PAVEMENT STRUCTURAL DESIGN TRAINING MANUAL

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MANUEL DE FORMATION SUR LA CONCEPTION DES CHAUSSÉES

Public Works & Government Services Canada
Architectural and Engineering Services
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Services d'architecture et de génie
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1.0 INTRODUCTION

1.1 SCOPE OF THE MANUAL

Pavements are constructed to provide ground surfaces for the movement of vehicles or other types of traffic and the design of these facilities is based on the needs and characteristics of the traffic to be served and on economic considerations. This manual is limited in scope to the structural design of pavements serving aircraft or ground vehicle traffic. Geometric design requirements are given in other publications.

The structural design of pavements outlined in this manual is primarily concerned with the thickness of pavements and their component layers, as necessary to provide sufficient bearing strength for the traffic loadings, and to attenuate frost effects. Other quality characteristics of a pavement structure, such as durability, roughness and skid resistance, are controlled by material and workmanship requirements contained in construction specifications.

The design methods given in this manual are used for pavements constructed at Canadian airports.

1.2 TYPES OF PAVEMENT STRUCTURE

Various types of pavement structure are illustrated in Figure 1.1. These structures are commonly designated as flexible or rigid depending on the principle being employed for the support of traffic loads. A flexible pavement structure distributes loads to the subgrade and depends on aggregate interlock, particle friction and cohesion for stability. A rigid pavement depends on the flexural beam strength of a Portland cement concrete slab for the support of traffic loads.

Hard surfaced pavements, categorized as asphalt, concrete or composite, provide a high level of service with uninterrupted, year round operation and minimum maintenance costs. An asphalt pavement is a flexible pavement structure with an asphaltic concrete surfacing course. A concrete pavement is a rigid pavement structure with a Portland cement concrete surface. Composite pavements containing a Portland cement concrete slab with an overlay of flexible construction may be a rigid or flexible system depending on the depth of overlay.

Flexible gravel surfaced pavements are constructed using a selected granular material that is overlaid by a higher quality base course material of adequate stability if uninterrupted service is required through wet periods. Gravel-surfaced pavements cost significantly less

1.2 TYPES OF PAVEMENT STRUCTURE (CONT'D)

for initial construction than hard-surfaced pavements, and they can be regraded and levelled relatively easily when surface irregularities develop due to settlement or frost heaving. Disadvantages include dust problems, loose surface particles and high maintenance costs for periodic regrading, compaction and replacement of erode surface material.

Some disadvantages of a gravel surfaced pavement can be eliminated at moderate cost by a surface treatment, although the ability to easily regrade the surface is then lost. A surface treatment is the single or multiple application of a liquid asphalt spray followed by the spreading and rolling in of a uniform-sized aggregate. Surface treatments are not normally employed on airfield pavements because of low durability, but are quite practical for low-volume roads.

Graded and compacted earth-surfaced pavements may sometimes be used for tire loadings which are light and infrequent. Compacted earth-surfaced pavements suffer to a greater degree the disadvantages of a gravel surfaced pavement, and they will usually be unserviceable during the spring thaw and during prolonged wet periods. The establishment of turf on a compacted earth surface provides some stability, reducing dust and erosion problems, but care of the turf increases maintenance requirements.

1.3 PAVEMENT COMPONENT LAYERS

Component layers of pavement structures are illustrated in Figure 1.1. The materials used in these layers are described below.

(a) Asphalt Surfacing Course

Asphalt surfacing courses consist of mineral aggregates bound by some type of asphalt material. Usually, asphalt surfacing courses consist of a hot-mixed asphaltic concrete which is manufactured using a penetration-grade asphalt cement, heated and mixed with the aggregates prior to placing. Occasionally, cold mixes may be used. Cold mixes may be mixed on grade using a liquid or emulsified asphalt and are less expensive but not as durable as hot mixes.

(b) Portland Cement Concrete Surfacing Course

Surfacing courses consisting of Portland cement concrete slabs are constructed with concrete manufactured using mineral aggregates and Portland cement. The concrete is pre-mixed prior to placing.

1.3 PAVEMENT COMPONENT LAYERS (CONT'D)

(c) Base Course

A base course is a layer immediately beneath the surfacing course and is constructed from well-compacted granular aggregates meeting high standards with respect to stability and durability characteristics. The base course contributes to pavement bearing strength, provides a platform for construction of the surfacing course, and in flexible pavements must have sufficient stability to withstand the high stresses imposed by aircraft tire pressures. Normally, unbound bases are employed but in special cases a stabilized base may be provided in which the aggregates are bound with asphalt or Portland cement.

(d) Sub-Base Course

Sub-base courses are constructed from selected granular aggregates which are not susceptible to frost action and with stability and durability requirements that are less demanding than those for base course aggregates. Sub-bases contribute to the pavement structure by providing an increase in bearing strength and in frost protection.

(e) Subgrade

A subgrade is the foundation on which the pavement is constructed and consists of the in situ soil, or, in fill sections, imported common material. The top 15 to 30 cm of subgrade is usually compacted to a higher density than the underlying subgrade material.

1.4 CONSTRUCTION SPECIFICATIONS

The materials used in pavement construction and the standard of workmanship have as much influence on pavement performance as the design of structural thicknesses. Consequently, the design methods presented in this manual are based on the assumption that construction materials and - workmanship will meet or exceed a minimum level of quality.

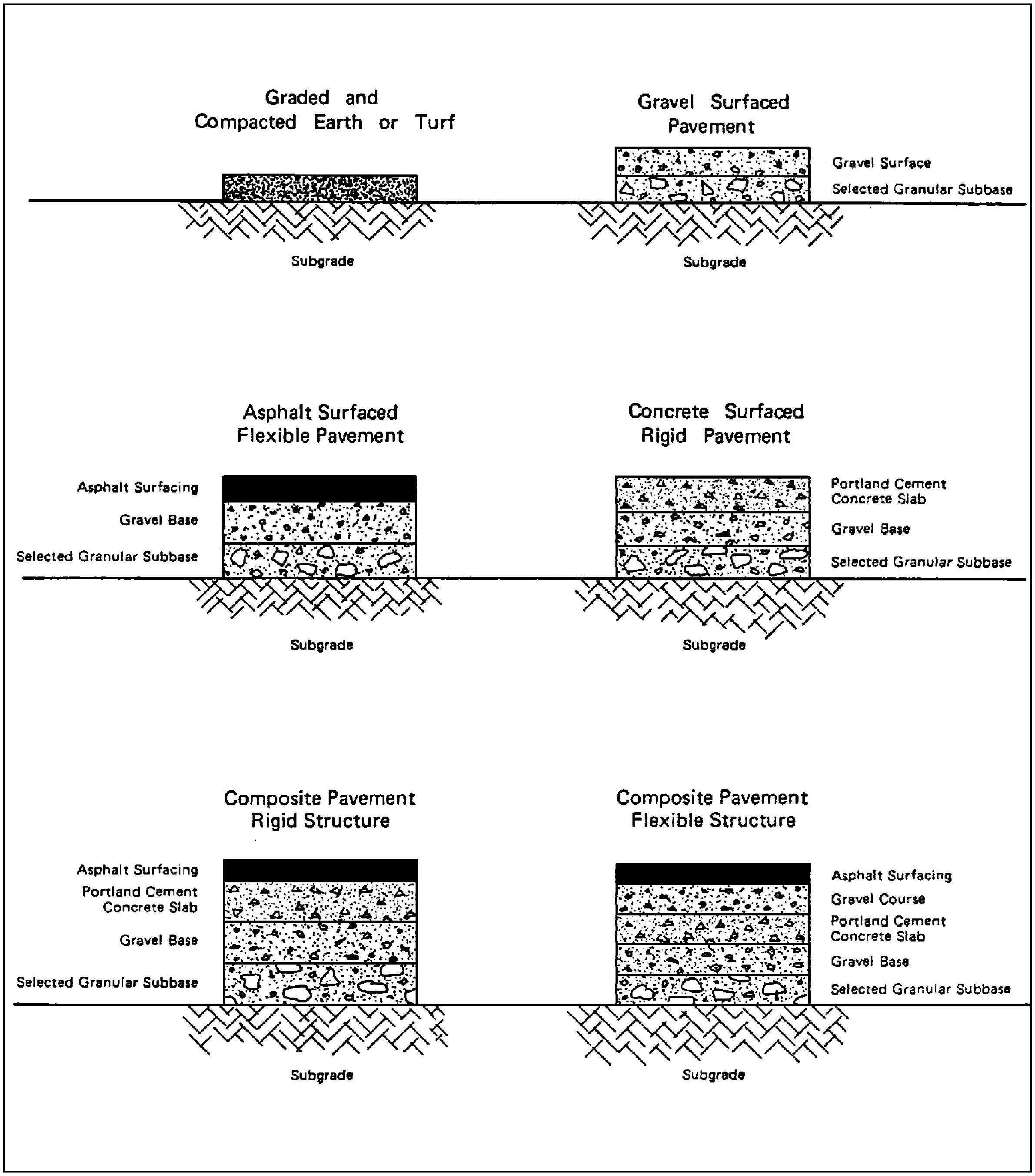
Specifications used for the construction of pavement layers should be edited versions of the National Master Construction Specifications: Heavy Civil. The commonly used sections are listed in Table 1.1. Editing of these guideline specifications should include the changing of requirements for aggregate and mix characteristics to the standards summarized in ASG-06 (AK-68-23) "Pavement Construction: Materials and Testing."

