CONCRETE PAVEMENT DESIGN FOR CANADIAN AIRFIELDS

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ABSTRACT

A brief synopsis is given of Transport Canada structural design practices for the provision of airfield concrete pavements at Canadian airports. Design considerations in related areas of construction, operations and evaluation are also discussed in a general manner. A detailed treatment of standards and practices may be found in the Transport Canada manuals listed in the references.

INTRODUCTION

An objective central to a pavement management system is the provision of pavement facilities at minimum total cost over the life of the facility or staged development under conditions of financial restraint. Consequently, a range of design alternatives must frequently be considered during the design process and a selection made based on the cost analysis prepared for each alternative.

The costing of design alternatives involves performance predictions for the various designs and estimates of maintenance and rehabilitation needs over the design period. Unfortunately, future costs are not solely dependent on structural design methods. They are equally affected by practices used in construction and operations, and by standards adopted for maintenance and level of service.

To fully perform the design function under a pavement management system, the designer cannot limit his attention to structural design methods alone but must consider the effect of practices and standards adopted within other areas of the system. The designer should play a role in establishing practices and standards within these other areas to ensure compatibility with his design assumptions.

CONCRETE AIRFIELD PAVEMENTS

The general experience of Transport Canada is that concrete pavements for Canadian airfields are an attractive design alternative under conditions of heavy aircraft traffic. Shut-down costs are usually high for rehabilitation or major maintenance of pavements serving heavy traffic. The durability characteristics and longer service life which can be achieved with concrete pavements are desirable features under such circumstances. As a result, concrete designs are frequently used for the construction of airfield pavements at major Canadian airports and apron areas at other airports.

STRUCTURAL DESIGN

Design Variables

Transport Canada structural design methods (1) for airfield concrete pavements incorporate the design variables of aircraft load, subgrade soil characteristics and site freezing index. Table 1 lists standard gear loadings and configurations which cover in incremental steps the range of actual loadings experienced with aircraft. For design purposes, a standard gear loading is selected from this Table representing the heaviest aircraft loading forecast for the pavement over a fifteen year period after construction.

The two major subgrade soil characteristics influencing design are bearing strength and frost susceptibility. Subgrade bearing strength (2) is defined in terms of plate bearing measurements and the standard measure is taken using a 30 inch diameter plate, 0.5 inch deflection and 10 repetitions of loading. Values used for design represent the lower quartile strength of the subgrade during the spring thaw period. The design of concrete pavements is not highly sensitive to subgrade bearing strengths and design values can often be estimated with sufficient accuracy from a comprehensive site soils investigation.

The degree of subgrade frost susceptibility is also a major factor in design as it influences the performance and service life of a pavement structure under frost conditions. When frost protection is incorporated into the design, requirements are based on the site average freezing index which is a measure of severity of freezing temperatures experienced over the winter period.

Pavement Layer Thickness

Unless the subgrade soil is non-frost susceptible or a reduced level of service is judged acceptable, the general practice of Transport Canada is to provide a depth of pavement structure for partial protection against frost heaving. This depth is given in Figure 1 as a function of site freezing index. Required combined thickness of base and sub-base is the difference between the depth of pavement structure needed for partial frost protection and the required depth of concrete slab outlined below. Base thickness is eight inches of Portland cement stabilized gravel for the design aircraft loading designated "future" in Table 1 and six inches of unbound gravel for the lesser design loadings. Sub-base thickness is then as necessary to provide the required combined thickness of base and sub-base. Where the subgrade soil is non-frost susceptible, the design incorporates a six inch unbound base course to provide a stable surface for construction of the concrete slab.

Required concrete pavement slab thicknesses for the standard loadings listed in Table 1 are shown in Figure 2. These slab thicknesses are based on limiting to 460 psi the flexural stress imposed in the slab by the design loading. Imposed flexural stresses are computed by the analysis for the central slab loading condition (3). Slab bearing modulus, k, on which required slab thickness depends, is shown in Figure 3 as a function of subgrade bearing strength and the combined thickness of base and sub-base provided in the design.

Reinforcement and Joint Spacings

Standard construction joint and reinforcement details which form part of the design are shown in Figures 4 and 5. Basically, the practice of Transport Canada is to employ plain, unreinforced concrete for airfield pavements. As indicated in Figure 5, crack control mesh or bars are used only in areas of mis-matched joints and tie-bars are used only for exterior partially sized panels.

