure, related to relative humidity.*

Code	Gain: Weight, %				Gain: Average	Relative Humidity
A	2.5,	2.5,	2.6,	2.3	2.45	88
B	3.0,	3.3,	2.9,	3.9	3.27	90.5
C	2.8,	2.6,	2.4,	2.2	2.50	88
D	1.5,	2.0,	2.7,	2.5	2.17	83
E	2.6,	2.5,	2.5,	2.7	2.57	89
F	2.7,	2.5,	2.7,	2.8	2.67	89
G	1.5,	1.8,	1.5,	1.8	1.65	80
H	4.2,	4.1,	4.4,	4.4	4.27	90
I	2.5,	2.5,	1.8,	2.4	2.30	85
J	2.5,	2.3,	2.5,	2.7	2.50	88
Average					2.63	87

having reached the temperature at the specified rate, it was kept constant so that each half cycle lasted 6 h. Degradation of the specimens was assessed from residual length change measurement.[3] Figure 4 shows the change of residual length change as a function of cycle number.

The following comments may be made:

(a) All specimens show detectable expansion ($\Delta L = 0.005$ percent) at fewer than 100 cycles. This is consistent with earlier findings according to which residual length change measurement is a reliable and sensitive method for detecting frost damage.

(*b*) In some instances the agreement between duplicate specimens was rather poor.

Salt-Scaling Test

The ten slabs were subjected to the CSA Standard A231.1 in which the specimen is frozen and thawed 50 times with a salt solution ponded on the surface. The results are shown in Fig. 5.

Dimensional Changes

Changes in the dimensions of the slabs exposed at the four sites were determined, as described in the previous section. Extension curves obtained from results of the slabs exposed in Ottawa are shown in Fig. 6. In Table 3, the slopes of the curves of specimen slabs at all sites are given.

Discussion

1. With the exception of those exposed at the Ottawa site, the exposed specimens showed no sign of any distress after five winters. On this basis all the products have to be judged as durable. This is surprising and inconsistent with the cyclical freeze-thaw test in which at least three types of slabs, I, G, and C, were found to be susceptible to frost by deteriorating after fewer than 250 cycles (Fig. 4). Significantly, according to the salt-scaling test, C is the best; I and G are relatively good. Although this test showed that Slabs B, A, and E were the most prone to the action of deicing salts, in the freezing and thawing test E was the best and A was among the best. According to the salt-scaling test, by far the most susceptible to the action of deicing salts is Specimen B, which showed signs of deterioration after 200 freezing and thawing cycles carried out in accordance with the test in ASTM Method C 666. According to the

[3]Litvan, G. G., *Materials and Structures*, Vol. 6, No. 34, July-Aug. 1973, pp. 293-298.

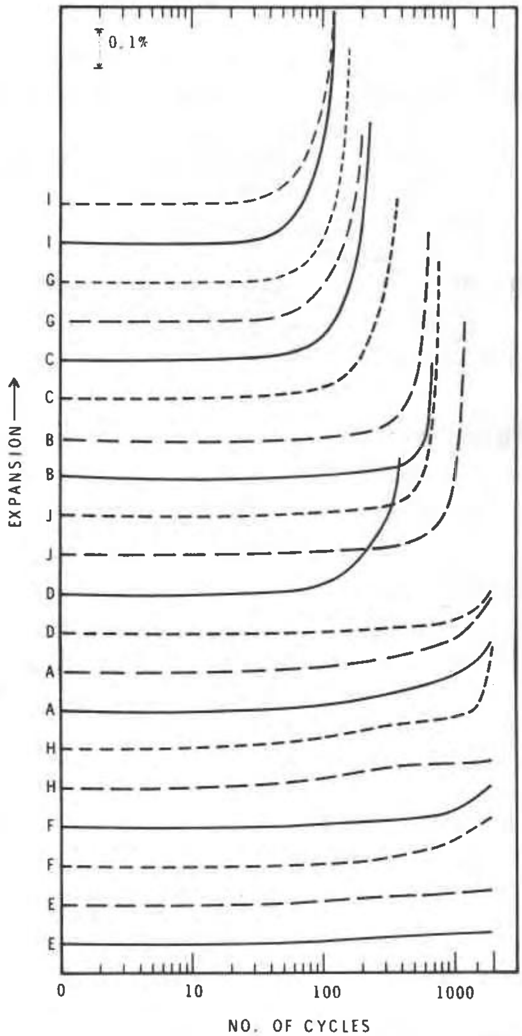

FIG. 4—*Expansion of patio slab sections as a function of freeze-thaw cycles.*

dimensional changes of the exposed slabs at all sites, the B slabs performed among the best (Fig. 6 and Table 3).