TABLE 1.1 - NATIONAL MASTER SPECIFICATIONS FOR AIRFIELD PAVEMENT CONSTRUCTION

Specification No.	Title
02111	Clearing and Grubbing
02070	Demolition and Removal
02211	Airfield Grading
02230	Aggregates, General
02234	Granular Sub-base
02233	Granular Base
02241	Lime - Stabilized Subgrade
02232	Cement - Stabilized Base
02512	Hot Mix Asphalt Concrete Paving
02521	Portland Cement Concrete Paving
02580	Pavement Marking
02581	Pavement Surface Cleaning
02577	Pavement Crack Cleaning and Filling
02514	Mixed-in-place Asphalt Paving
02546	Asphalt Prime
02547	Asphalt Tack Coat
02578	Asphalt Slurry Seal Coat
02579	Coal Tar Slurry Seal Coat

Note: These master specifications should be edited to comply with airfield construction material requirements given in ASG-06 "Pavement Construction: Materials and Testing".

FIGURE 1.1 - TYPICAL PAVEMENT SECTIONS



2.0 DESIGN FACTORS

2.1 DESIGN PARAMETERS

Other than construction materials, the major factors influencing pavement design are related to traffic, subgrade soil characteristics and site climatic conditions. These factors are discussed in this Chapter, and methods are given for determining values for the following pavement design parameters:

- design loading,
- subgrade bearing strength,
- site freezing index.

2.2 TRAFFIC LOADING

2.2.1 AIRCRAFT LOADINGS

Aircraft loading characteristics which influence pavement design are:

(i) gross operating weight of the aircraft and the distribution of this weight on the main supporting gears;

(ii) number and spacing of tires in the supporting gears;

(iii) tire inflation pressure.

These loading characteristics are given in Appendix A for a variety of present day aircraft.

Airport pavements are usually designed for a class of aircraft rather than for a particular aircraft. In accordance with this practice and to simplify design procedures, a series of twelve standard gear loadings have been selected which span the range of current aircraft loadings. The standard gear loadings are listed in Table 2.1 and some aircraft that have loading characteristics equivalent to each of these standard gear loading are listed in Table 2.2.

The type of aircraft expected to use the facility over the 15 to 20 year period following construction should be determined from planning studies or the airport

2.2.1 AIRCRAFT LOADINGS (CONT'D)

master plan, and the appropriate standard gear loading for design should then be selected from Table 2.2.

2.2.2 GROUND VEHICLE LOADING

A variety of ground vehicles may be used at airports. Access roads and carparks will be subject to loads typical of provincial highways. However, some specialized service, emergency and maintenance vehicles peculiar to airports will exceed permissible highway limits. Table 2.3 lists the loading characteristics of a number of specialized vehicles which may be found in the vicinity of airports.

In most situations, airport roads and car parks are designed for one of the four standard loadings given in Table 4.2. The type of traffic expected to use a road or carpark facility should be determined from planning studies and the appropriate standard loading for design should then be selected from Table 4.2.

2.2.3 TRAFFIC FREQUENCY AND OVERLOAD RATIO

The performance of a pavement structure depends to a significant degree on the frequency of traffic loadings. This variable is not considered directly during design because of the difficulties inherent in estimating its value over the service life of the pavement structure. The design philosophy normally adopted is to accommodate an unrestricted number of load applications by the design loading.

A related variable is overload ratio, which is a measure of the load imposed on a pavement structure compared to the load for which the pavement is designed. Overload ratio is used in the evaluation of airport pavements subjected to a load heavier than the design load. ln some special design situations, overload ratio may be used to manipulate design requirements to reflect the influence of traffic frequency.

The overload ratio for a flexible pavement subject to an aircraft load involves a comparison of two subgrade bearing strength values. The first bearing strength is the value required for the existing thickness of the pavement structure to equal the aircraft design strength requirements. This value is divided by the actual subgrade bearing strength to form the overload ratio.

2.2.3 TRAFFIC FREQUENCY AND OVERL0AD RATIO (CONT'D)

The overload ratio for a rigid pavement subject to an aircraft load involves a comparison of two flexural stress values. The ratio is formed by calculating the flexural stress induced in the concrete slab by the aircraft loading and dividing this induced stress by the allowable design flexural stress of 2.75 MPa.

Aircraft pavements are usually designed for an overload ratio of one. Design requirements, however, contain a safety factor and aircraft operations which give an overload ratio greater than one can normally be allowed. On the basis of overload ratios, aircraft operations are classified as follows:

Overload Ratio	Classification of Aircraft Operation
< 1.25	Unrestricted Operations
1.25 - 1.50	Limited Operations
1.50 - 2.00	Marginal Operations
> 2.00	Emergency Use Only

2.3 SUBGRADE CHARACTERISTICS

2.3.1 SOIL SURVEYS

A thorough knowledge of subgrade soil characteristics should be developed prior to the design and construction of a pavement. Requirements for soil and construction material surveys are given in AK-68-90, Geotechnical Surveys.

2.3.2 SUBGRADE BEARING STRENGTH

A characteristic of subgrade soils which directly influences the design of pavements is the subgrade bearing strength. The current standard measure of subgrade bearing strength, denoted "S", is the load in kN required to produce a deflection of 12.5 mm after 10 load repetitions when applied to the subgrade surface through a 750 mm diameter rigid plate. Methods of measuring pavement and subgrade bearing strength are given in AK-68-31 "Airport Pavement Evaluation: Bearing Strength".

2.3.2 SUBGRADE BEARING STRENGTH (CONT'D)

Subgrade bearing strengths will vary throughout a pavement area, and at any given location will vary with the time of year. The strength value used for design purposes is the lower quartile strength of the pavement area which occurs during the spring thaw period. Lower quartile strength is that strength value for which 25 percent of the area will be weaker and 75 percent will be stronger. Where several strength measurements are available, lower quartile strength value, SLQ, may be calculated as:

$$S_{LQ} = \bar{x}_n - 0.675\,\sigma_{n-1}$$

where $\bar{x}_n$ is the average of "n" strength measurements and σ_{n-1} is their standard deviation.