Due to the absence of crack control steel, the spacing of contraction and construction joints to prevent thermally induced cracking has traditionally been designed at 20 feet, with a construction joint placed along the centerline of runways and taxiways. In recent years, construction joint spacing in major projects has been increased to 25 feet to accommodate slip form paving equipment and to avoid the outside wheels of current wide bodied jet aircraft tracking along the joint.

CONSTRUCTION

The success of any structural design is controlled to a large extent by construction standards for materials and workmanship and the adherence to these standards during construction. The designer should play as large a role as construction supervision personnel in the setting of these standards. Material properties and workmanship required by Transport Canada for the construction of concrete pavements are outlined in Master construction specifications (4). Construction inspection and quality control testing requirements are also established in written form (5) as standards for construction supervision personnel.

Concrete mix requirements are of special interest as these requirements are directly related to structural design practices. Cement content of the mix is specified to be in the range of 485 to 525 lbs per cubic yard of mix, the upper limit established to control excessive shrinkage and the lower limit set on the basis of strength and durability characteristics. Cement is paid as a separate item so that the contractor has no incentive to minimize the cement quantities. With good aggregates and quality control, this cement content normally produces 28 day flexural strengths in the order of 650 to 700 psi and higher values can be expected as the concrete ages. As protection against poor aggregates and quality control, standard specifications also require an average 28 day flexural strength not less than 575 psi with a standard deviation not greater than 9 percent of the average. As design is based on limiting flexural stresses under the design load to 460 psi, these construction practices introduce a design safety factor and indirectly allow for fatigue considerations under the design loading and for limited operations by overweight aircraft.

AIRCRAFT TRAFFIC CONTROL

For the economic analysis of design alternatives and for future programming purposes, concrete airfield pavements designed and constructed in accordance with Transport Canada standards are assigned a service life of 20 to 25 years before rehabilitation is required. Maintenance during this period is expected to be minimal and normally not to exceed one percent per annum of initial construction costs. These assumptions are no longer valid if aircraft loadings substantially exceed design values. An operations system is therefore required for the control of aircraft traffic so that allowable loadings are not exceeded, or where decisions are taken to allow overloading, such decisions are made realizing the implications with respect to maintenance costs and shorter service life.

The system used by Transport Canada (6) is the issuance of an airport pavement load rating chart, which is a key plan of the airfield pavements at the airport with a load rating value assigned to each pavement. The load rating for concrete pavements is determined from Figure 2 on the basis of the existing slab thickness and assigned bearing modulus value. Aircraft have also been assigned a load rating value by comparing their slab thickness design requirements to those for the standard gear loadings.

Control is exercised by comparing the load rating of the aircraft to the load rating of the pavement and operating certificates are issued without further study if the load rating of the aircraft does not exceed by more than one the load rating of the pavement. Requested operations by heavier aircraft are referred to design personnel for special study. Depending on a number of factors such as age and condition of the pavement, scheduled rehabilitation measures and projected frequency of operations, permission to operate may be given to aircraft which produce a calculated flexural stress in the pavement of up to 900 psi.

EVALUATION

Since significant variations can be expected from the performance and service life predicted at the time of design, a pavement evaluation system is a necessity for effective planning and budget programming. Performance records generated under an evaluation program are also a valuable feedback to evaluate the effectiveness of design, construction, maintenance and traffic control practices. The three main elements of Transport Canada's pavement evaluation program are structural condition and performance surveys (7), roughness measurements (8) and skid resistance measurements (9) .

Pavement structural condition surveys are undertaken once a year at major international airports and once every two years at other airports. Their purpose is to provide a subjective rating of any load associated or environmentally induced defects in the pavement structure and to update estimates of remaining service life. A typical condition report for concrete pavements is shown in Table 2.

Pavement surface roughness measurements by Wisconsin road meter are undertaken on most major runways at two year intervals. These measurements are converted to roughness indexes which are plotted as shown in Figure 6 to provide a roughness performance chart for the facility. Measurements obtained with the Wisconsin road meter satisfactorily reflect short wavelength roughness characteristics of the runway profile but do not detect longer wavelength components which may adversely affect aircraft. When pilot complaints of roughness are received and roughness is not indicated by road meter measurements, the runway profile is determined by a rod and level survey and analyzed as indicated in Figure 7 to identify areas of deficiency.