The freezing and thawing test, and to a greater extent the salt-scaling test, are noted for yielding easily reproducible and very representative results. Owing to the scarcity of long-term performance studies, the size of the discrepancy between predicted and actual field performance is not generally recognized. In connection with the large-scale Naperville Farm

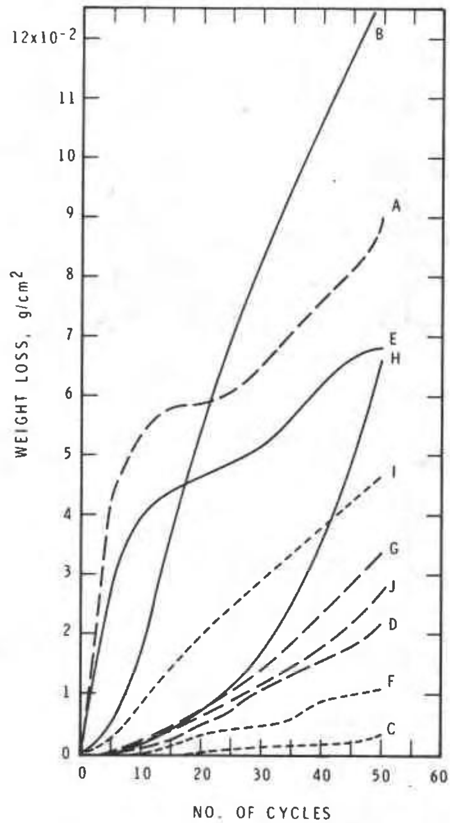

FIG. 5—*CSA salt scaling test.*

program of the Portland Cement Association, in which concrete specimens were tested in two different laboratories and exposed, T. C. Powers pointed out[4]: "During these laboratory tests *every specimen was damaged,* some much more than others. These tests gave no indication that of more than 1000 specimens exposed out of doors, 87 percent would remain undamaged after more than 20 years of outdoor exposure."

The results of this present study are fully consistent with these observations. On the basis of the tests, at least three slabs should have been judged unacceptable on the basis of one test and another three on the basis of the other test. It appears that the best products in the lot would have been eliminated by this process.

It can then be concluded that the results of the conventional tests bear

[4]Powers, T. C., *Cement, Lime and Gravel,* May 1966, pp. 143-148.