Subgrade bearing strengths are normally measured during the summer and fall months, and these values must be adjusted by a Spring Reduction Factor to estimate spring values. Where frost penetrates the subgrade soil, the following Spring Reduction Factors are applied to reduce the lower quartile subgrade bearing strength obtained from measurements made during summer and fall months.

Subgrade Soil Type	Spring Reduction Factor
Gravel	0%
Medium and coarse sands	10%
Silty clay and clay soils	15% - 45%
Silt, very fine sands	45% - 50%

Estimates of Spring Reduction Factor may also be obtained by plotting subgrade soil gradation on Figure 2.1 and taking a weighted average where weighting is by per cent of the material falling within each reduction range.

In selecting a Spring Reduction Factor, consideration should also be given to subgrade moisture content, ground-water levels and site reports concerning frost heaving. When the water table is within one metre of the pavement surface, the percentage Spring Reduction Factor should be increased by 10 for each soil type.

New flexible pavement facilities are generally designed using a conservative estimate of subgrade bearing strength rather than measured values. The actual

2.3.2 SUBGRADE BEARING STRENGTH (CONT'D)

bearing strength of the pavement structure is established by measurement after construction.

When designing new pavement facilities at an existing airport, subgrade bearing strength values for the site will frequently be available from strength measurements made on existing pavements at the airport. These values may be used for designing the new facility provided subgrade soil conditions are similar.

When designing pavement facilities at a new airport location or at an airport where no strength measurements have been made, a value of subgrade bearing strength for design purposes may be selected from Table 2.4, based on the subgrade soil classification established in the soils survey.

2.4 SITE CLIMATIC CONDITIONS

2.4.1 FREEZING AND THAWING INDICES

Freezing index is a measure of the severity of freezing conditions over a winter season. The depth of frost penetration, and hence pavement frost protection requirements, are related to this variable. Freezing index is measured in degree-Celsius days (°C-days) and is calculated as the summation of daily average air temperatures over the freezing period (with the negative value converted to positive after summation). An example calculation is given in Table 2.5.

Thawing indices are a similar measurement and are of interest for the design of pavements in permafrost areas. These indices are the summation of daily average air temperatures over the thaw period.

Freezing and thawing indices for existing airports are listed in the airport pavement technical data inventory. When required for new sites, freezing and thawing indices may be calculated from meteorological temperature records, or may be estimated from Figures 2.2 and 2.3.

2.4.2 FROST AND THAW PENETRATIONS

The depth of frost penetration into ground surfaces is a variable of interest in a number of engineering design situations. Analytical methods are available for the calculation of frost penetration, but these methods require extensive data on subsurface soil characteristics. With a knowledge of site air freezing index only, approximate values may be estimated from Figures 2.4 to 2.6.

The data in Figures 2.4 to 2.6 resulted from a program of measuring frost penetrations at a number of Canadian airports. Figure 2.4 for snow cleared asphalt surfaced pavements shows maximum frost penetration recorded, plotted against air freezing index at the site for the winter season in which the measurements were made. Figure 2.5 is a similar plot for snow cleared concrete surfaced pavements.

The penetration of frost in pavements actually depends on pavement surface temperatures which are slightly higher than air temperatures on the average. For this reason, penetration does not occur until air freezing index reaches a certain minimum value. For this same reason, frost penetration in concrete surfaced pavements is slightly higher than in asphalt surfaced pavements due to the effect of colour on radiation absorption.

Figure 2.6 shows frost penetration versus air freezing index for snow covered natural ground surfaces. For this surface condition, frost penetrations are highly variable because they depend on the depth of snow cover, and on when the snow arrives relative to the start of freezing temperatures. Although frost penetrations are highly variable for this surface condition, a maximum potential value can be identified in Figure 2.6 which corresponds to the case of little or no snow cover. This maximum potential value is useful when considering burial depths for such installations as water or drainage pipe which must be protected from frost.

While frost penetration is of interest in seasonal frost zones, the corresponding variable of interest in permafrost areas is the depth of thaw which occurs during summer. Figures 2.7 and 2.8 give some data on measured thaw penetration versus air thawing index, for gravel surfaced pavements and for natural ground surfaces respectively.

2.4.3 FROST PROTECTION REQUIREMENTS

The penetration of frost into pavement subgrades can have two major detrimental effects. If the subgrade soil is frost susceptible and water is present, frost

2.4.3 FROST PROTECTION REQUIREMENTS (CONT'D)

penetration will induce ice lensing in the subgrade with subsequent frost heaving and development of roughness at the pavement surface. When this ice melts during spring thaw, the excess water and loss of density combine to decrease subgrade and pavement bearing strength.

Figure 2.9 gives the minimum depth of pavement structure to attenuate the effects of frost heave. This minimum depth of pavement structure is a function of the site average annual air freezing index calculated over a 10-30 year period. A comparison with Figures 2.4 and 2.5 shows that the protection provided compared to depth of frost penetration varies with the severity of freezing conditions. In climates with a low freezing index, the minimum pavement thickness required for frost protection corresponds to the full depth of average frost penetration; in cold climates, the protection requirement corresponds to roughly one-third of frost penetration.

The following guidelines apply to the incorporation of frost protection requirements into the design of a pavement structure subject to subgrade frost penetration:

(i) frost protection should generally be provided for pavements with paved surfaces constructed on frost susceptible subgrades;

(ii) frost protection is not required for pavements with unbound surfaces such as gravel, when surface irregularities caused by frost heave can readily be corrected by regrading;

(iii) frost protection is not required for pavements constructed on non-frost susceptible subgrade soils. Gravel and sands with less than 10 percent passing the 0.075 mm sieve are considered non-frost susceptible;

(iv) frost protection requirements may be waived under a number of special circumstances:

    (1) the pavement structure is to be a temporary facility;

    (2) stage construction is contemplated;

    (3) the pavement is for an infrequently travelled road and a low quality structure can be tolerated.

The pavement frost protection requirements given in Figure 2.9 are largely

2.4.3 FROST PROTECTION REQUIREMENTS (CONT'D)

empirical in nature. Experience has shown that when combined with adequate subsurface drainage, they will satisfactorily attenuate frost heave effects in most situations.

Standard frost protection requirements are not sufficient to prevent excessive differential frost heaving when pockets of highly frost susceptible soil exist in an otherwise non-frost susceptible subgrade. Special measures are required for this situation; usually excavation of the frost susceptible pockets to the depth of frost penetration or to 1.20 m below the finished pavement surface (whichever is less) and replacement with non-frost susceptible material is required. Also, large boulders embedded in a matrix of fine soils can be raised by frost action to create a bump at the pavement surface. Such boulders should be removed during construction if they are found within the top 0.5 m of subgrade.