Skid resistance measurements are normally conducted with the Swedish Skiddometer at periodic intervals on major runways and measurements are summarized as shown in Figure 8. Texture finishes for concrete pavements during the years have progressed from burlap drag to transverse brooming and current specifications require transverse combing. Problems identified to date by skid resistance measurements are generally due to surface contaminants such as rubber buildup in touchdown zones rather than to concrete properties or texture finish.

PERFORMANCE

Older concrete pavements constructed at larger airports by Transport Canada have generally all been overlaid for strengthening purposes due to the introduction of DC-8 and B707 type aircraft in the late 50's and early 60's. Recently constructed pavements are too new for an evaluation of performance. However, there are nine major runways of concrete construction in the national airports system which are serving large aircraft and are of sufficient age for performance trends to be identified. A summary of these runways and their performance is given in Table 3. Of the nine runways, three are performing well and may exceed their original life expectancy of 20-25 years. However, six runways will require rehabilitation within a few years - three due to unacceptable levels of surface roughness caused by frost heaving and the others due to structural deficiencies related to material or construction problems.

Canadian experience with concrete airfield pavements suggests that pavement performance which fails to meet design objectives can usually be attributed more to deficiencies in other areas than to inadequacies in the structural design methods. Consequently, it is considered that future research and development efforts associated with concrete airfield pavements may be more beneficial in improving pavement performance if primarily directed to areas other than structural design.

REFERENCES

1. "Pavement Design and Rehabilitation", Transport Canada, Airport Facilities Branch, Manual AK-68-12, Ottawa, March 1976.

2. "Pavement Strength Measurement and Evaluation", Transport Canada, Airport Facilities Branch, Manual AK-68-31, Ottawa, November 1975.

3. Packard, R.G., "Design of Concrete Airport Pavement", Portland Cement Association, Skokie, Illinois, 1973.

4. "Heavy Civil Construction Specifications", Transport Canada, Airport Facilities Branch, Manual AK-68-20, Ottawa, December 1975.

5. "Pavement Construction Supervision", Transport Canada, Airport Facilities Branch, Manual AK-68-23, Ottawa, June 1976.

6. "Pavement Evaluation for Aircraft Operations", Transport Canada, Airport Facilities Branch, Manual AK-68-30, Ottawa, March 1976.

7. "Pavement Condition Surveys", Transport Canada, Airport Facilities Branch, Manual AK-68-32, Ottawa, December 1976.

8. "Runway Roughness Measurement and Evaluation", Transport Canada, Airport Facilities Branch, Manual AK-68-33, Ottawa, March 1977.

9. "Runway Friction", Transport Canada, Airport Facilities Branch, Manual AK-72-60, Ottawa June 1976.

TABLE 1 STANDARD GEAR LOADINGS		LOAD RATING NUMBER												
		1	2	3	4	5	6	7	8	9	10	11	12	FUTURE
SINGLE WHEEL GEAR	GEAR LOAD (KIPS)	4	7	10	13	18	25	30	—	—	—	—	—	—
	TIRE PRESSURE (P.S.I.)	50	55	60	65	70	80	90	—	—	—	—	—	—
DUAL WHEEL GEAR	GEAR LOAD (KIPS)	—	—	—	20	25	30	40	50	65	85	—	—	—
	TIRE PRESSURE (P.S.I.)	—	—	—	75	85	90	100	125	155	155	—	—	—
	DUAL TIRE SPACING (INCHES)	—	—	—	22	22	23	25	27	30	35	—	—	—
DUAL TANDEM WHEEL GEAR	GEAR LOAD (KIPS)	—	—	—	—	—	—	—	—	100	150	200	250	285
	TIRE PRESSURE (P.S.I.)	—	—	—	—	—	—	—	—	160	170	225	260	270
	DUAL TANDEM TIRE SPACING (INCHES)	—	—	—	—	—	—	—	—	25 x 45	35 x 60	42 x 65	45 x 65	45 x 65

