Portland Cement Concrete Airport Pavement Performance in Canada

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In the first part of the paper portland cement concrete design considerations and construction practices used by the Canadian Department of Transport are discussed. This gives the background to the main subject of the paper showing the Department of Transport pavement evaluation procedures and experimental data for (a) portland cement concrete pavement strength, measured by field plate load tests; (b) curling of portland cement concrete pavements due to variation of the temperature gradient within the pavement; (c) the effect of curling of portland cement concrete pavement on pavement roughness; and (d) performance of airport portland cement concrete pavements in Canada.

• THE Canadian Department of Transport, Construction Branch, is responsible for the design and construction of all the major and most of the minor airports in Canada. There are 272 licensed and 481 unlicensed civil airports in the country, of which the Department owns and operates 117 and participates to varying degrees in the construction of the remainder.

DESIGN CONSIDERATIONS

Pavement design is based on static loading condition. Loadings are arranged in classes A to I, depending on airport class and operation.

Type A loading is 500-kip gross weight, 275-psi tire pressure (DC-8 wheel configuration). Type I loading is 27-kip gross weight, 50-psi tire pressure (single wheel).

Under ordinary conditions the design policy of the Department is to construct aircraft parking aprons and runway ends in portland cement concrete. For the rest of the paved areas the choice of pavement surfacing material is made on the basis of economy.

The standard design (1) is non-reinforced portland cement concrete. Slab sizes are 20 ft by 20 ft with a reduction for the edge slab to 12.5 ft by 20 ft. Expansion joints are not provided and no load transfer devices are used in the dummy joints. The construction joints are keyed. Standard joint details are shown in Figures 1, 2 and 3.

Pavement thickness is determined on the basis of the original Westergaard equation (2, 3), assuming a central loading condition. A safety factor of 1.2 is applied to the 28 days flexural strength of the concrete. At present, on the basis of field experience, it is considered advisable to limit the pavement thickness of portland cement concrete to 15 in. This limit is not usually exceeded even when the theoretical analysis would indicate otherwise.

Protection against subgrade frost action is provided for in the design by the combined thickness of portland cement concrete pavement, base and subbase up to about one-half the expected depth of frost penetration, based on the 10-yr average freezing index, and the correlation presented in Figure 4.

Paper sponsored by Committee on Pavement Condition Evaluation.

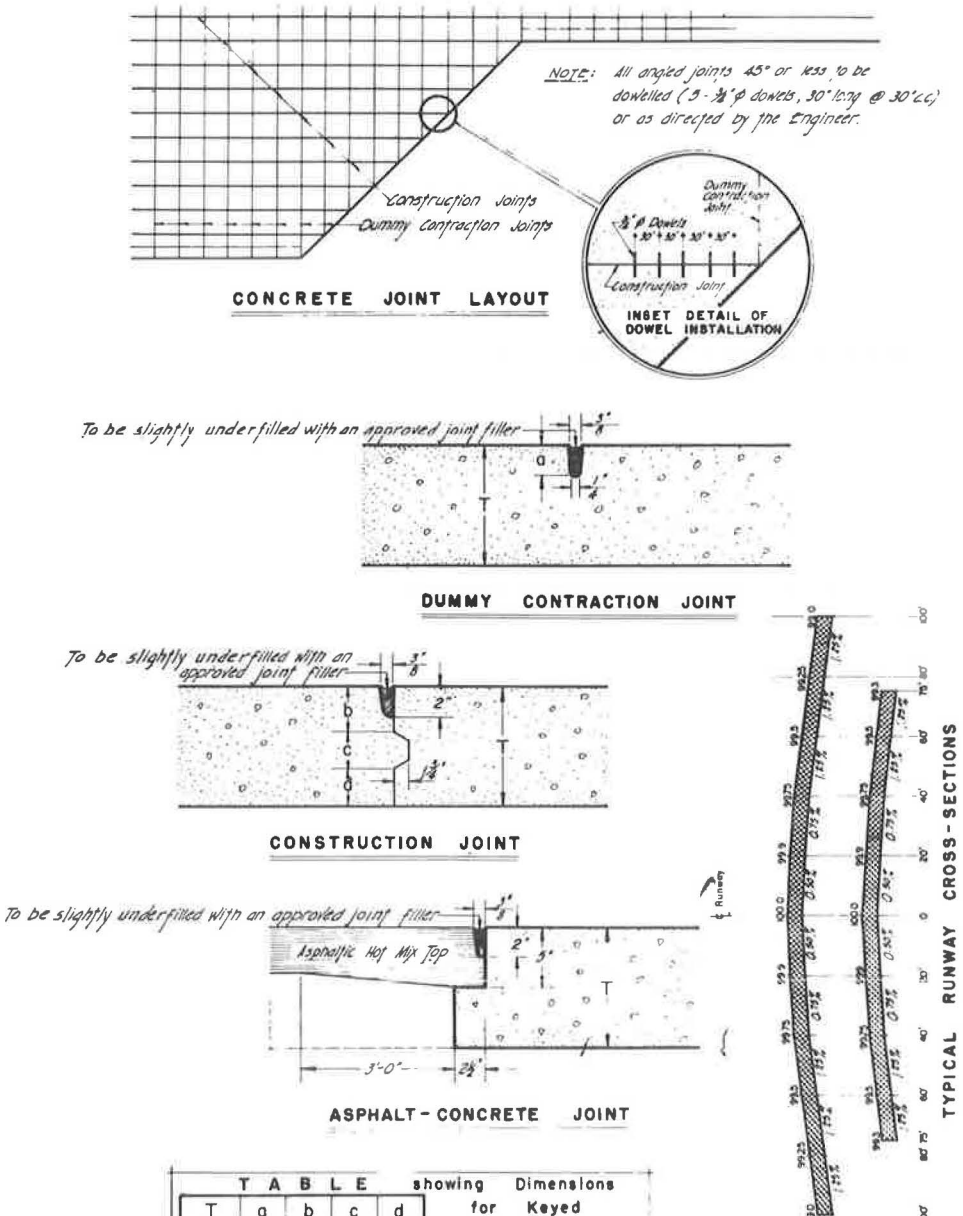
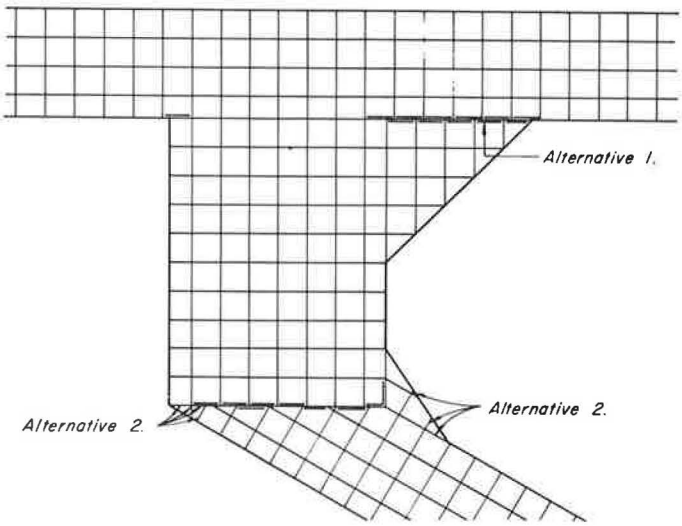


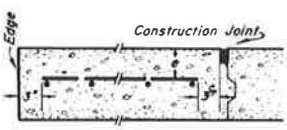
TABLE showing Dimensions for Keyed Construction Joints

T	a	b	c	d
8"	2"	3"	2½"	2½"
9"	2"	3½"	3"	2½"
10"	2"	4"	3"	3"
11"	2½"	4"	3½	3½"
12"	2¼	4½"	4"	3½"
13"	2½"	5"	4"	4"
14"	2½"	5½"	4½"	4"
15"	2¾"	5½"	5"	4½"
16"	3"	6"	5"	5"

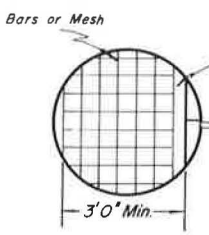
Figure 1. Concrete joints' construction details.



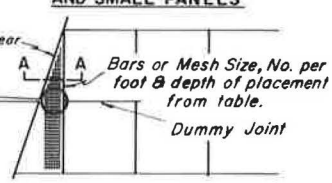
SUGGESTED LOCATION FOR USE OF STANDARD REINFORCING JOINTS



SECTION A-A



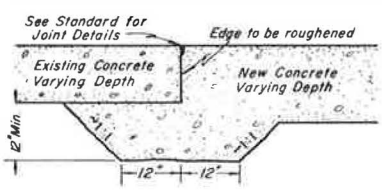
REINFORCEMENT OR DOWELLING REQUIRED FOR MISMATCHED JOINTS AND SMALL PANELS

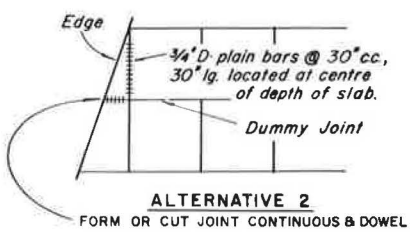


ALTERNATIVE 1

ODD SLABS WHERE JOINT IS NOT CONTINUOUS

PROPOSED JOINT DETAIL FOR TRANSITION BETWEEN NEW AND EXISTING RIGID PAVEMENT





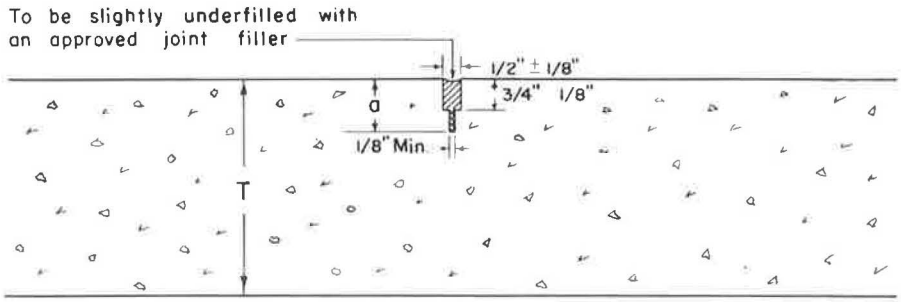
ALTERNATIVE 2

FORM OR CUT JOINT CONTINUOUS & DOWEL

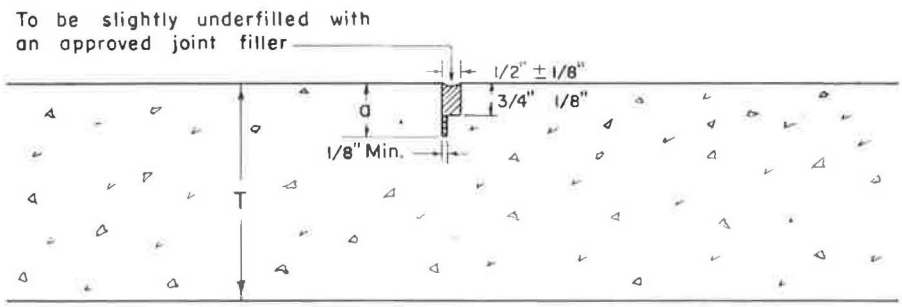
TABLE

SLAB DEPTH INCHES	BAR or MESH	NO. PER FOOT	DEPTH OF BAR
		Both Directions	e
9"	3/16"	2	3 1/4"
10"	5/16"	1	3 1/2"
11"	5/16"	1	3 3/4"
12"	5/16"	1	4"
13"	1/4"	2	4 1/4"
14"	1/4"	2	4 1/2"
15"	1/4"	2	4 3/4"
16"	1/4"	2	5"

Figure 2. Concrete joints' construction details.