TABLE 2.1 - STANDARD GEAR LOADINGS

STANDARD GEAR LOAD RATING	CHARACTERISTICS OF STANDARD GEAR LOADINGS								
	SINGLE WHEEL GEAR		DUAL WHEEL GEAR			DUAL TANDEM GEAR			
	Gear Load (kN)	Tire Pressure (MPa)	Gear Load (kN)	Tire Pressure (MPa)	Dual Tire Spacing (cm)	Gear Load (kN)	Tire Pressure (MPa)	Dual tandem Tire Spacing (cm)	
1	20	0.30							
2	30	0.35							
3	45	0.40							
4	60	0.45	80	0.50	50				
5	80	0.50	110	0.60	55				
6	110	0.55	130	0.65	60				
7	140	0.60	170	0.70	65				
8			220	0.85	70				
9			290	1.05	75	440	1.10	65x115	
10			400	1.15	90	660	1.20	90x150	
11						900	1.55	110x165	
12						1120	1.80	115x165	

TABLE 2.2 - AIRCRAFT CORRESPONDING TO STANDARD GEAR LOADINGS

S.G.L.	Aircraft
1	Piper Apache/Aztec Cessna Cutlass/Skylane Beech Bonanza/Baron DHC2 Beaver
2	Beech King Air 90 Srs. Cessna 421 Golden Eagle DHC6 Twin Otter
3	Cessna Citation I Swearingen Metro/Merlin Piper Cheyenne III
4	DC 3 DHC8 Dash 8 Gates Learjet 55, 56
5	Gulfstream G159 F27 HS748 Dart Herald
6	Convair 580/640 Canadair CL215 Dassault Falcon 50

S.G.L.	Aircraft
7	DC-4 BAE-146-100 Canadair CL699, 601
8	DC-9-15 DC-6, 6B Gulfstream II, III Argosy A W650 BAE-146-200
9	BAC-111-500 DC-9-21, 32 Hercules C130
10	B707-120B B737-200/300 B767-200 DC-7 L1049 Super Constellation
11	B-747-100 DC-10-20 B707 320/420 Airbus A-300 VC-10-1100, 1150 Super
12	Concorde B-747-200 DC-10-10, 30, 40 L-1011-100, 200, 500 B727-200 DC-8-62, 63, 72, 73

Note: Listing above is for selected aircraft when at maximum operating weight and tire pressure. For other aircraft and aircraft operating at reduced operating weights and tire pressures, see AK-77-68-500, AK-67-09-140 or AK-68-30.

TABLE 2.3 - GROUND VEHICLE LOADING CHARACTERISTICS

Vehicle		Gross Weight (kN)	Gear Load (kN)	Wheel Spacing Dual (cm)	Wheel Spacing Tandem (cm)	Tire Pressure (MPa)	Vehicle Loading Group
EMERGENCY							
Small Foam		73.9	23.6	32	-	0.38	1
Crash Rescue		65.8	18.5	-	-	0.31	1
1000 gal. Foam		169.0	59.2	-	142	0.62	2
2000 gal. Foam		287.6	77.7	-	-	0.62	4
MAINTENANCE							
Small Snow-plow		92.1	27.8	-	-	0.59	2
Lg. Snow-plow		109.4	32.5	-	-	0.59	2
7200 Snow Blower		126.8	37.8	-	-	0.69	2
Snow Blast Blower		151.2	40.8	-	-	0.59	2
Spreader Truck		276.0	106.6	33	142	0.69	3
FUEL TANKERS							
Imperial	7000	329.2	93.6	33	132	0.62	3
	8000	400.3	88.8	33	137	0.69	3
	9500	415.9	109.6	30	122	0.55	3
	11000		111.2	36	130	0.55	3
	12500	600.5	118.0	30	122	0.62	3
Petrofina	12000	542.9	82.4	36	122	0.59	2
Shell	4500	249.1	100.0	38	-	0.62	4
	7100	378.1	111.2	41	-	0.62	4
	11600	511.6	73.6	36	119	0.48	2
	15000	582.7	133.2	33	127	0.69	4
Standard	3500						
	14000		77.8	28	-	0.55	3
		640.5	146.8	36	132	0.62	4
OTHERS							
Planemate		361.6	90.4	-	-	0.48	4
Pass Car		Var.	Var.	-	-	Var.	1
Transport Truck		(axle group)					
Front axle		53.4	26.7	-	-	0.70	3
Single axle		97.6	48.8	32	-	0.70	3
Tandem axle		177.6	88.8	30	180	0.70	3
Triple axle		266.4	133.2	30	244+488	0.70	3
TOW TRACTORS							
Lectra Haul	T150						
International	T180F	747.3	186.8	-	-	1.03	4
	T225SL						
	T300SL	114.8	28.7	-	-	0.52	
	T300SL	142.3	35.6	-	-	0.52	
	T500S	218.0	54.5	-	-	0.76	
	T800S	177.9	44.5	-	-	0.62	
	T800S	489.3	122.3	-	-	0.72	4
		689.5	172.4	-	-	0.97	4
		520.4	130.1	-	-	0.72	4

TABLE 2.4 - TYPICAL SUBGRADE BEARING STRENGTHS

Subgrade Soil Type	Usual Spring Reduction % *	Subgrade Bearing Strength (kN)		
		Fall Range	Design Value	
			Fall	Spring
GW - well-graded gravel	0	290-400	290	290
GP - poorly graded gravel	10	180-335	220	200
GM - gravel with silty fines	25	135-335	180	135
GC - gravel with clay fines	25	110-245	145	110
SW - well-graded sand	10	135-335	180	160
SP - poorly graded sand	20	110-200	135	110
SM - sand with silty fines	45	95-190	120	65
SC - sand with clay fines	25	65-155	85	65
ML - silt with low liquid limit	50	90-180	110	55
CL - clay with low liquid limit	25	65-135	85	65
MH - silt with high liquid limit	50	25-90	40	20
CH - clay with high liquid limit	45	25-90	55	30

*** Note:** When the water table is within 1 m of the pavement surface, the % spring reduction factor should be increased by 10% for each soil type except GW and GP.

TABLE 2.5 - EXAMPLE FREEZING INDEX CALCULATION

Region:				Site:		
Month	**November/78**	**December/78**	**January/79**	**February/79**	**March/79**	**April/79**

Day	**Daily Temp**	**Index Count**	**Daily Temp**	**Index Count**	**Daily Temp**	**Index Count**	**Daily Temp**	**Index Count**	**Daily Temp**	**Index Count**	**Daily Temp**	**Index Count**
1	+5	0	-8	58	-7	285	-19	600	-8	928	-8	1131
2	+4	0	-10	68	-4	289	-18	618	-7	935	-5	1136
3	+6	0	-6	74	-6	295	-18	636	-7	942	-1	1137
4	+6	0	-4	78	-8	303	-15	651	-9	951	-2	1139
5	+8	0	-3	81	-9	312	-15	666	-8	959	0	1139
6	+7	0	-4	85	-12	324	-15	681	-11	970	-1	1140
7	+8	0	-8	93	-8	332	-12	693	-12	982	-1	1141
8	+10	0	-10	103	-5	337	-15	708	-8	990	0	1141
9	+5	0	-12	115	-3	340	-11	719	-7	997	0	1141
10	+3	0	-12	127	-1	341	-10	729	-6	1009	+1	1140
11	0	0	-12	139	+2	339	-14	743	-6	1015	0	1140
12	-1	1	-11	150	+4	335	-13	756	-4	1019	+1	1139
13	+1	0	-8	158	+3	332	-12	768	-6	1025	-1	1140
14	+1	0	-4	162	+2	330	-14	782	-5	1030	+1	1139
15	-1	1	-2	164	+1	329	-11	793	-7	1037	+1	1138
16	-1	2	-4	168	-2	331	-9	802	-5	1042	+2	1136
17	-2	4	-6	174	-4	335	-12	814	-4	1046	0	1136
18	0	4	-6	180	-8	343	-13	827	-3	1049	+2	1134
19	+1	3	-5	185	-10	353	-10	837	-6	1055	+3	1131
20	0	3	-3	188	-14	367	-7	844	-8	1063	+1	1130
21	-1	4	-3	191	-18	385	-8	852	-7	1070	+2	1128
22	-3	7	-5	196	-22	407	-10	862	-6	1077	+3	1125
23	-3	10	-8	204	-19	426	-11	873	-5	1082	+2	1123
24	-6	16	-9	213	-18	444	-8	881	-4	1086		
25	-8	24	-9	222	-15	459	-9	890	-3	1089		
26	-4	28	-10	232	-15	474	-10	900	-8	1097		
27	-4	32	-8	240	-18	492	-9	909	-5	1102		
28	-5	37	-8	248	-20	512	-11	920	-3	1105		
29	-6	43	-9	257	-23	535			-3	1108		
30	-7	50	-10	267	-26	561			-7	1115		
31			-11	278	-20	581			-8	1123		