RATING SCALE	AIRPORT: *TORONTO INTERNATIONAL*		PAVEMENT AREA								
	OBSERVER: *A. SMITH*	DATE: *20 NOV 75*	05 R-23 L	TAXI A	TAXI E	TAXI G	TAXI L	TAXI P	APRON I	APRON IX	
0 - NONE 1 - MINOR 2 - MODERATE 3 - MAJOR 4 - SEVERE	CRACKING	CORNER	1	1	1	2	2	0	2	1	
		EDGE	1	1	0	2	2	0	2	1	
		LONGITUDINAL	1	1	0	2	2	1	2	1	
		TRANSVERSE	1	2	0	2	3	0	2	1	
	SCALING		0	1	0	0	0	0	1	0	
	SPALLING		1	1	0	0	2	0	2	0	
	JOINT STEPPING AND FAULTING		0	0	0	1	1	0	2	1	
	CONCRETE DISINTEGRATION		0	0	0	0	2	0	1	0	
	PUMPING		0	0	0	0	0	0	1	0	
	LOSS OF JOINT FILLING		2	2	1	2	3	0	2	1	
	SUBGRADE SETTLEMENT		1	0	0	0	1	0	2	0	
	FROST HEAVE		0	0	0	0	0	0	0	0	
	PATCHING		1	2	0	3	2	0	3	0	
	LOCALIZED RECONSTRUCTION		0	0	0	0	0	0	0	0	
8-10 VERY GOOD 6-8 GOOD 4-6 FAIR 2-4 POOR 0-2 VERY POOR	SURFACE ROUGHNESS		8	7	9	5	4	10	5	9	
	SURFACE DRAINAGE (PONDING)		8	8	9	5	5	9	6	9	
	SUBSURFACE DRAINAGE		8	7	8	6	6	8	7	9	
	GENERAL CONDITION		8	7	9	5	3	10	5	9	

TABLE 2 TYPICAL CONDITION REPORT – CONCRETE PAVEMENT

TABLE 3 CONCRETE RUNWAY PERFORMANCE SUMMARY

AIRPORT	RUNWAY	STRENGTH PARAMETERS		YEAR BUILT	PERFORMANCE			ESTIMATED SERVICE LIFE (YEARS)	
		K(p.c.i.)	h(in)		STRUCTURAL	DURABILITY	ROUGHNESS	REMAINING	TOTAL
EDMONTON INTL.	01 - 19	250	12	1958	GOOD	GOOD	FAIR (FROST HEAVE)	3 -4	21 - 22
EDMONTON INTL.	11 - 29	250	12	1958	GOOD	GOOD	FAIR (FROST HEAVE)	2 -3	20-21
MONTREAL DORVAL INTL.	06R-24L	220	12	1958	FAIR (CRACKING)	POOR (Cracking)	FAIR	3 -5	21 - 23
VANCOUVER INTL.	12 - 30	170	14	1960	GOOD	GOOD	GOOD	5 -10	21 - 26
QUEBEC CITY	06-24	225	12	1961	FAIR	GOOD	GOOD	5 - 10	20-25
TORONTO INTL.	05R-23L	250	14	1961	GOOD	GOOD	GOOD	8 - 12	23-27
MONTREAL DORVAL INTL.	06L-24R	220	12	1961	FAIR (CRACKING)	POOR (SPALLING, DIS-INTEGRATION)	POOR	3 - 5	18-20
REGINA	07-25	410	11	1962	FAIR (SUBGRADE SETTLEMENT)	GOOD	FAIR (FROST HEAVE)	3-4	17-18
HALIFAX INTL.	06-24	100	12	1969	FAIR (CRACKING)	POOR (SUBSTANDARD AGGREGATES)	FAIR	6-10	13-17