SAWED CONTRACTION JOINT



ALTERNATE SAWED CONTRACTION JOINT DETAIL

TABLE SHOWING JOINT DIMENSIONS				
T	a			
6"	1 1/4"			
7"	1 1/2"			
8"	2"			
9"	2"			
10"	2"			
11"	2 1/4"			
12"	2 1/4"			
13"	2 1/2"			
14"	2 1/2"			
15"	2 3/4"			
16"	3"			

Figure 3. Concrete joints' sawed joint details.

CONSTRUCTION PRACTICE

Paving operations are performed with concrete having as low slump as practical (close to zero slump) depending on the contractor's construction methods and machinery. Cement content varies between 5.5 to 6.0 Canadian bags of cement (87.5 lb) per cubic yard of concrete. This may be increased if conditions so dictate. Four to 6 percent of

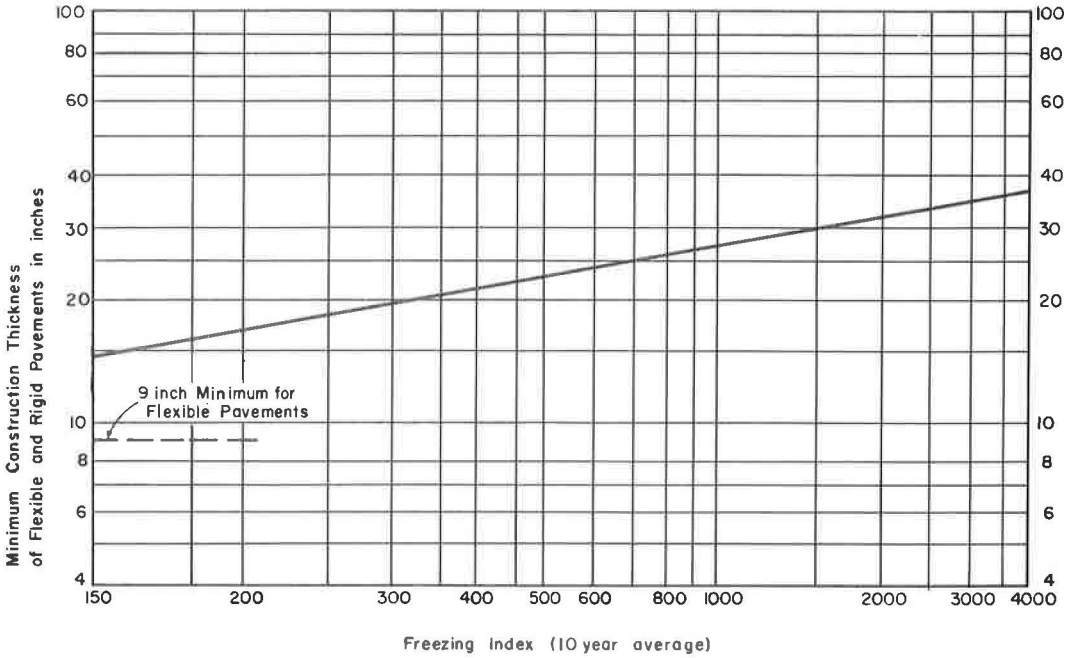


Figure 4. Minimum depth of frost protection for flexible and rigid pavements.

entrained air is obtained by use of an approved air-entraining agent. Except for this, further additives are used only in exceptional circumstances.

The quality of curing of the finished pavement affects strengths. One of the simplest methods of curing is the application of membrane curing compound. This is the method that most contractors choose from the alternatives specified in the Department of Transport Standard Specifications.

Difficulties were experienced with the quality of various membrane curing compounds supplied and also with the reproducibility of the quality control test results. During the winter of 1962, a program was set up by the Construction Branch of the Department of Transport and performed by the Department of Public Works Testing Laboratories to determine the major factors affecting moisture loss from the finished concrete after the application of concrete curing compound. The result of this testing program is given in the Appendix.

On the basis of the data obtained, the Standard Specifications have been changed to insure minimum acceptable solids content of the curing compounds and the reproducibility of the laboratory quality control test results.

Performance is related to built-in smoothness or roughness of the rigid pavement. It is affected by the quality of the joint forming operation, the placement and condition of the concrete forms used, the type of joint filling operation. A large variety of joint filling methods and filler materials are being laboratory and field tested to improve present practice.

Maximum deviation for irregularities of the finished pavement surface is specified in the Standard Specifications as ¼ in. in 15 ft.

PORTLAND CEMENT CONCRETE PAVEMENT STRENGTH AS MEASURED BY PLATE LOAD TESTING

As part of the Department's 1959/60 load testing program the static load-carrying capacity of portland cement concrete pavements was determined at five airport sites with varying subgrade soil conditions, subbases and portland cement concrete slab thicknesses (4).

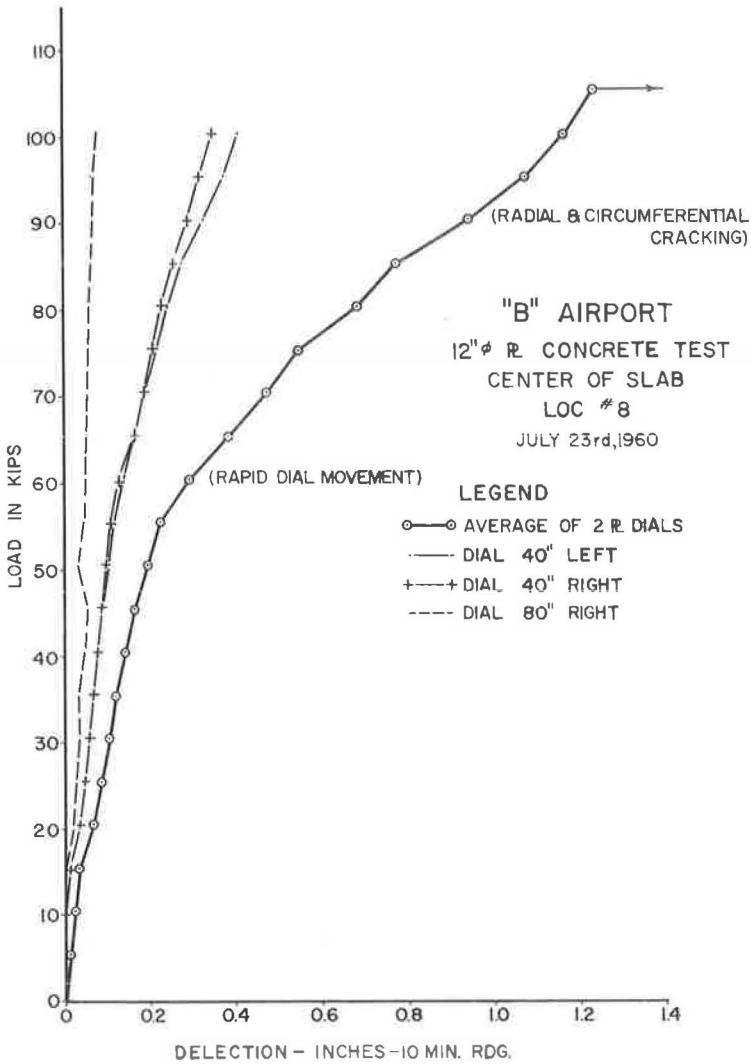


Figure 5. Sample load vs deflection graph.

Typical load-deflection diagram obtained from these tests is shown in Figure 5. As can be seen, the yield load (about 55 kips) and the collapse load (about 90 kips) can be differentiated.

Typical cracking pattern is shown in Figure 6. Radial and circumferential cracks are in evidence, which is in accordance with the plastic theory of plates. The field load-carrying capacity values obtained were compared by the theoretical load-carrying capacity computed on the basis of the Westergaard equation.

Figure 7 shows the ratio of static load-carrying capacity to theoretical strength (Westergaard analysis) in function of pavement thickness for center loading condition, for the free corner and for the protected corner case.

Similar comparison has been made by Meyerhof (8, 9) on the basis of an ultimate strength analysis using the plastic theory.

The data show that under static loading conditions, the Westergaard equation reproduced the load-carrying capacity fairly well for the free corner case. For the central loading conditions the static loads carried by the pavements have been considerably higher than predicted by the Westergaard equation.

On the basis of field performance of portland cement concrete pavements, it is the Department's experience that the Westergaard equation gives a conservative estimate of load-carrying capacity under Canadian construction, climatic and traffic environmental conditions.

CURLING

The absolute magnitude of portland cement concrete slab curling as a function of the temperature gradient within the slab was determined by an instrumented portland cement concrete slab at Halifax International Airport (1960 studies). Temperature instrumentation was provided by the Nova Scotia Technical College.

Details of the layout and installation of the measuring device are given in Figure 8. An example of the temperature regime of the 12-in. portland cement concrete slab for a 24-hr period (August 15-16, 1961) is shown in Figure 9. The temperature difference between the top and bottom of the slab for the same period is shown in Figure 10 and the relative movement of the slab under the influence of the given temperature gradient is shown in Figure 11. The maximum temperature difference between the top and bottom of the portland cement concrete slab for the period

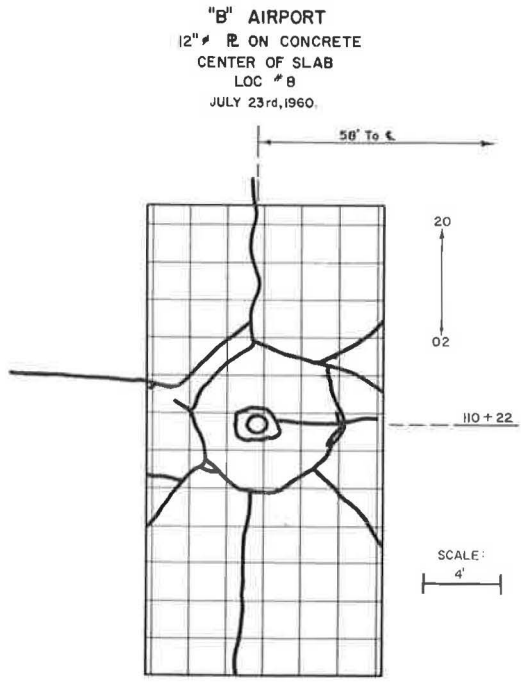


Figure 6. Sample slab cracking diagram.