Freezing Index for 1978/79 Freezing Season - 1141°C - Days

FIGURE 2.1 - SPRING REDUCTION FACTOR

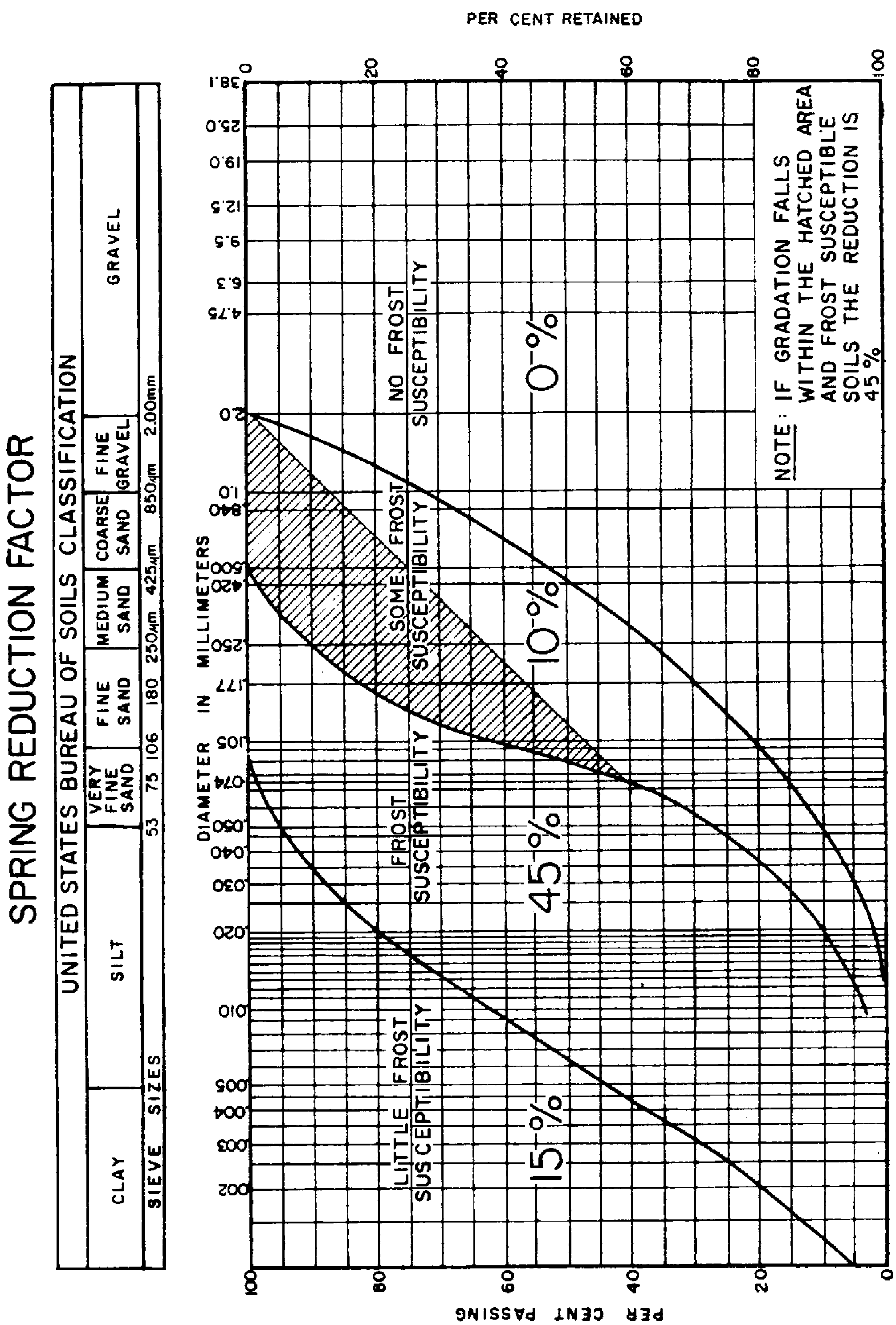


FIGURE 2.2 - FREEZING INDICES - CANADA

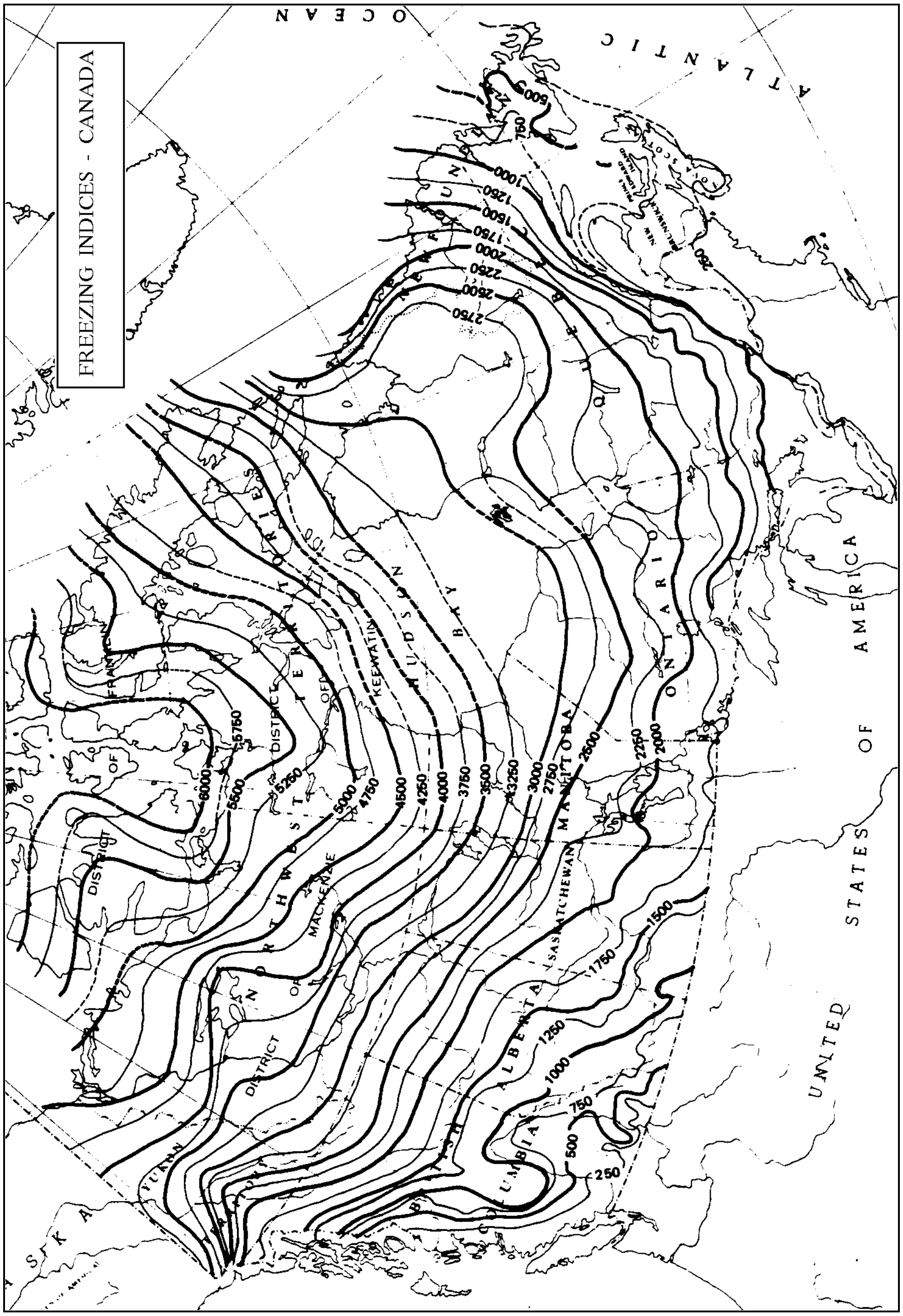