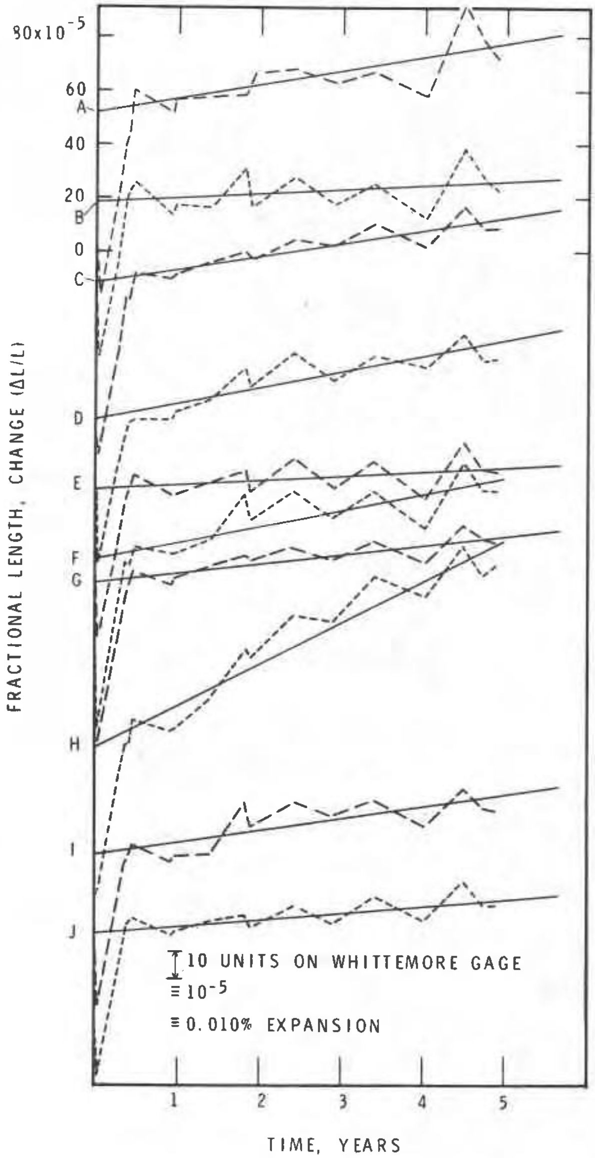

FIG. 6—*Average dimensional changes of slabs exposed in field, Ottawa.*

TABLE 3—*Slope and correlation coefficient of the average dimensional change versus exposure time curves.*

	Halifax		Ottawa		Windsor		Saskatoon				
Code	Slope	Correlation Coefficient	Slope	Correlation Coefficient	Slope	Correlation Coefficient	Slope	Correlation Coefficient	Sum of Slopes	Average	Rank
A	−2.36	0.554	+5.16	0.727	−8.46	0.689	−0.377	0.073	−6.037	−1.51	6
B	−2.23	0.421	+1.51	0.320	−6.91	0.641	−2.79	0.501	−10.42	−2.60	2
C	−0.34	0.107	+4.62	0.886	−10.55	0.880	−1.69	0.338	−7.96	−1.99	4
D	+1.76	0.396	+5.48	0.837	−6.91	0.730	−1.43	0.423	−1.10	−0.27	8
E	−0.52	0.126	+1.74	0.430	−6.40	0.629	+1.73	0.262	−3.45	−0.86	7
F	+0.02	0.034	+5.53	0.760	−4.41	0.500	+1.93	0.402	+3.07	+0.77	9
G	−1.17	0.299	+3.26	0.804	−10.20	0.851	−4.98	0.731	−13.09	−3.27	1
H	+8.23	0.887	+14.90	0.947	+8.17	0.689	+4.70	0.590	+36.00	+9.00	10
I	−0.873	0.253	+4.04	0.791	−6.04	0.769	−3.93	0.806	−6.80	−1.70	5
J	−1.13	0.333	+2.50	0.686	−6.84	0.760	−2.68	0.654	−8.15	−2.04	3

little relation to actual performance and the procedures appear to be far too severe.

2. The dimensions of an exposed slab will be altered by thermal effects, change in moisture content, and change in mechanical properties due to hydration, freezing and thawing, and alkali reactivity.

In the present investigation, thermal effects can be disregarded because the results were obtained, to the utmost extent possible, at the same temperature. Measurements were made at the same time of the season on days when the air and surface temperatures reached predetermined values.

As the slabs had been stored indoors, their moisture content at the outset of exposure was low and the initial expansion shown in Fig. 6 must be ascribed to wetting. This is consistent with the increase of moisture content indicated by the curves of Fig. 3. As stated earlier, the moisture content after the initial period was found to be constant and of a level which is normally produced by exposure to 87 percent relative humidity of the slabs. Constant moisture content does not preclude redistribution between free and bound water as hydration proceeds, as was shown by the contraction of the specimens at sites other than Ottawa (Table 3). Expansions indicated by the curves in Fig. 6 should then be attributed to either frost damage or alkali reactivity.

By far the largest expansion at all sites occurred in Specimen H. Examination of the dimensional changes at the Ottawa site shows that H slabs expanded on the average of 0.07 percent in 1786 days (Fig. 7), well above