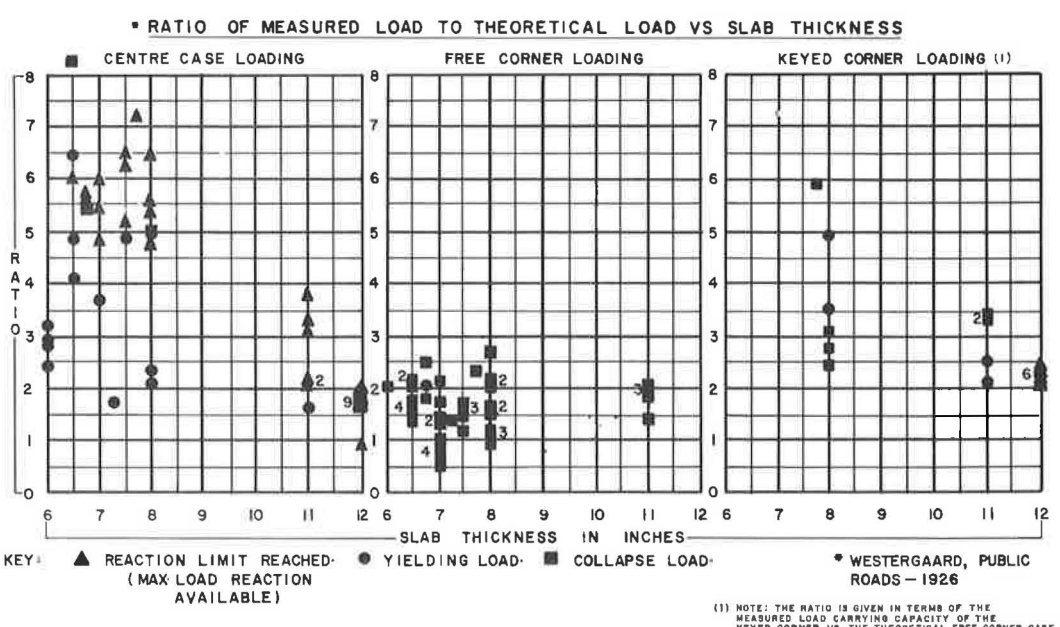


Figure 7. Load tests carried out on portland cement concrete airport pavements.

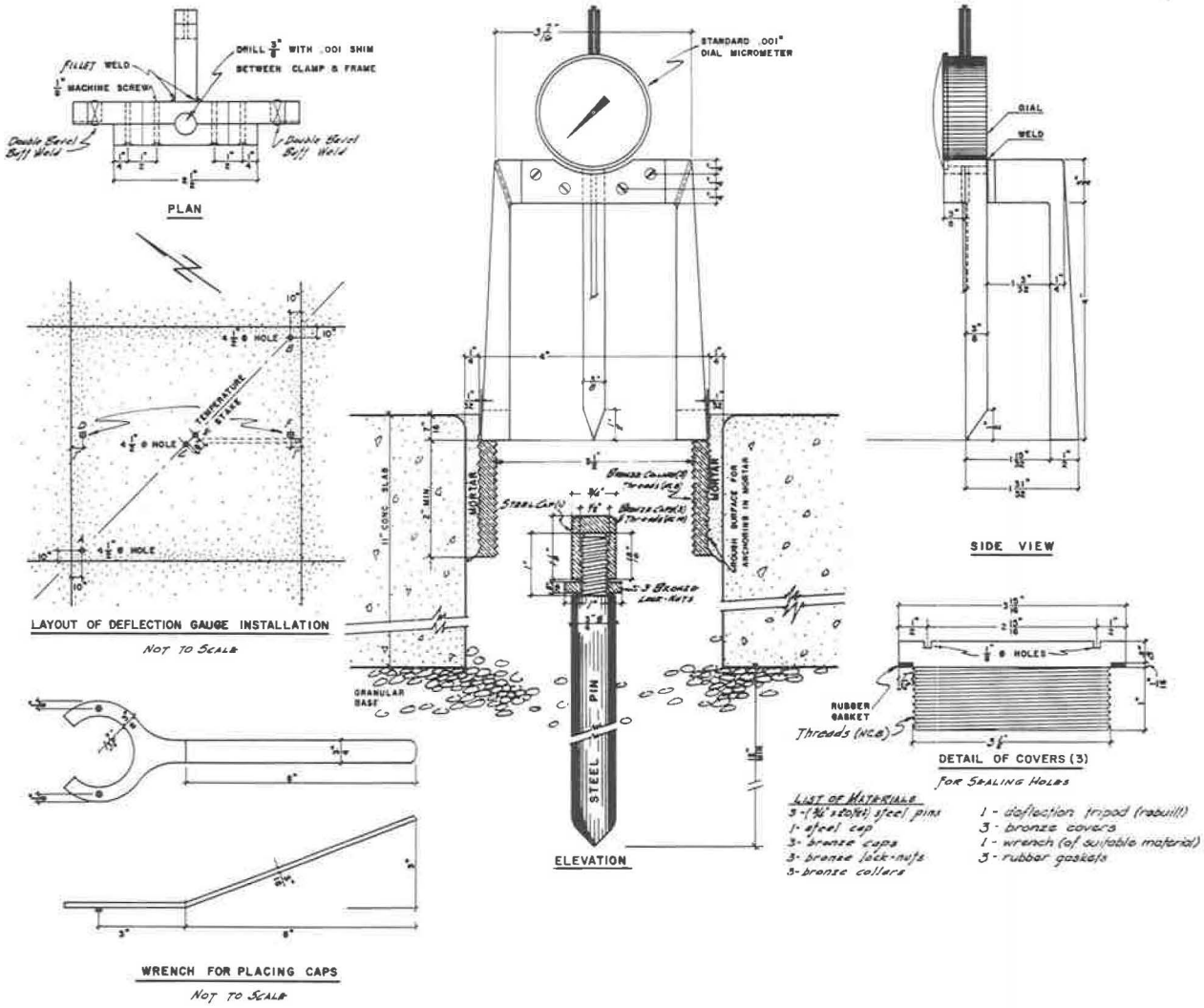


Figure 8. Proposed deflection gage installation.

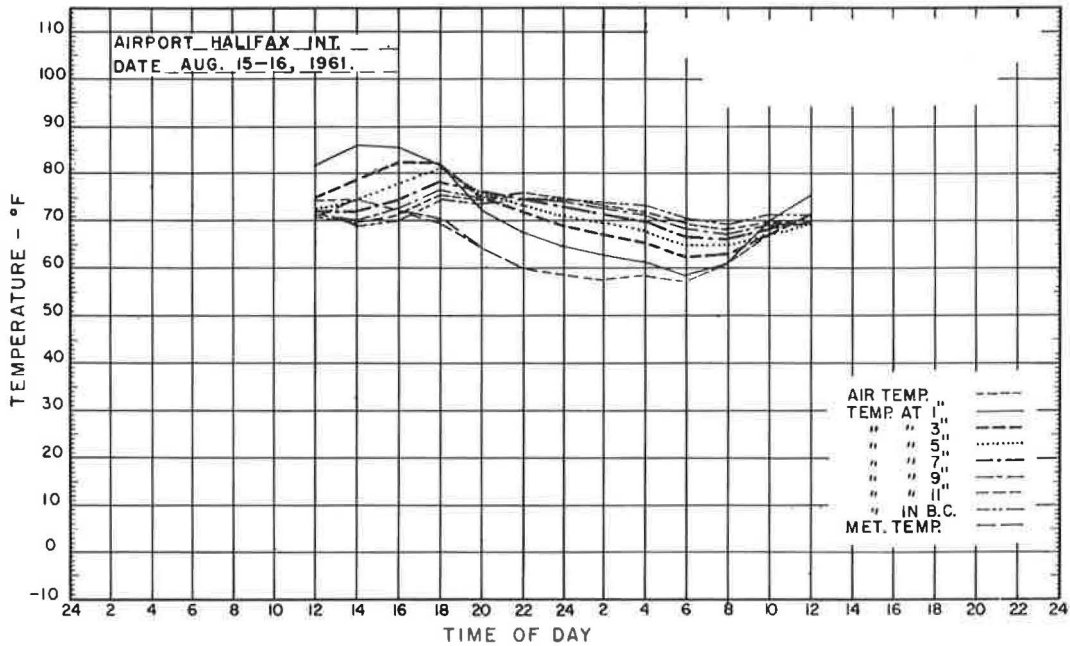


Figure 9. Portland cement concrete curling data: temperature vs time.

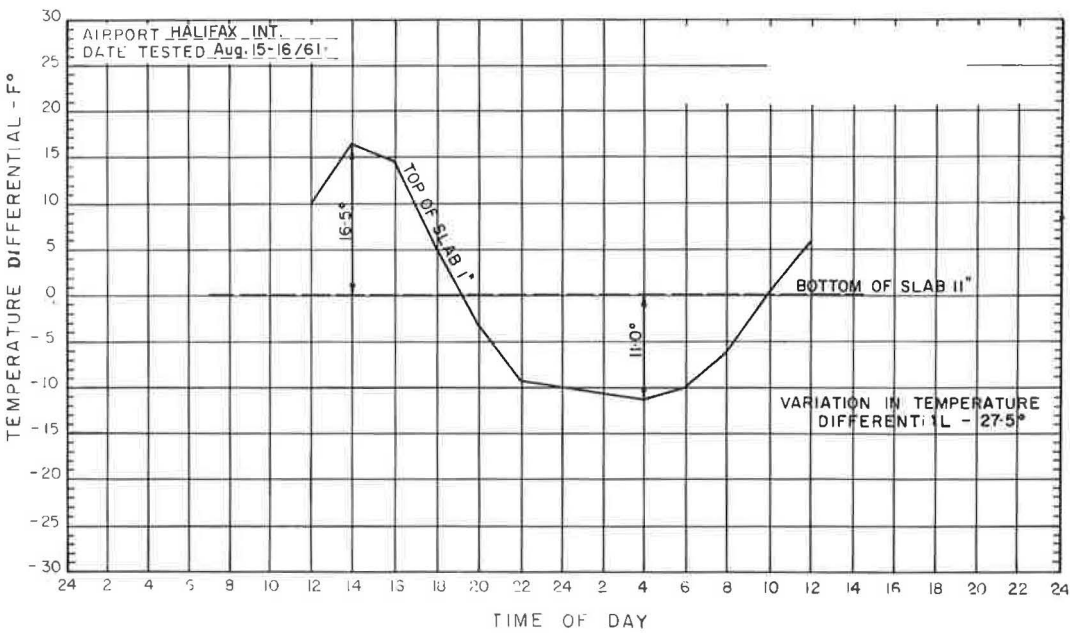


Figure 10. Portland cement concrete curling data: temperature differential vs time.

of one year (1961) is shown in Figure 12. The absolute magnitude of portland cement concrete slab curling (Department of Transport construction procedure) in function of the temperature gradient within the slab is shown in Figure 13.