FIGURE 2.3 - THAWING INDICES - CANADA

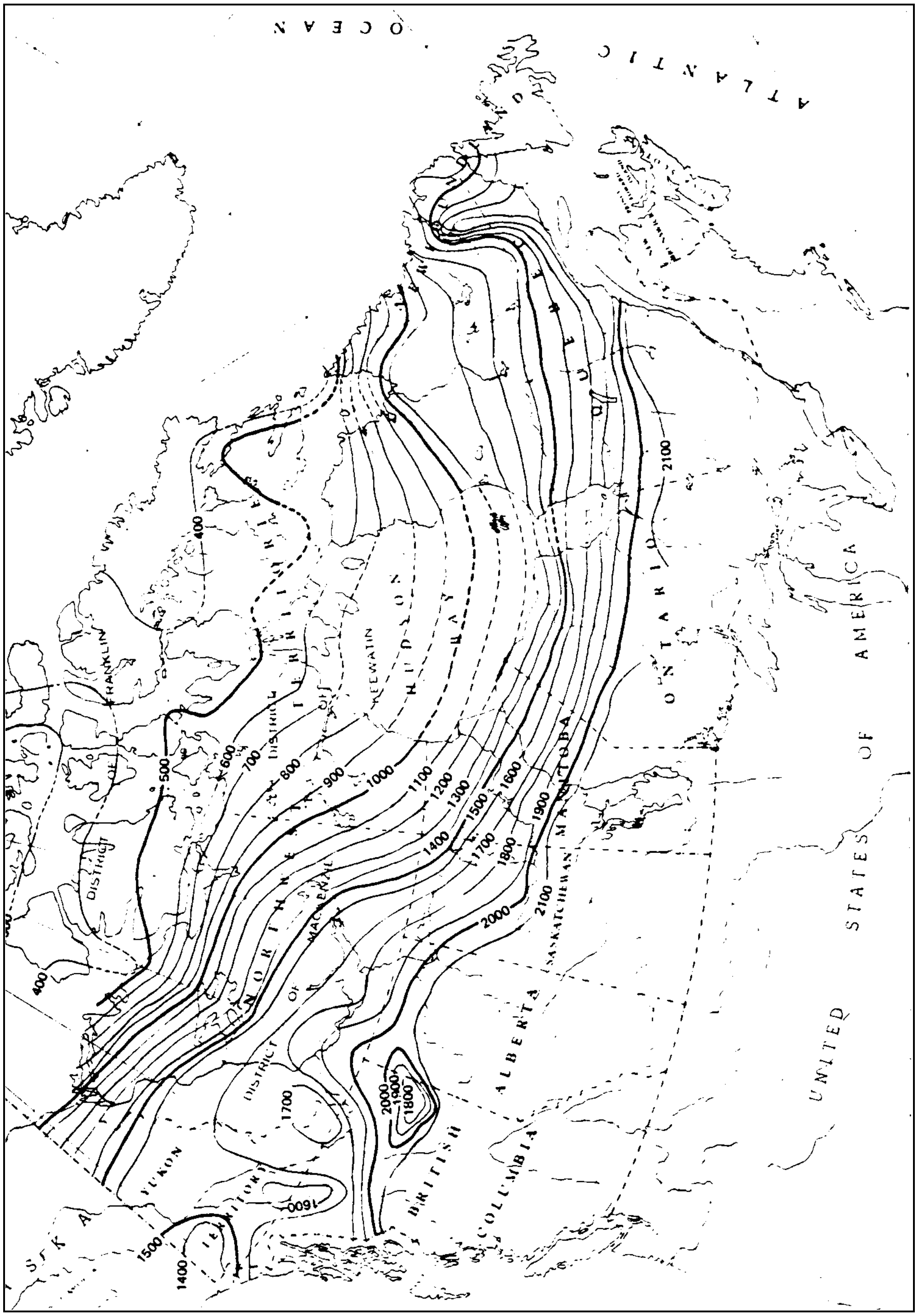


FIGURE 2.4
MAXIMUM FROST PENETRATION IN ASPHALT SURFACED PAVEMENTS

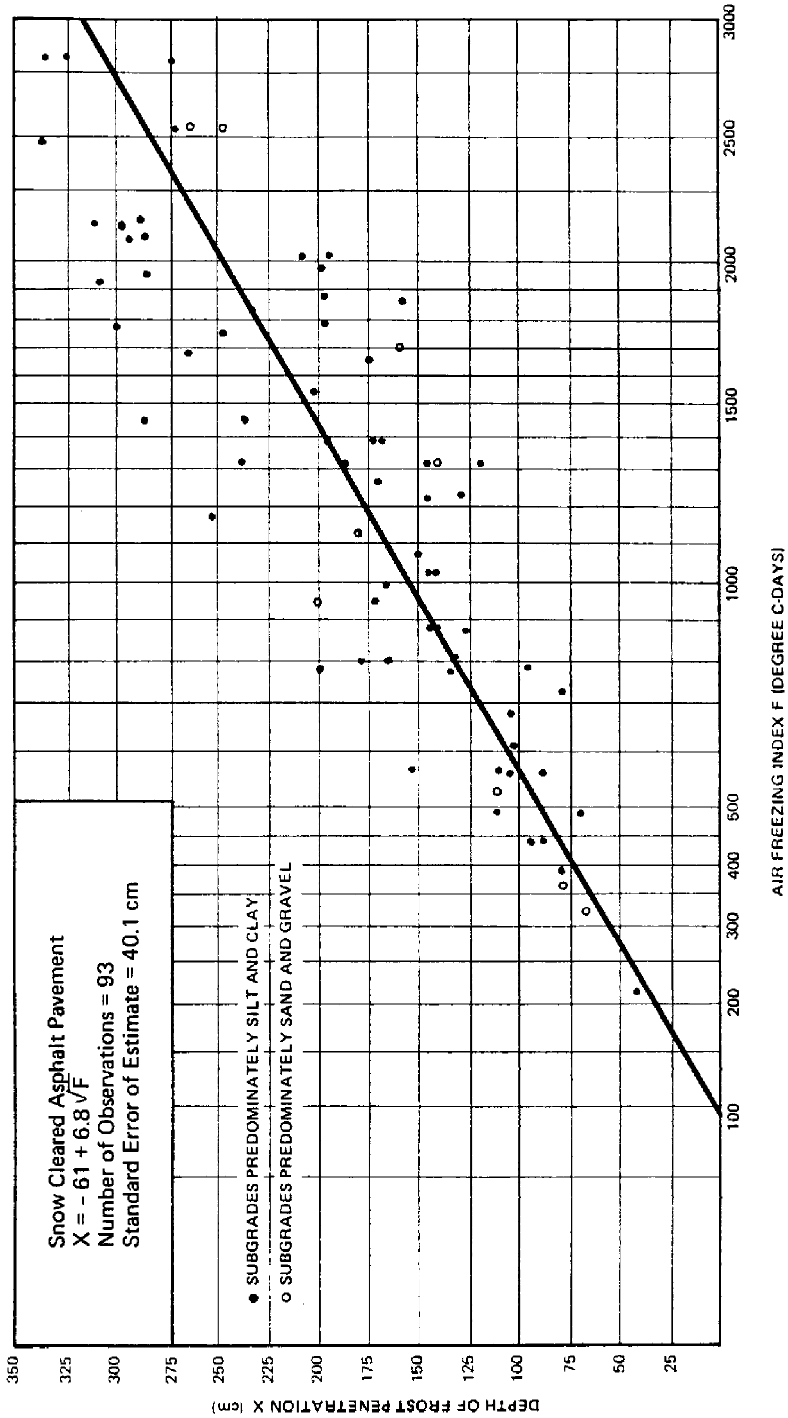


FIGURE 2.5