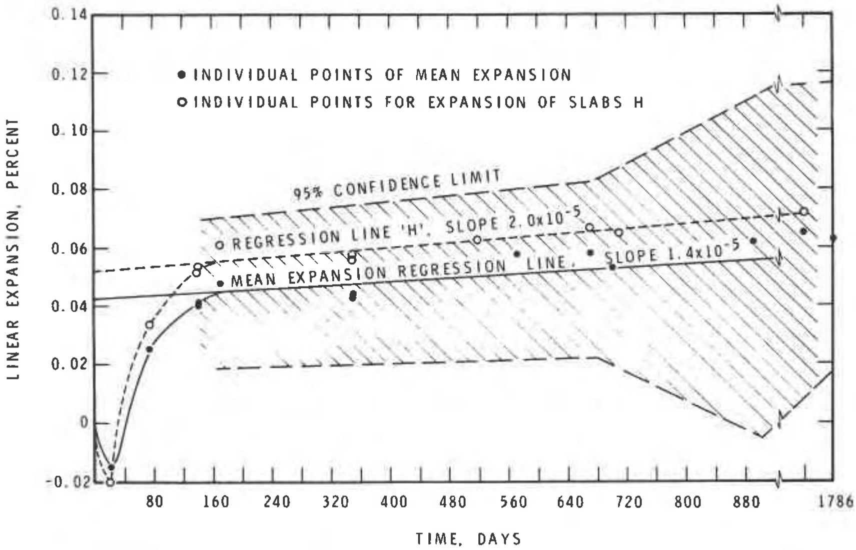

FIG. 7—*Mean expansion of all the patio slabs on the walk at NRC Ottawa (H is also shown for comparison).*

the mean regression line of all the slabs. Specimens of Slab H were found to be highly frost resistant by alternate freezing and thawing test but failed in the salt ponding test. In light of what has been said, these results offer little guidance as to the cause of the expansion.

A modified version of the concrete prism test (CSA Standard for Alkali Aggregate Reaction A23.2-14A), was used to ascertain the alkali reactivity of the aggregates in the slabs. Because aggregates used in the fabrication of the slabs were not available for each type, prisms were sawn from the slabs which had been stored indoors for 3 years.

According to the results of the concrete prism test shown in Fig. 8, Specimen H expanded 0.127 percent in 3 years; this is well outside the 95 percent confidence limits of the mean expansion of all the patio slabs excluding H. This expansion, which is greater than that found with the field-exposed specimen, together with the marked map cracking leaves little doubt about the reactivity of the aggregate in Slab H.

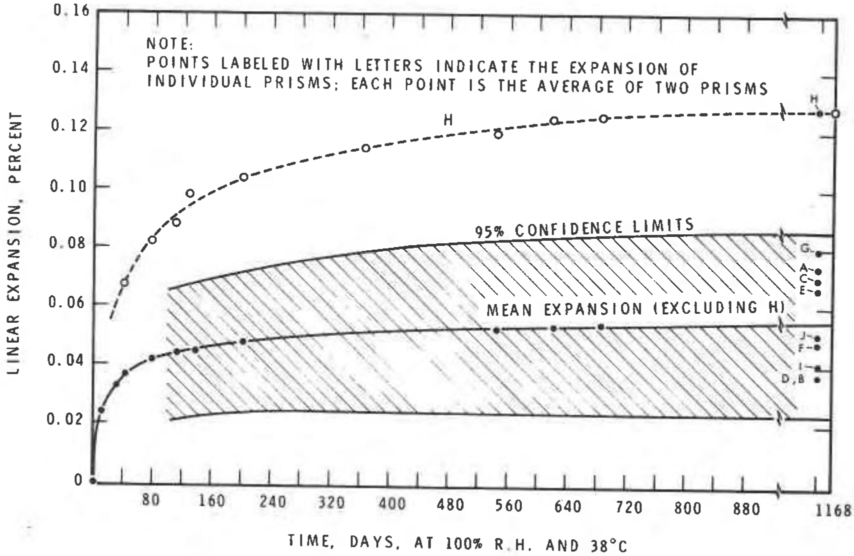

FIG. 8—*Mean expansion of prisms cut from patio slabs (tested according to modified concrete prism test CSA A23-2-24).*

Conclusions

The following tentative conclusions have been reached:

1. From the point of view of frost action Ottawa is the most severe region of the four exposure sites. Halifax (Maritime), Saskatoon (Prairie), and Windsor are far less severe.

2. The conventional laboratory tests, under conditions prevailing in the present program, yielded predictions which show little, if any, agreement with actual field performance.

3. The moisture content of the exposed slabs is fairly constant and is of the level that normally occurs at exposures at 87 percent relative humidity.

4. All slabs, except H, are durable.

5. The aggregate in Slab H is attacked by the alkali in the concrete.