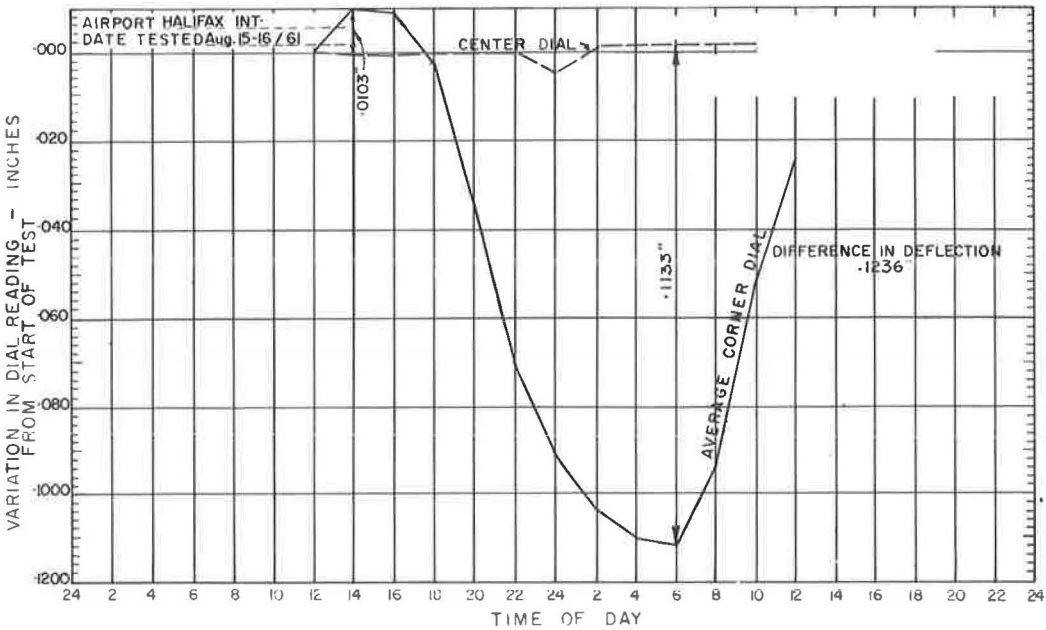


Figure 11. Portland cement concrete curling data: slab deflection vs time.

The maximum movement of the slab corner in respect to the middle of the slab was measured as more than 0.12 in. During static portland cement concrete load testing, initial cracking was observed at deflections slightly more than 0.1 in.

It was observed that in most of the cases maximum downward curling occurred about 2 PM and upward curling about 2-6 AM all year round. The maximum temperature difference within the concrete slab observed was 20 F at the end of July.

EFFECT OF CURLING OF PORTLAND CEMENT CONCRETE ON PAVEMENT ROUGHNESS

On the basis of the Halifax experiment the measured magnitude of curling was such that it influenced the smoothness of portland cement pavements.

To determine the influence of curling on the portland cement concrete roughness a program was initiated in 1962 and 1963 during which quantitative measurements were made on a given portland cement concrete pavement profile under varying temperature gradient conditions using the Department of Transport British-designed and built roughness measuring equipment (British Road Research Laboratories, 5).

A schematic sketch of the equipment is shown in Figure 14. The equipment provides a scale profile of the pavement surface using as a datum a floating level established by 16 irregularly spaced wheels; graphically integrates all the upward movements of the recording wheel, due to pavement irregularities relative to the floating level; and determines the distribution of the pavement roughness in 0.1-in. increments from 0.1 to 1.5 in.

For the purpose of this study the integration value (inch/mile) was used as a measure of roughness.

Two sets of results were obtained. One for a regular surface (Fig. 15) and another set for the same reference line, but the portland cement concrete surface was whitewashed. This, of course, changed the temperature regime within the slab (Fig. 16).

Figure 15 demonstrates that there is a definite variation in roughness during a given day under a given set of temperature gradients in the slab from the minimum value of 142 in./mi to the maximum of 167 in./mi measured under given conditions (17.6% increase).

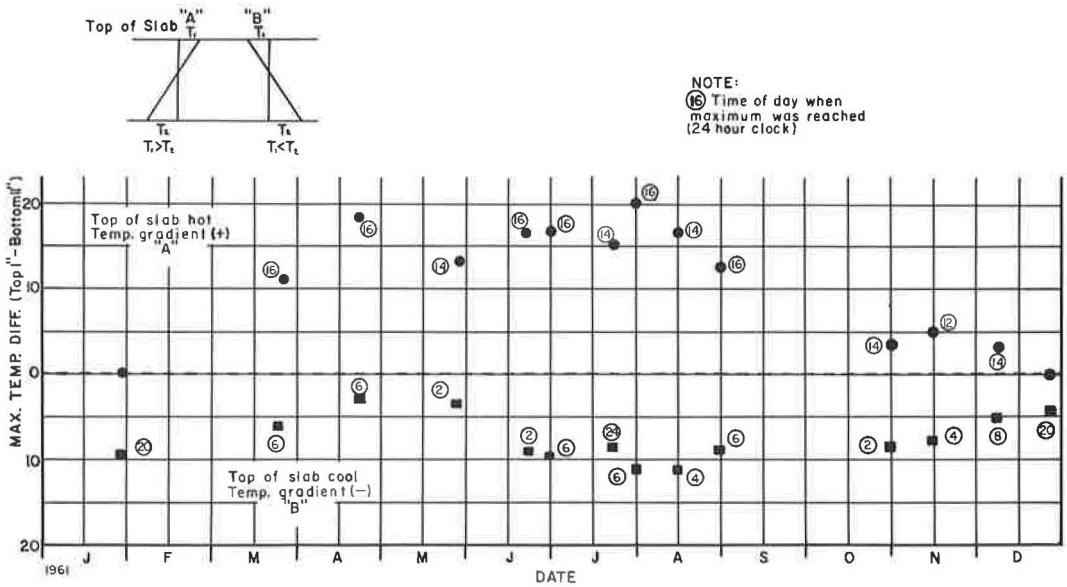


Figure 12. Maximum temperature difference vs time (top and bottom of portland cement concrete slab).

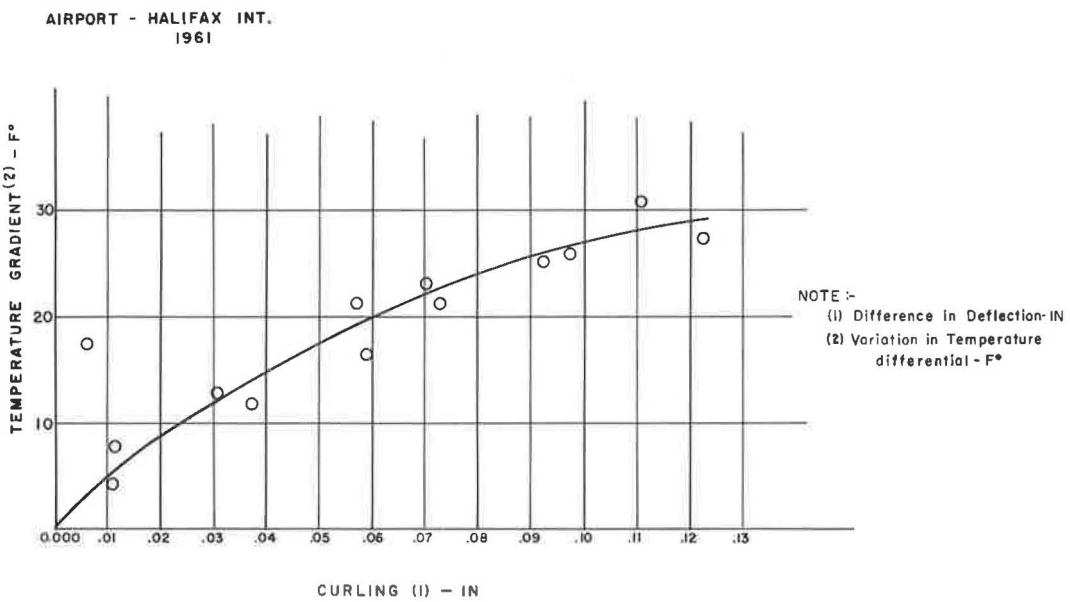


Figure 13. Portland cement concrete slab, curling results; temperature gradient vs curling.

Figure 16 shows that the whitewashed surface reduces the temperature gradient within the slab and consequently the resulting curling and roughness to the maximum and minimum values of 140 in./mi and 150 in./mi, respectively, under similar test conditions (7.1% increase).

Interpreting these results it is emphasized that the maximum air temperature difference was not identical in both measurements. (ΔT_1 = 32 F for the unpainted slab and ΔT_2 = 24 F for the whitewashed pavement.) The previous air temperature history will also influence the results.

PORTLAND CEMENT CONCRETE PAVEMENT PERFORMANCE

The determination of pavement performance is an integral part of the Department of Transport's pavement design and evaluation procedure.

Pavement performance is evaluated by the following factors: (a) pavement condition survey, and (b) pavement roughness measurements.

By performing pavement condition surveys, the structural continuity of the pavement surface is determined together with the possible causes of the various surface defects. The performance of such a survey is standardized in the Department of Transport Pavement Design and Construction Manual, Section 6, "Pavement Condition Survey."

Such a survey is always performed by experienced construction engineers. An example of the results of a portland cement concrete pavement condition survey for a given airport site is shown in Figure 17.

On the basis of these studies of 71 airport sites and the evaluation of 266 pavement units, the performance of Canadian portland cement concrete pavements has been summarized in function of pavement age in Figure 18.

Of course, there is considerable scatter of the data as a wide variety of subgrade types (soil ranges from GW to CH), portland cement concrete pavement thickness (from 7 to 14 in.), and environmental conditions (traffic density and intensity, freezing indices ranging from 800 to 5,000, etc.), is included in the summary.