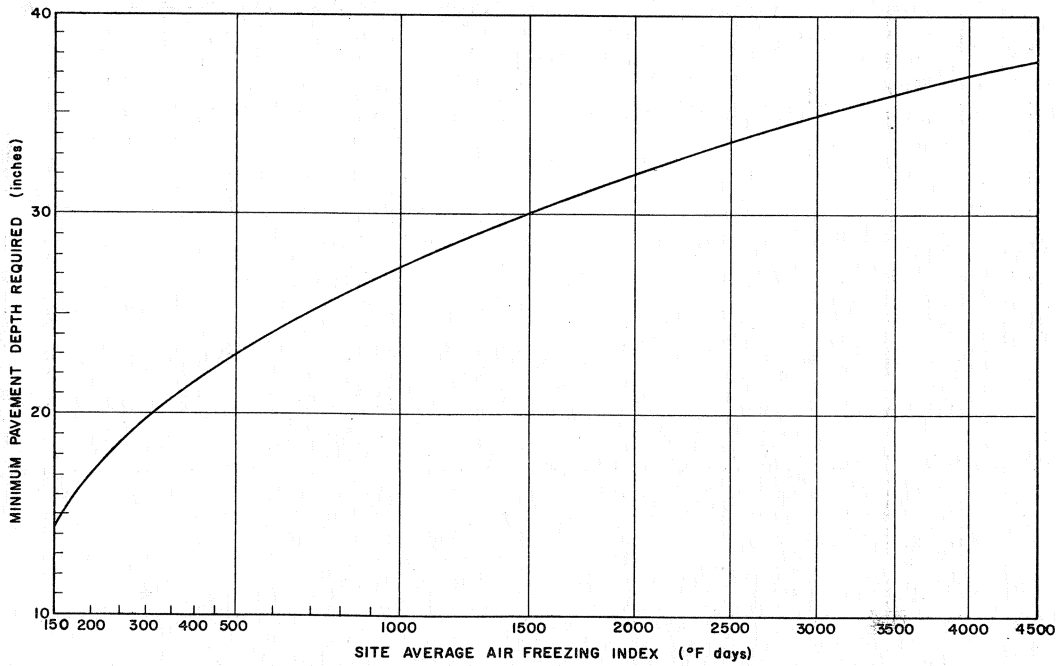


Fig. 1 PARTIAL FROST PROTECTION REQUIREMENTS

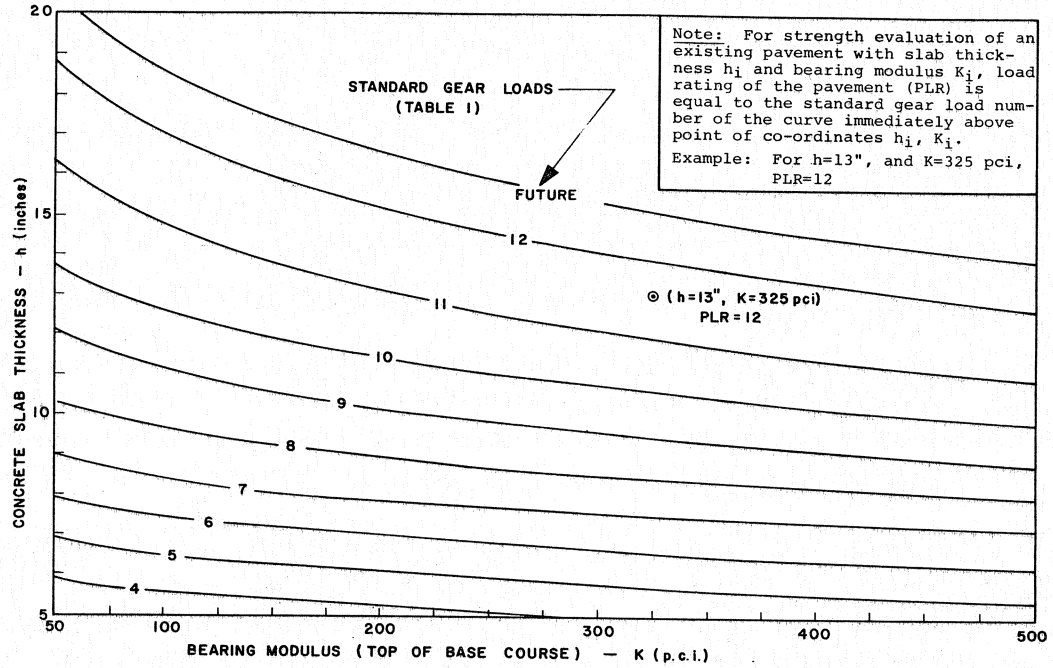


Fig. 2 CONCRETE SLAB THICKNESS REQUIREMENTS