MAXIMUM FROST PENETRATION IN P.C.C. SURFACED PAVEMENTS

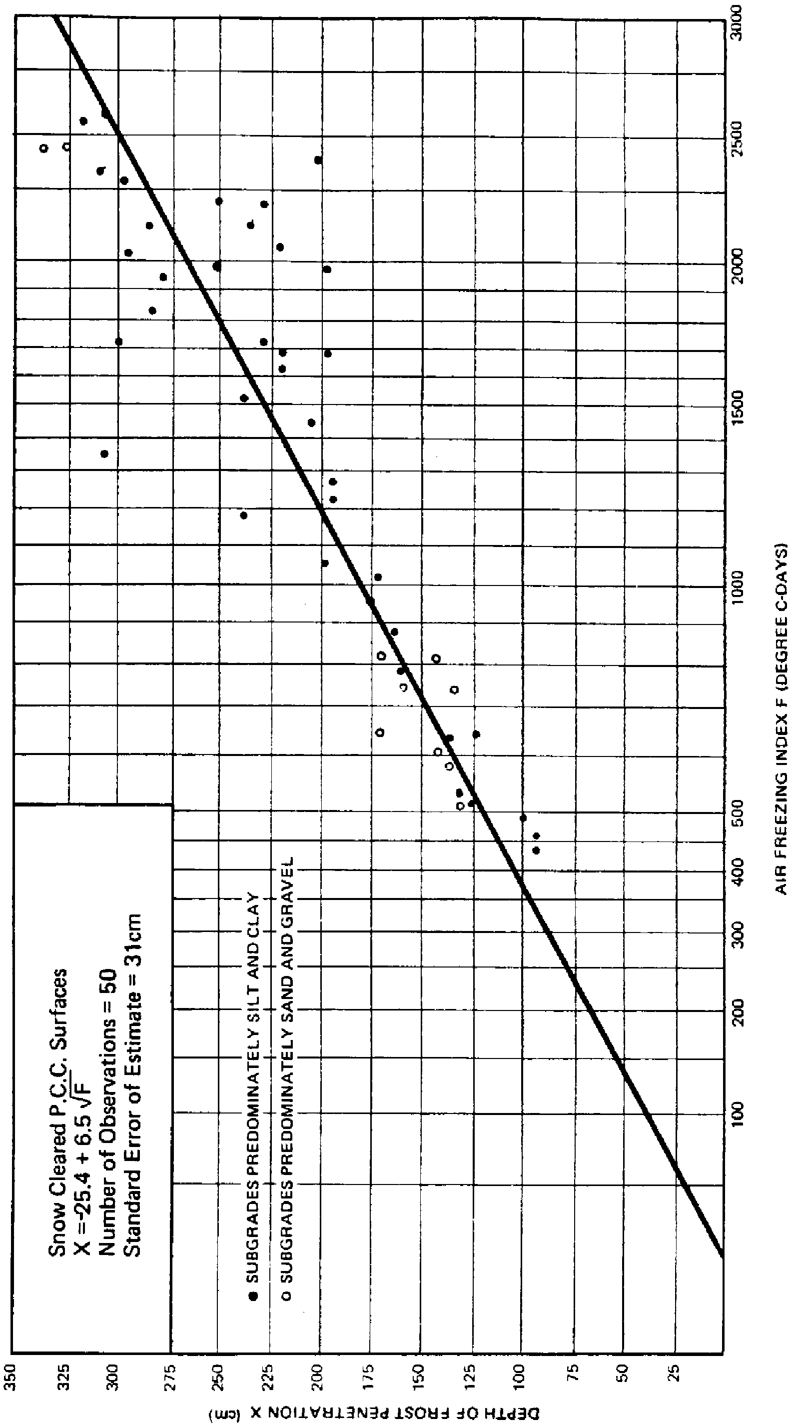


FIGURE 2.6
MAXIMUM FROST PENETRATION IN UNDISTURBED SNOW COVERED AREAS

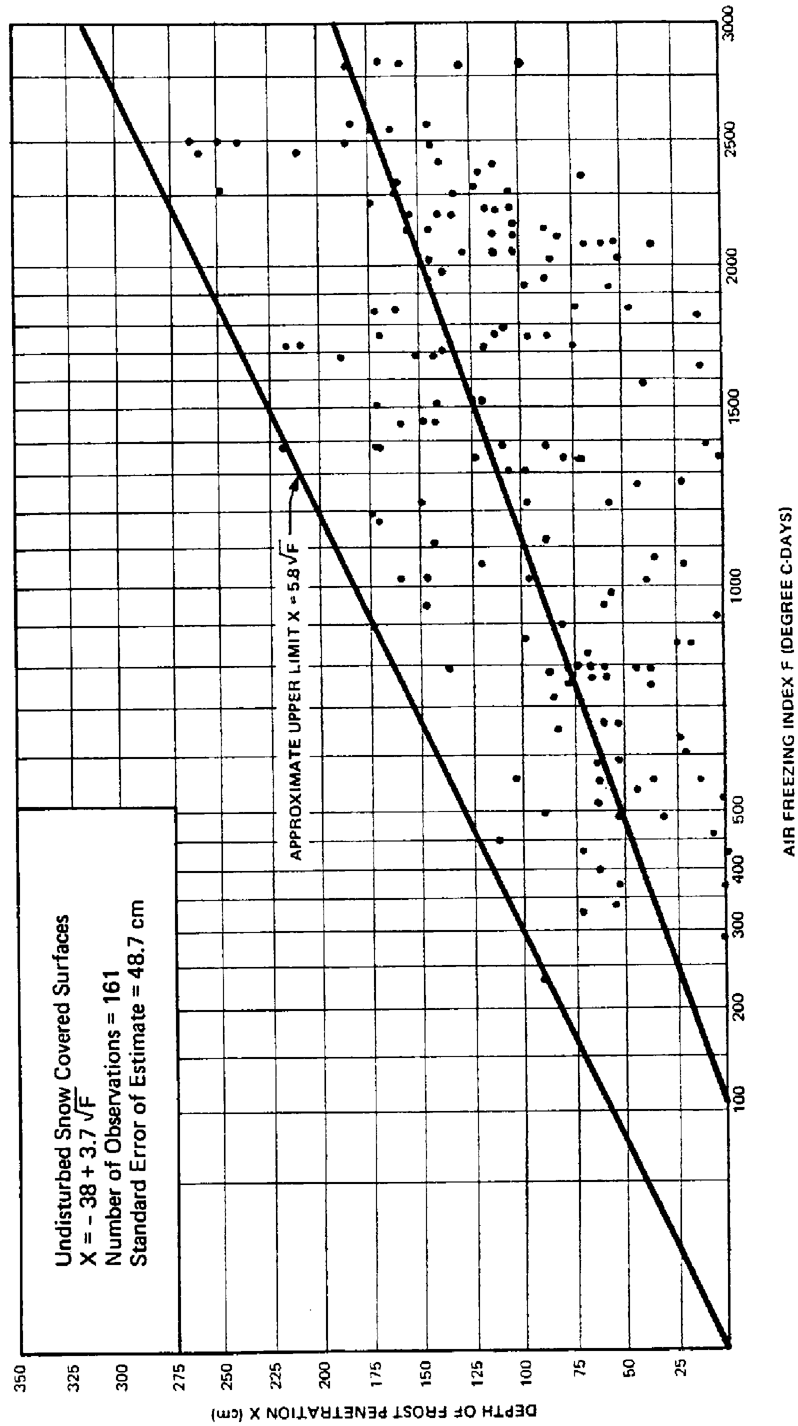


FIGURE 2.7