As one of the results of the pavement condition survey, Figure 18 has considerable usefulness in planning. It is conditioned by the fact that aircraft traffic density and loading underwent revolutionary changes during the last 20 years, the time span of the service life of the pavements surveyed. Consequently, the findings are valid only for the Canadian Department of Transport Pavement Inventory.

A straight-line correlation was used between pavement performance and pavement age as the wide distribution of the data did not warrant the use of more complex function.

The data collected and the correlation presented might be used for the following:

1. Determination of the rate of depreciation in terms of time and cost of the Canadian airport pavement inventory as a whole (about 0.2 units per year – 2%).
2. On the basis of Department of Transport experience, Canadian airport construction practice, aircraft traffic and climatic environmental conditions, limited data indicate that major reconstruction of portland cement concrete pavements taking place in about 20 years at an approximate Department of Transport performance rating of 4.5.
3. Determination of the gained service life of the pavement by tighter quality control measures. For every 0.2 performance unit increase of the zero pavement age performance (as-built performance), the useful pavement life is extended by one year. On this basis, the value of quality control can be expressed in terms of direct monetary benefit.

Roughness measurements are made as part of the Department's pavement performance studies for the following reasons:

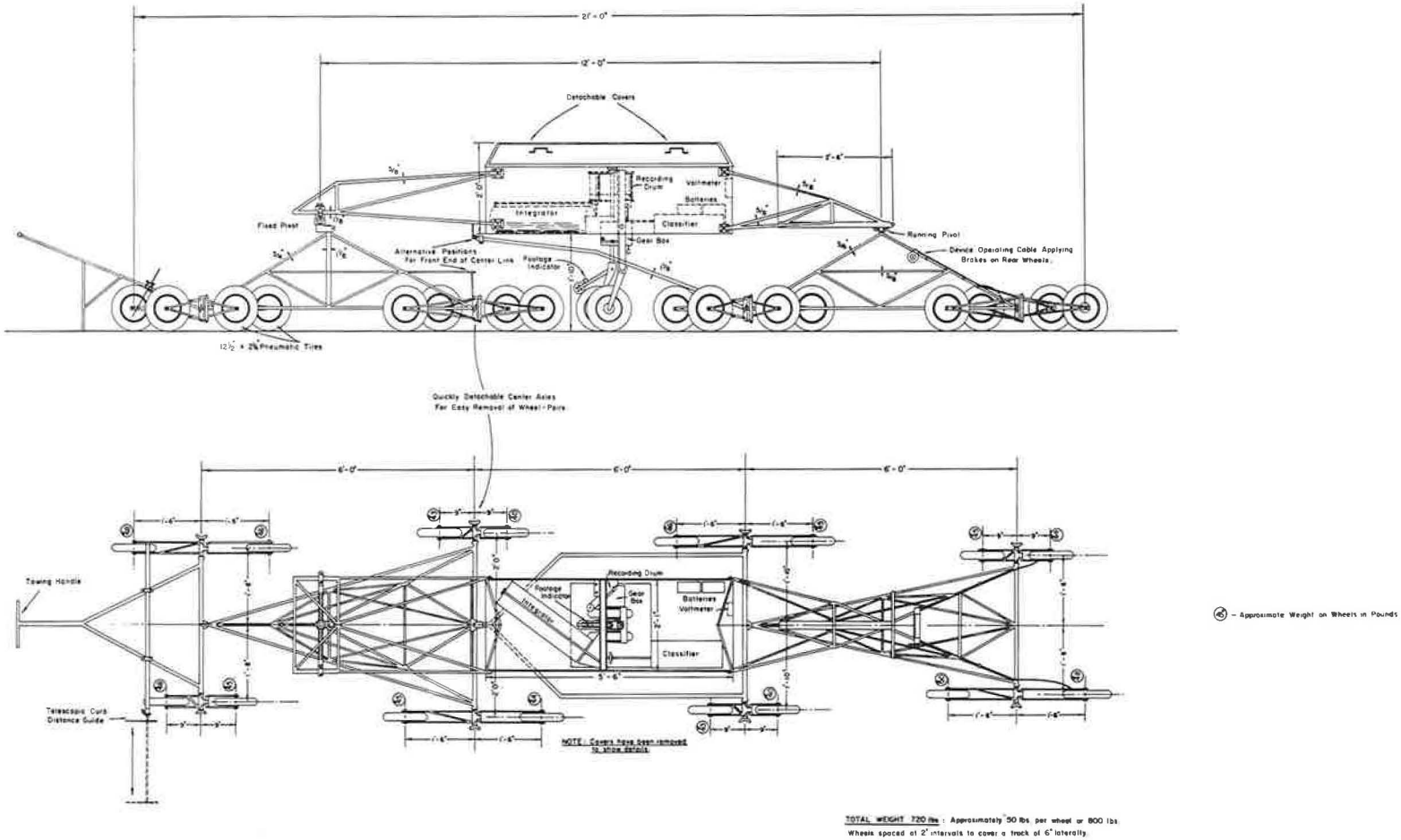


Figure 14. British Road Research Laboratory profilometer.

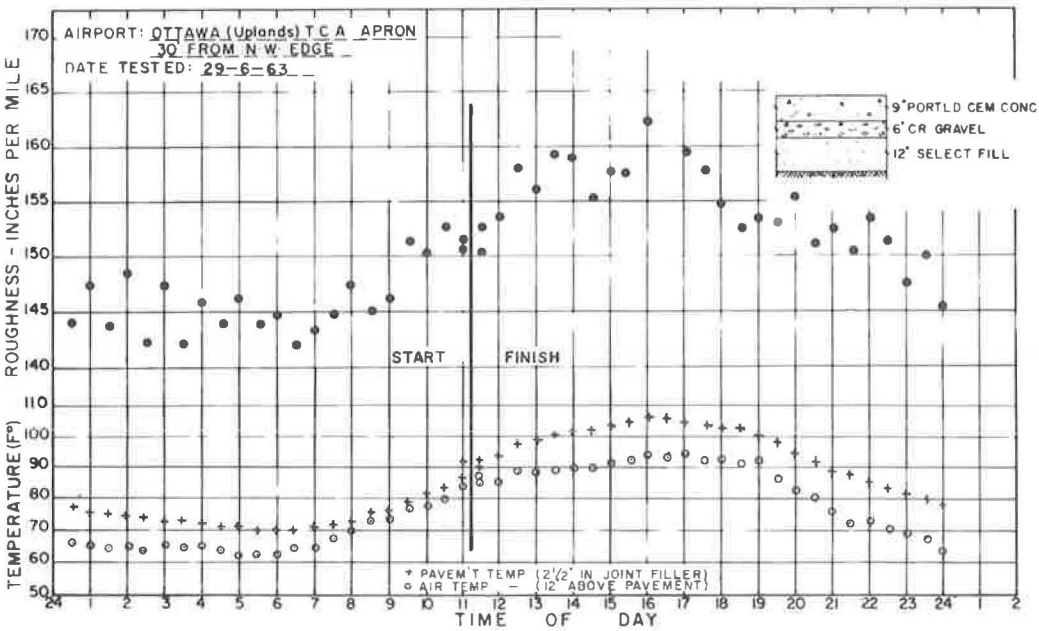


Figure 15. Plain portland cement concrete roughness tests: roughness and temperature vs time.

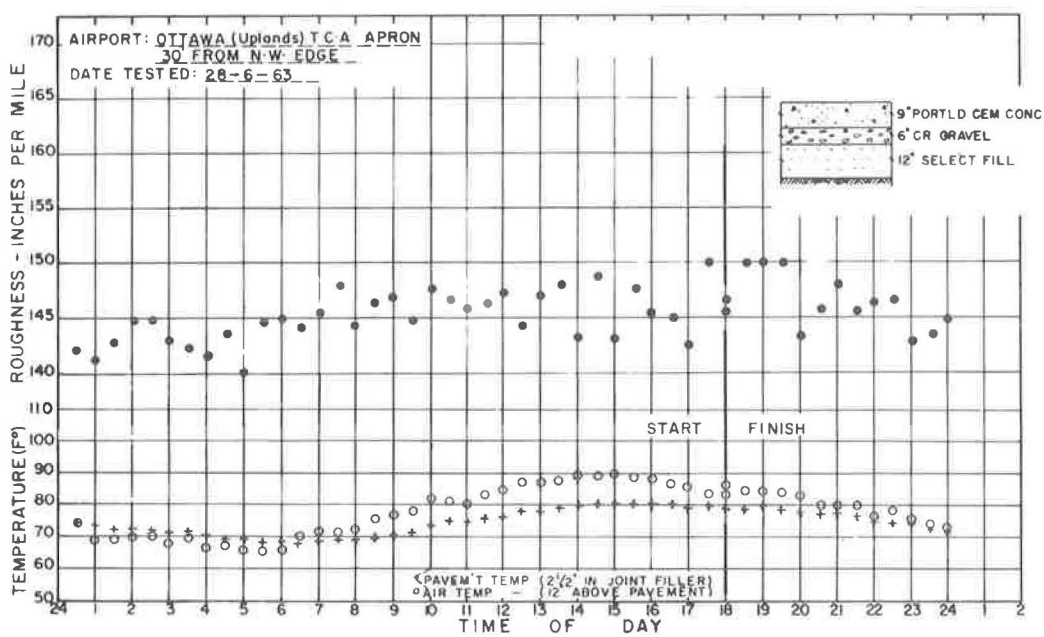


Figure 16. White portland cement concrete roughness tests: roughness and temperature vs time.