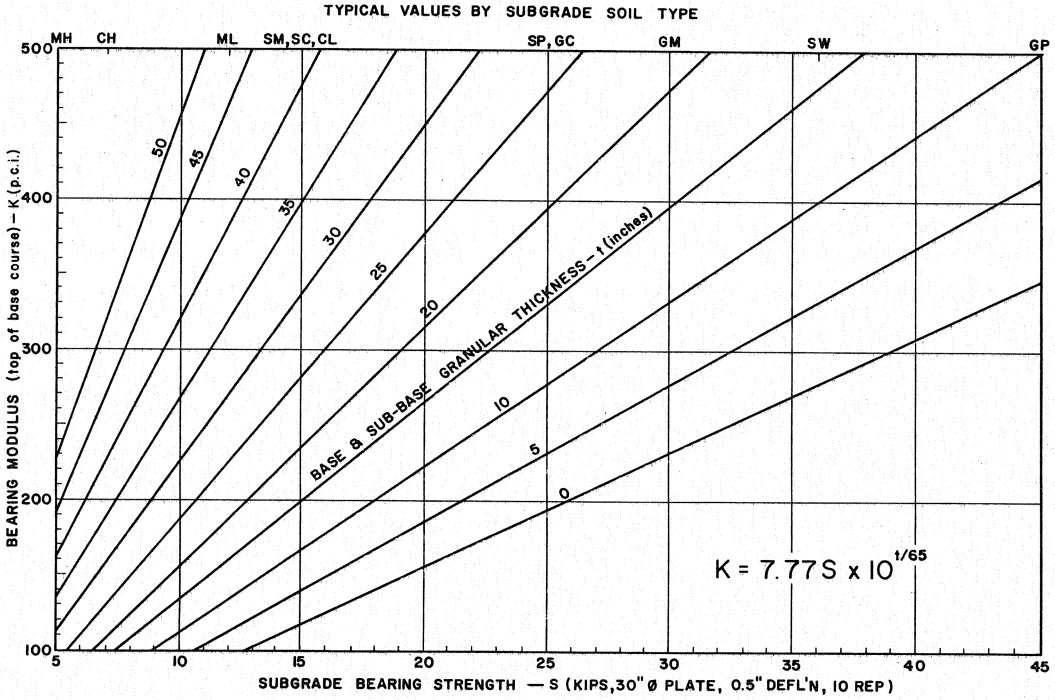


Fig. 3 DETERMINATION OF BEARING MODULUS "K"

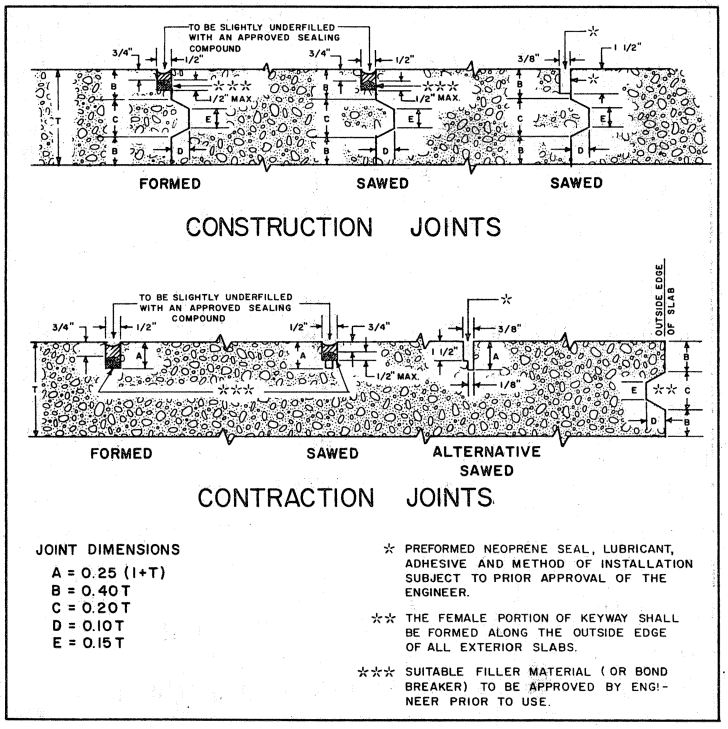
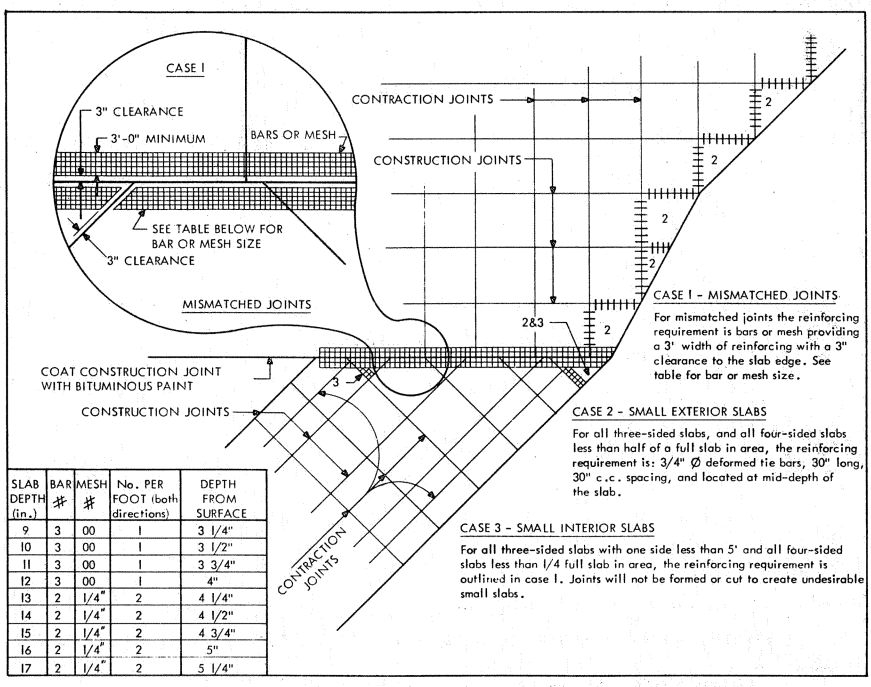