DEPARTMENT OF TRANSPORT

Revised 12/6/63

AIR SERVICES CONSTRUCTION BRANCH

CONDITION REPORT – RIGID PAVEMENT

AIRPORT AIRPORT "A"

OBSERVER J. FENNESSY

DATE 23 JULY 1963

EXTRA SHEET OF REMARKS 1

		12 Button	30 Button	Elephant Bar At Old 25 Button	TAXI A	TAXI B	(Old) Apron I	(1955) Apron I	(1962) Apron I
CRACKING	CORNER	0	1[A]	2	2	2	2	1[E]	0
CRACKING	EDGE	0	0	1	1	2	2	1[E]	0
CRACKING	LONGITUDINAL	0	0	2	2[B]	3	2	0	0
CRACKING	TRANSVERSE	0	0	3	3	3	3	0	0
	SCALING	0	0	1	1	1	2	0	0
	SPALLING	0	0	1	2	2	2	0	0
	JOINT STEPPING & FAULTING	0	0	2	2	1	2	0	0
	CONCRETE DISINTEGRATING	0	0	1	0	1	1	0	0
	PUMPING	0	0	2	0	0	0	0	0
	LOSS OF JOINT FILLING	0	0	1	1	0	1	0	2
	SUBGRADE SETTLEMENT	0	0	2	3	3	2	1[E]	0
	FROST HEAVE	0	0	1	1	1	1	1[E]	0
	PATCH	0	0	0	1	1	1	0	0
	LOCALIZED RECONSTRUCTION	0	0	0	1[D]	1[D]	1[D]	0	0
	SURFACE ROUGHNESS	7	7	5	4	4	4	6	5
	SURFACE DRAINAGE (PONDING)	8	8	7	8*	8	6	8	7
	SUBSURFACE DRAINAGE	7	7	7	7	7	7	7	-
	GENERAL CONDITION	9	9	5	5	4	5	7	8
		N	N	N	N	N	N	N	N
	WORK REQUIRED				C				

0: NONE
1: MINOR
2: MODERATE
3: MAJOR
4: SEVERE

10, 9, 8 – VERY GOOD – A
7, 6 – GOOD – B
5 – FAIR – C
4, 3 – POOR – D
2, 1, 0 – VERY POOR – E

DRAINAGE REMARKS:

Drainage & Frost Heave Remarks & Ratings By Resident Engineer.

Graded Areas & Sides in Good Condition.

* Except Ponding shown as Major on Plan (TAXI A)

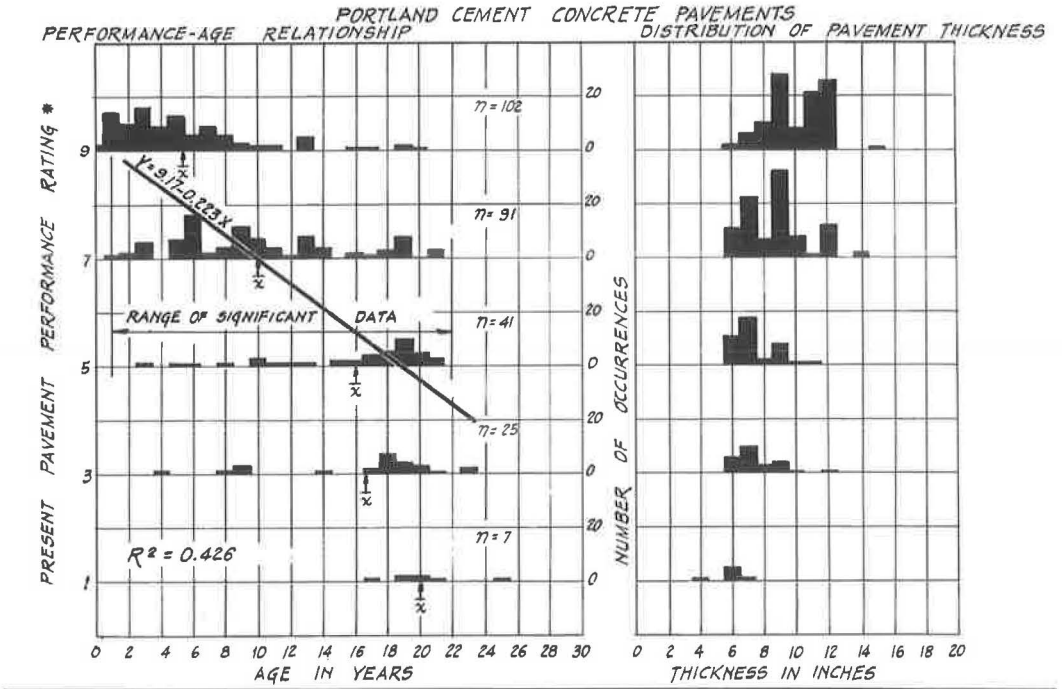
Most catch basins have heaved up.

Sub Surface Drainage good except often in Spring when open Ditch at East End of Field either freezes or plugs with snow, it causes water to back up & flood buildings and East End of the Field.

GENERAL REMARKS:

N = No sympathetic cracking
A = 1 only at Junction with flexible/Rigid Pavement
B = Almost entirely in outer bays (Centre 40' almost void of Longitudinal Cracks)
C = 75% cracking on Taxi A in outer Bays; caused probably by loss of Material under Edges.
D = Reconstructed after Ducts Laid.
E = Entirely at Raised Catch Basin near Taxi B.

Figure 17.



* Pavement Rating based on D.O.T. "Pavement Design & Construction Manual," Section 6, Pavement Condition Survey, March, 1963.
NOTE: 266 Sections investigated on 71 Airports

Figure 18.

1. Quality control check on new constructions.
2. Determination of the effect of environmental condition on pavement performance as expressed by roughness and change of roughness in function of time. Canadian Good Roads Association Special Technical Committee studies show that environment is one of the major influencing factors determining pavement performance. Both the AASHO Road Test and Canadian Good Roads Association studies show that pavement performance can be properly expressed in terms of pavement roughness.
3. Determination of the effect of pavement roughness on aircraft performance.

The roughness of pavements is measured in three phases:

1. Long wave roughness (over 25-ft wave length) measured by leveling.
2. Short wave roughness measured by the previously described profilometer.
3. Micro roughness (skid resistance) measured by the "Portable Skid Resistance Tester" developed by the Road Research Laboratories, England (6).

Typical short wave roughness index profile (inch per mile) is shown in Figure 19. The roughness index was based on measurements taken along the runway in the most probable wheel path of a DC-8 aircraft. Typical short wave roughness distribution diagrams are shown in Figure 20 based on roughness counter measurements (distribution of the size of pavement roughness in 0.1-in. increments).

In the Department of Transport experience the roughness index for a newly constructed portland cement concrete pavement with formed joints is about 60 in./mi. This value improves if the joints are sawn and the joint filling operation is properly performed. Roughness on in-service pavements was measured as high as 130 in. per mile.

Roughness measurements show that, in the Department of Transport construction practice, asphalt pavements are constructed considerably smoother than portland cement concrete pavements.

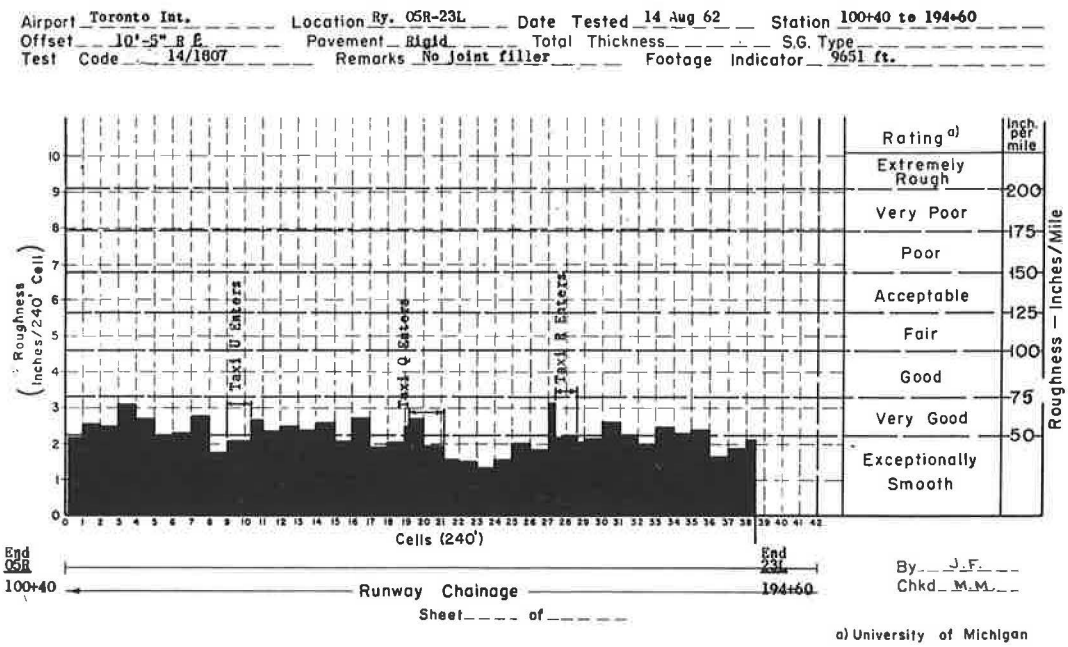


Figure 19. Profilometer data sheet (pavement roughness distribution).

TABLE 1

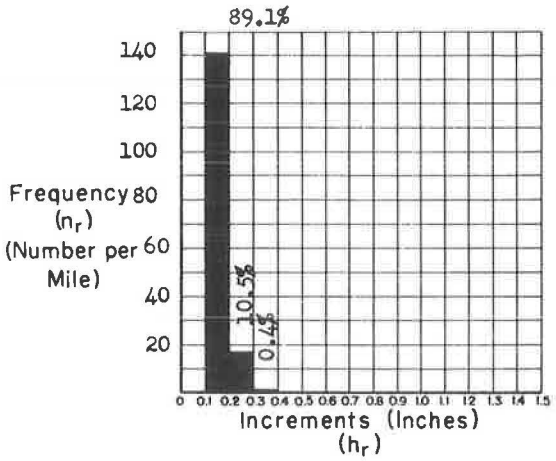
SUMMARY SHEET OF SKID RESISTANCE DATA

Airport	Date Tested	Pavement Type	100μ X	Range	No. of Tests
Sault Ste. Marie	23 May '63	F	73.0	63-85	40
		R	82.4	75-98	12
Sudbury	29 May '63	F	62.8	48-78	28
		R	70.6	59-79	14
North Bay	6 June '63	F	66.7	53-78	50
		R	73.4	67-82	24
Timmins	8 June '63	F	71.3	65-81	20
		R	—	—	—
Earlton	9 June '63	F	71.7	68-75	8
		R	—	—	—
Lakehead	22 July '63	F	72.1	66-80	18
		R	73.8	67-83	8
Winnipeg	27 July '63	F	73.3	62-83	33
		R	68.9	55-95	46
Portage la Prairie	14 Aug. '63	F	71.4	65-77	34
		R	68.6	55-78	10
Regina	16 Aug. '63	F	68.6	51-83	18
		R	73.4	65-80	14
Saskatoon	28 Aug. '63	F	80.7	71-87	28
		R	77.6	70-84	26
Cold Lake	6 Sept. '63	F	74.4	65-82	46
		R	72.0	60-83	20
Namao	20 Sept. '63	F	77.3	60-88	45
		R	72.5	59-63	34
Edmonton	3 Oct. '63	F	—	—	—
		R	73.5	65-82	86
Lethbridge	17 Oct. '63	F	79.9	74-85	25
		R	76.6	72-79	6
Calgary	25 Oct. '63	F	84.0	41-102	74
		R	81.6	63-96	13
Victoria	20 Nov. '63	F	82.2	70-89	47
		R	86.0	82-95	6

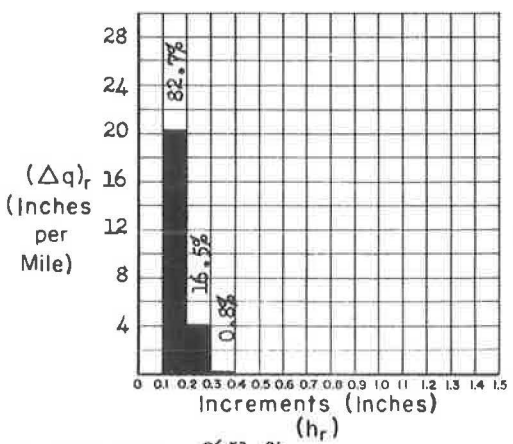
PROFILOMETER DATA SHEET
(FREQUENCY HISTOGRAM)

Airport Toronto Inter'l. Location Ry. 05R-23L Date Tested 14 Aug '62
Station 100+40 - 194+60 Offset 10' 5" R of ℄
Pavement Rigid Total Thickness S.G. Type

Test Code: YZ 14/307 Remarks: No Joint Filler



h_r	n'_r	n_r	$\bar{h}_r$	$(\Delta q)_r$
.1	245	140.9	.145	20.43
.2	29	16.7	.245	4.09
.3	1	0.6	.330	.20
.4				
.5				
.6				
.7				
.8				
.9				
1.0				
1.1				
1.2				
1.3				
1.4				
1.5				
	Total		q =	24.72



$(\Delta q)_r = n_r \times \bar{h}_r$

$\bar{h}_r = h_r + 0.045$

$\bar{h}_{r_{MAX.}} = h_{r_{MAX.}} + 0.030$

n'_r = Number per test length (footage indicator)

$n_r = n'_r \times f$

$f = \frac{5280}{9190} = 0.575$

Footage Indicator 9651 ft.
Footage Correction Factor 1/1.05
Corrected Footage 9190 ft. Δp = 85.19 inches

q = Classifier Index 24.7 inches/mile
p = Integrator Index 49.0 inches/mile

By J.F.
Chkd M.M.

Figure 20.

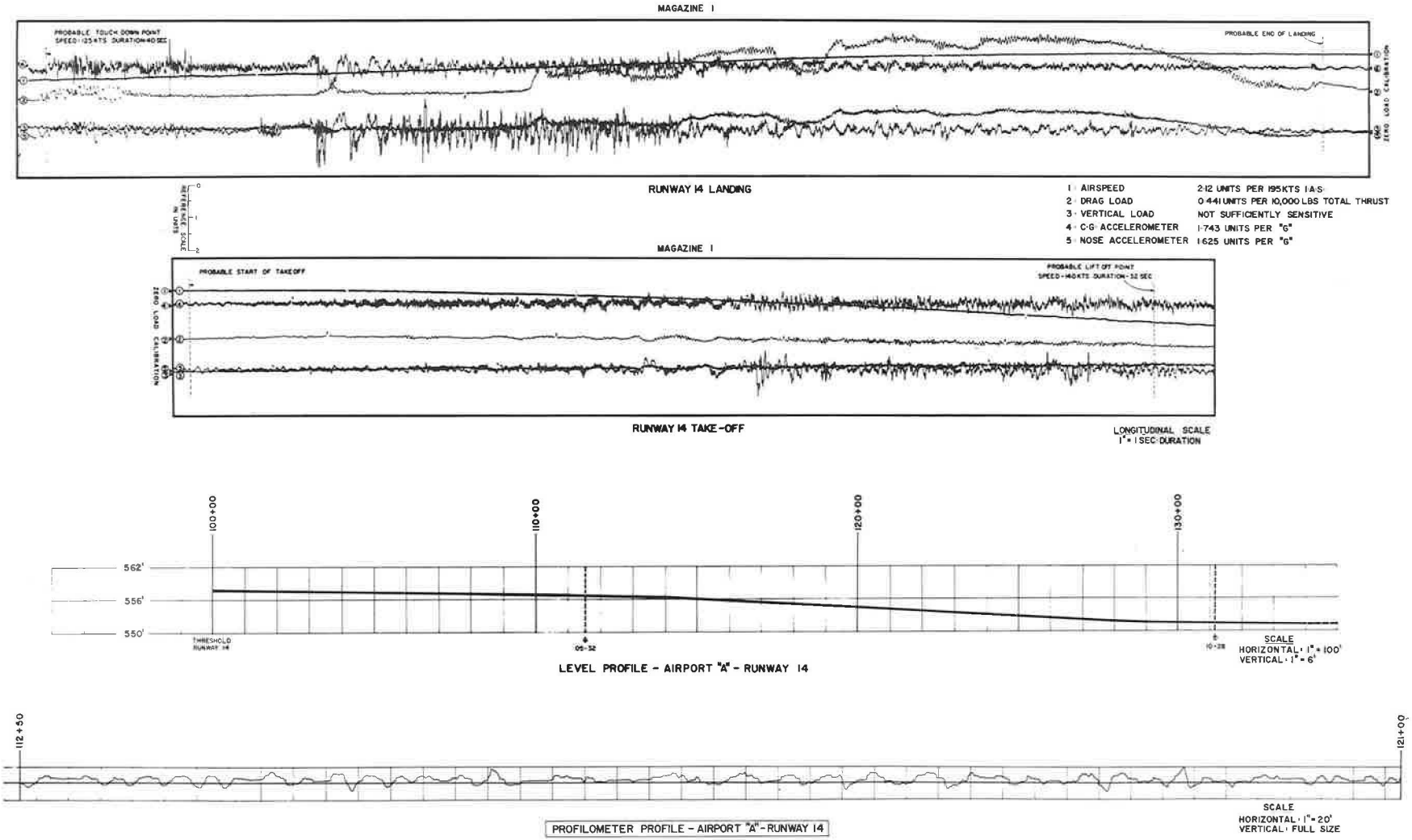


Figure 21. Typical pavement roughness data and dynamic aircraft (DC-8) response.

TABLE 2

SUMMARY OF DC-8 RESPONSE TO ROUGHNESS DATA (1963)

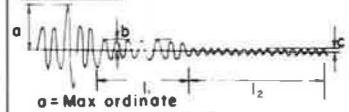
Airport	Op.	Runway	Air Speed lift off or touchdown	A/C Op. Weight	Max C.G. Acc. Ord.	Avg C.G Acc. Ord.	Max Nose Acc. Ord.	Avg Nose Acc. Ord.	Max Horiz Ld. Leg[1]
			kts	kips	g	g	g	g	kips
UL	T.O.	06R	136	213·5	1·63	1·039			−4·4
	L.	06L	120	183·3	1·68	1·056	1·30	1·074	18·8
	T.O.	28	138	217·4	1·39	1·054	1·21	1·036	7·9
	L.	24L	110	192·0	1·29	1·069	1·65	1·090	18·4
	T.O.	28	138	201·0	1·21	1·054	1·23	1·049	−3·9
	L.	28	115	189·0	1·72	1·079	1·36	1·071	20·5
	T.O.	28	144	207·8	1·36	1·064	1·30	1·043	−4·2
	L.	24L	117	188·0	1·42	1·062	1·33	1·078	12·0
	T.O.	06R	138	210·3	1·20	1·049	1·18	1·043	−8·6
	T.O.	28	132	204·6			1·30	1·052	−9·9
	L.	24L	110	169·8			1·71	1·126	
	T.O.	24R	140	210·6			1·22	1·060	−6·5
	L.	06L	125	190·0			1·34	1·061	8·2
YZ	L.	14	125	197·7	1·52	1·064	1·63	1·095	20·3
	T.O.	14	140	238·6	1·21	1·049	1·36	1·045	−6·0
	L.	28	123	203·6	1·53	1·061	1·36	1·064	17·2
	T.O.	28	142	244·8	1·30	1·048	1·28	1·034	−7·0
	L.	14	112	176·0	1·63	1·036	1·41	1·096	28·3
	T.O.	32	132	205·9	1·64	1·051	1·28	1·027	4·2
	L.	14	124	185·5	1·67	1·084	1·84	1·087	20·4
	T.O.	28	142	242·3	1·18	1·040	1·18	1·045	−5·1
	L.	32	110	176·4	1·45	1·072	1·63	1·073	17·2
	T.O.	32	138	202·9	1·63	1·056	1·26	1·030	−5·8
	L.	32	123	193·3	1·57	1·096	1·44	1·093	12·8
YZ	T.O.	32	145	240·5	1·48	1·062	1·32	1·055	−4·1
	L.	32	122	193·4	1·48	1·082	1·62	1·096	11·0
	T.O.	32	140	203·0	1·21	1·043	1·34	1·035	−8·2
	T.O.	32	144	239·2	1·41	1·067	1·33	1·060	−12·9
	L.	32	118	199·8			1·34	1·068	−5·0
	L.	14	115	190·2			1·42	1·102	
	T.O.	14	125	226·1			1·26	1·078	
	L.	14	122	194·9			1·39	1·122	22·4
	T.O.	32	140	235·6			1·47	1·059	−10·9
	T.O.	32	139	204·9			1·22	1·050	−3·2

REMARKS

1. Largest numerical value.

Blanks indicate missing curves on film.

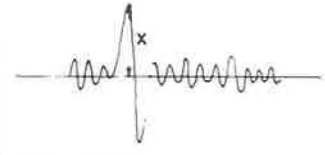
Avg. C.G. Acc.



a = Max ordinate

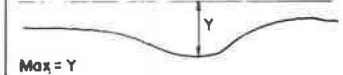
$$\text{Avg. C G} = \frac{bl_1 + cl_2}{l_1 + l_2}$$

Max Acc. Reading



Max = 1+X

Airspeed, Horiz.