Fig. 4 CONCRETE JOINT DETAILS



SLAB DEPTH (in.)	BAR #	MESH #	No. PER FOOT (both directions)	DEPTH FROM SURFACE
9	3	00	1	3 1/4"
10	3	00	1	3 1/2"
11	3	00	1	3 3/4"
12	3	00	1	4"
13	2	1/4"	2	4 1/4"
14	2	1/4"	2	4 1/2"
15	2	1/4"	2	4 3/4"
16	2	1/4"	2	5"
17	2	1/4"	2	5 1/4"

Fig. 5 JOINT LAYOUT AND STEEL REQUIREMENTS

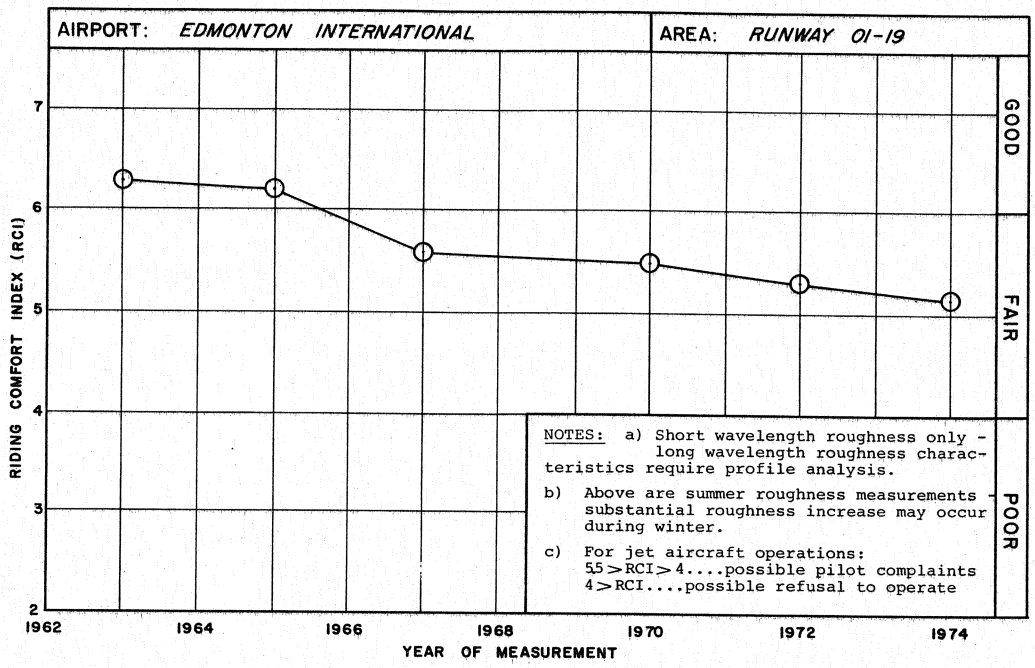


Fig. 6 RUNWAY ROUGHNESS PERFORMANCE CHART

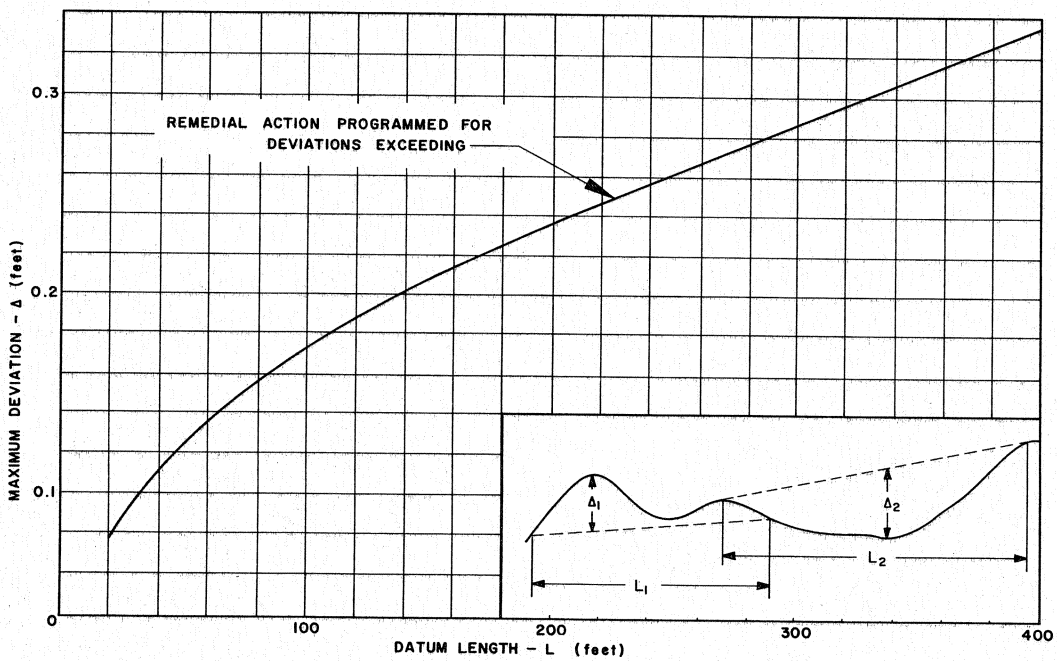


Fig. 7 LONG WAVELENGTH (PROFILE) ROUGHNESS CRITERIA

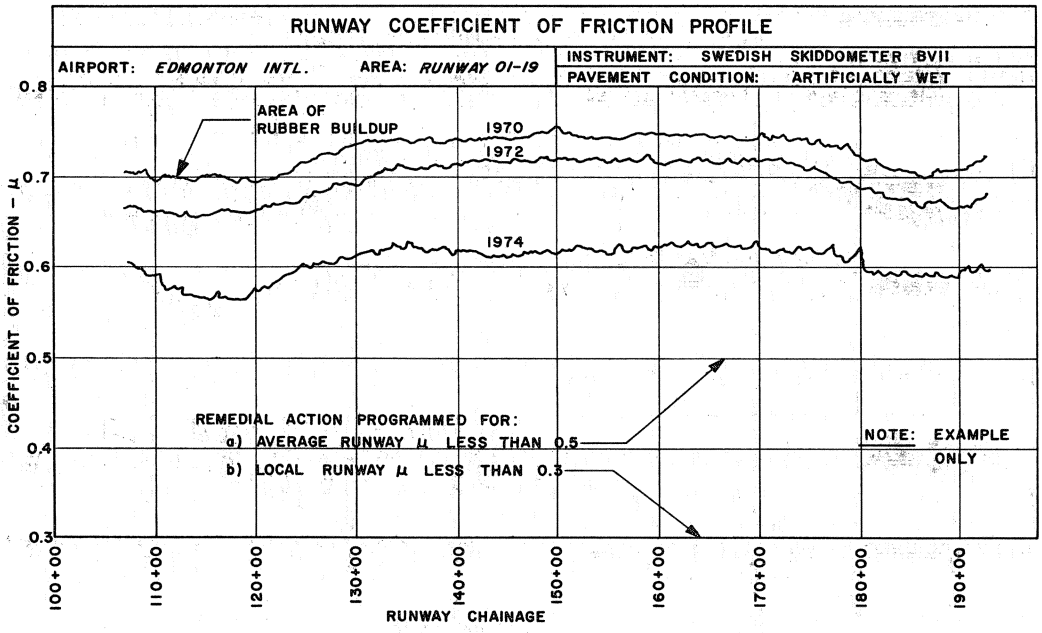


Fig. 8 TYPICAL SKID RESISTANCE PERFORMANCE CHART