Max = Y

YC	L.	28	126	185·6	1·66	1·056	1·49	1·076	25·2
	T.O.	28	140	201·6	1·14	1·041	1·15	1·030	−2·9
	L.	28	130	185·6	1·40	1·052	1·49	1·064	30·0
	T.O.	28	152	232·9	1·16	1·038	1·23	1·038	−4·6
	L.	28	118	195·0	1·36	1;042	1·50	1·071	24·8
	T.O.	28	150	208·2	1·47	1·039	1·22	1·015	−5·1
	L.	28	120	200·0	1·22	1·050	1·33	1·061	16·5
	T.O.	28	134	224·5	1·36	1·045	1·17	1·018	−3·4
	L.	28	128	190·3	1·54	1·062	1·34	1·056	16·4
	T.O.	10	143	206·4	1·15	1·034	1·14	1·020	−2·6
	L.	10	118	186·1	1·40	1·051	1·53	1·059	−21·4
	T.O.	10	140	221·2	1·17	1·043	1·17	1·016	−3·7
	L.	10	121	185·5	1·28	1·036	1·31	1·040	19·9
	T.O.	10	143	194·4	1·14	1·038	1·15	1·029	−2·0
YC	L.	10	117	177·3	1·37	1·063	1·40	1·081	15·3
	T.O.	10	142	229·3	1·19	1·040	1·18	1·029	−2·7
	L.	28	131	189·4			1·37	1·086	20·8
	T.O.	28	136	195·1	1·14	1·035	1·16	1·033	−7·3
	L.	28	115	177·2			1·46	1·080	9·9
	T.O.	28	142	229·1	1·33	1·037	1·17	1·029	−7·7
VR	L.	08	124	184·6	1·36	1·050	1·74	1·053	11·8
	T.O.	08	148	203·9	1·26	1·046	1·18	1·034	−3·9
	L.	26	118	193·6	1·28	1·052	1·30	1·062	25·5
	T.O.	26	128	218·6	1·44	1·036	1·26	1·023	−6·3
	L.	26	125	191·1	1·50	1·043	1·36	1·059	9·4
	T.O.	26	141	205·5	1·17	1·043	1·14	1·027	−5·3
	L.	08	122	178·1	1·23	1·032	1·35	1·053	17·2
	T.O.	26	142	195·5	1·14	1·037	1·12	1·019	−2·6
	L.	08	128	178·8			1·45	1·088	10·4
	T.O.	08	140	193·6	1·17	1·045	1·16	1·030	−5·9
	L.	08	115	176·0			1·44	1·088	
	T.O.	08	138	192·4			1·36	1·066	
	L.	26	118	179·0			1·33	1·086	12·9
	T.O.	26	140	196·0			1·11	1·021	−6·5
XD	L.	11	128	173·7			1·88	1·111	
	T.O.	11	140	195·2			1·27	1·088	
	L.	11	110	174·3			1·52	1·162	
XD	T.O.	11	138	234·6			2·12	1·070	
	L.	19	116	182·3			1·80	1·095	8·8
	T.O.	19	140	196·9			1·20	1·056	−6·3
	L.	19	127	177·0			1·43	1·101	20·5
	T.O.	19	133	232·9			1·29	1·061	−6·9

Data evaluation and presentation are still in an experimental state. At present the data are evaluated on the inch-per-mile roughness index basis. Studies performed on the collected data show that the variance of roughness measurements is a better measure of pavement roughness than the inch-per-mile index value. This, of course, confirms the recent AASHO Road Test results.

A study is in progress to express roughness in terms of physical quantities which would allow a dynamic analysis. A statistical measure is being sought which would express roughness on the basis of wave length and amplitude frequencies obtained from the raw data without mathematical manipulation.

Micro roughness (skid resistance) measurements are given in Table 1 (not an absolute value as it is related to the measuring equipment used and the technique employed). Measurements are made on wet surfaces. No complaints have been received from pilots and operators to date. It is considered that the quoted order of magnitude of 0.65-0.80 is well within the limit of safe aircraft operation.

For the measurements of actual aircraft loading on pavements and aircraft response to pavement roughness, an in-service DC-8 aircraft was instrumented.

This project was carried out in cooperation with Trans-Canada Air Lines and the National Aeronautical Establishment of the National Research Council of Canada.

The following instrumentation was placed on the aircraft, in accordance with the recommendations of the Douglas Aircraft Company: (a) center of gravity acceleration, (b) acceleration of the nose wheel, and (c) main gear load (C-1 vertical, C-2 horizontal).

Typical ground roughness and aircraft response measurements are shown in Figure 21.

The data are in the process of analysis. The order of magnitude of some of the average and maximum results obtained during given operations is summarized in Table 2. The maximum horizontal load measured was 28.3 kips. Landing and take-off speeds and the average level of aircraft response to pavement roughness are also indicated. Work is in progress to establish a statistically significant measure of aircraft response to any given pavement roughness.

This will help to establish construction specification limits for new construction and to determine the necessity of major maintenance operation for in-service pavements.

The vertical strain gages located on the main under-carriage did not give significant results, because they were installed in a location where the vertical and horizontal strain components interacted.

The vertical load on the pavement was estimated on the basis of the "acceleration factor" measured in the center of gravity of the aircraft.

During the test operations the following maximum acceleration factors were measured: taxiing operation, 1.31 (104 operations); landing operation, 1.72 (52 operations); take-off operation, 1.64 (52 operations).

During landing and take-off operations, part of the aircraft weight is carried by the wings, depending on aircraft speed, braking action, thrust reversal, and the use of "spoilers" and "flaps."

Taking into account all these factors, it is estimated that the maximum load acting on the pavement is 1.5 times the aircraft gross weight under regular operating conditions.

In the Department's pavement design practice this impact factor is not taken into consideration as the subgrade soil is able to sustain high intensity loading of short duration without appreciable amount of deformation.

ACKNOWLEDGMENTS

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Appendix

OBSERVATIONS AND COMMENTS ON THE ASTM TEST AND SPECIFICATION FOR MEMBRANE FORMING CURING COMPOUNDS

In ASTM Standards C 156-55T and C 309-58, the type of brush used and the time of brushing of the surface of the sample has not been clearly defined. Laboratory test results shown in Figure 22 show the influence of the type of brush used and the time of brushing on the moisture loss. The relationship between the percent non-volatile solids on the moisture loss as function of time of curing compound application is shown in Figure 23.

The time of brushing of the surface of the samples and the type of brush used has influenced the formation of laitance. If such laitance is formed, the effectiveness of the concrete curing compound water retention capacity is reduced.

Also the time of application of the compound is critical. If the compound is applied when the surface has dried out to a critical degree, the concrete might absorb some of the applied material and pinholes could form in the surface making it possible for moisture to evaporate from the concrete.

For laboratory acceptance testing of concrete curing compounds, at present 2.5 hours are specified as maximum application time in Department of Transport specifications. This is a conservative estimate of field conditions.

To insure proper curing the percentage of non-volatile solids is of course of primary importance. The function presented in Figure 23 demonstrates this clearly. On the basis of 2.5-hr maximum application time and the correlations obtained in Figures 22 and 23, the minimum solid content of 30% is insured.

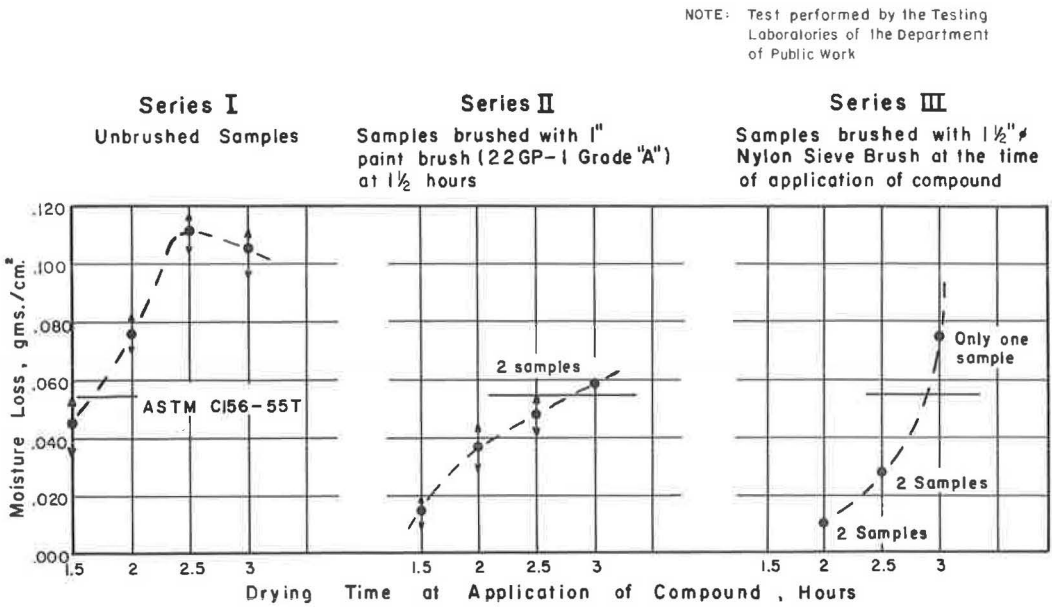

Figure 22. Concrete curing compounds: moisture loss vs drying time (30% non-volatile solids).

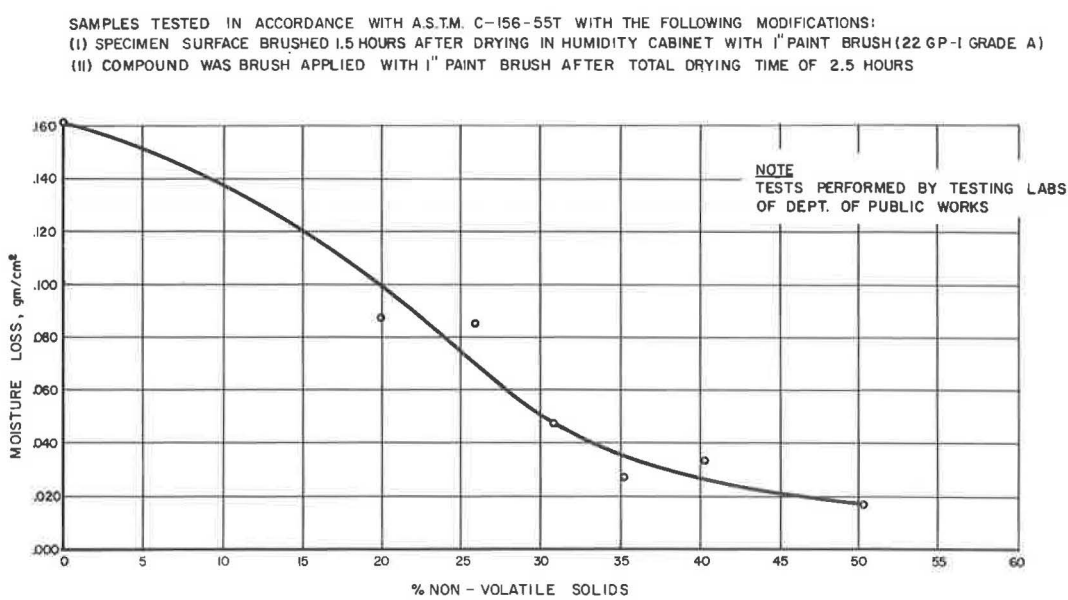

Figure 23. Concrete curing compound: moisture loss vs solid content.