MAXIMUM THAW PENETRATION IN GRAVEL SURFACED RUNWAYS ON PERMAFROST

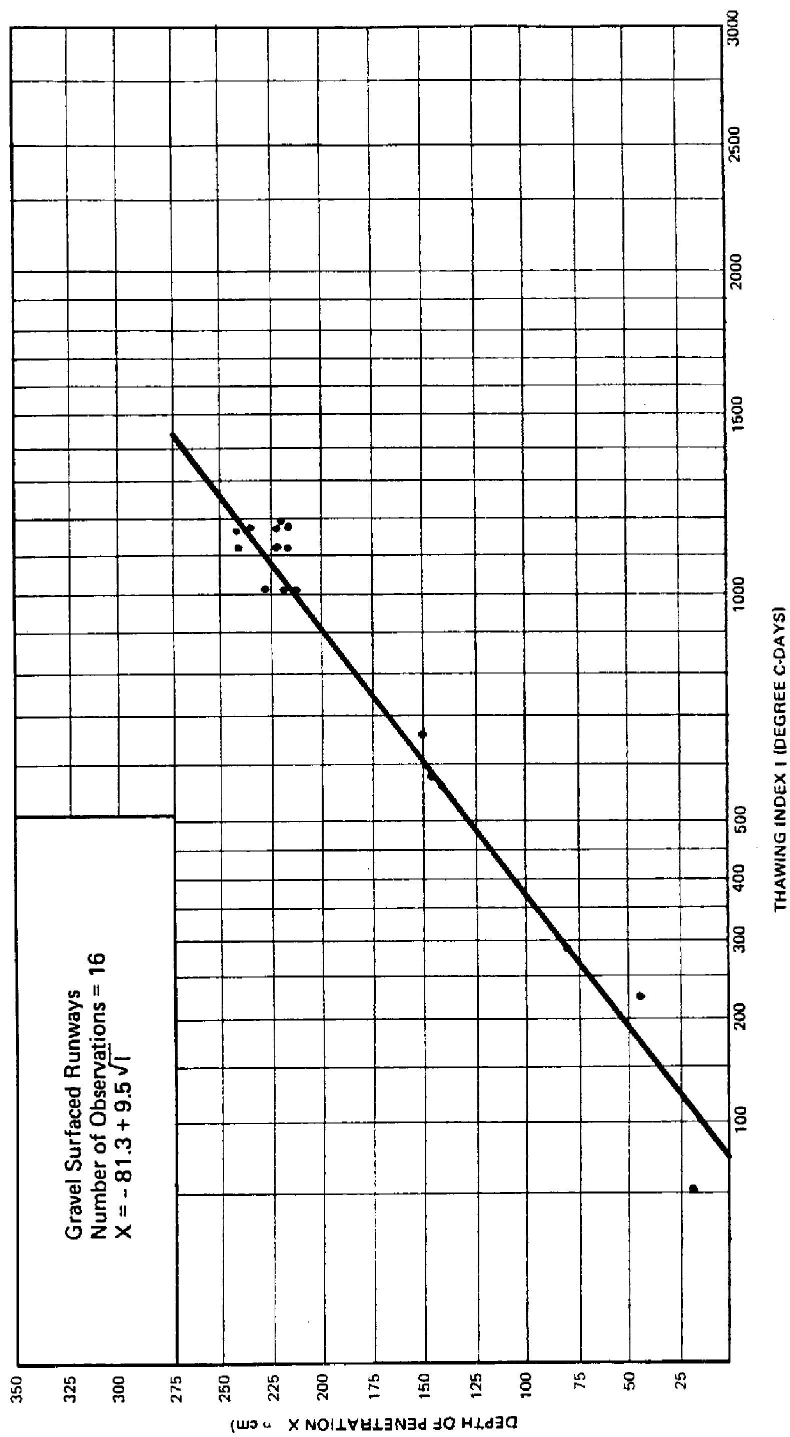


FIGURE 2.8
MAXIMUM THAW PENETRATION IN UNDISTURBED PERMAFROST AREAS

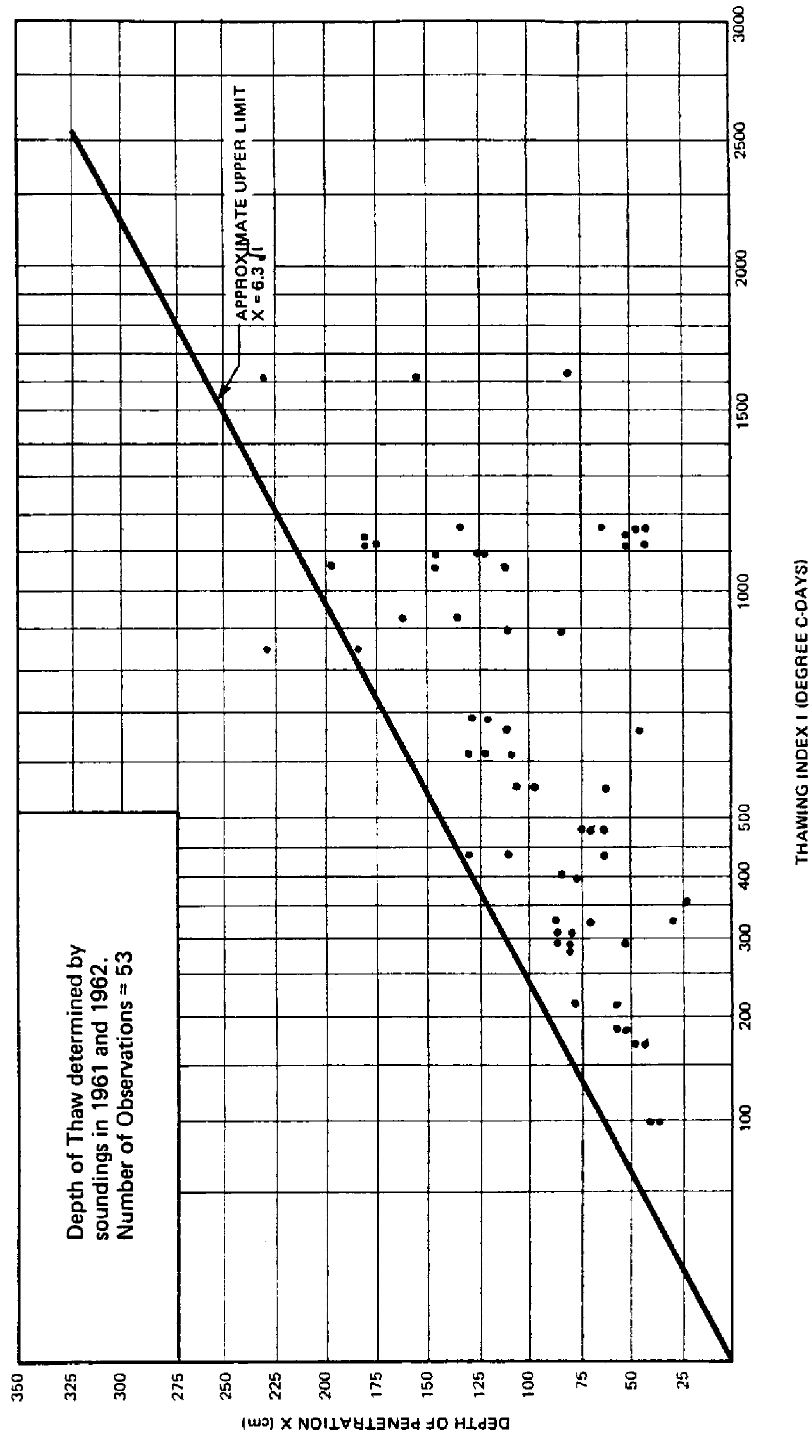
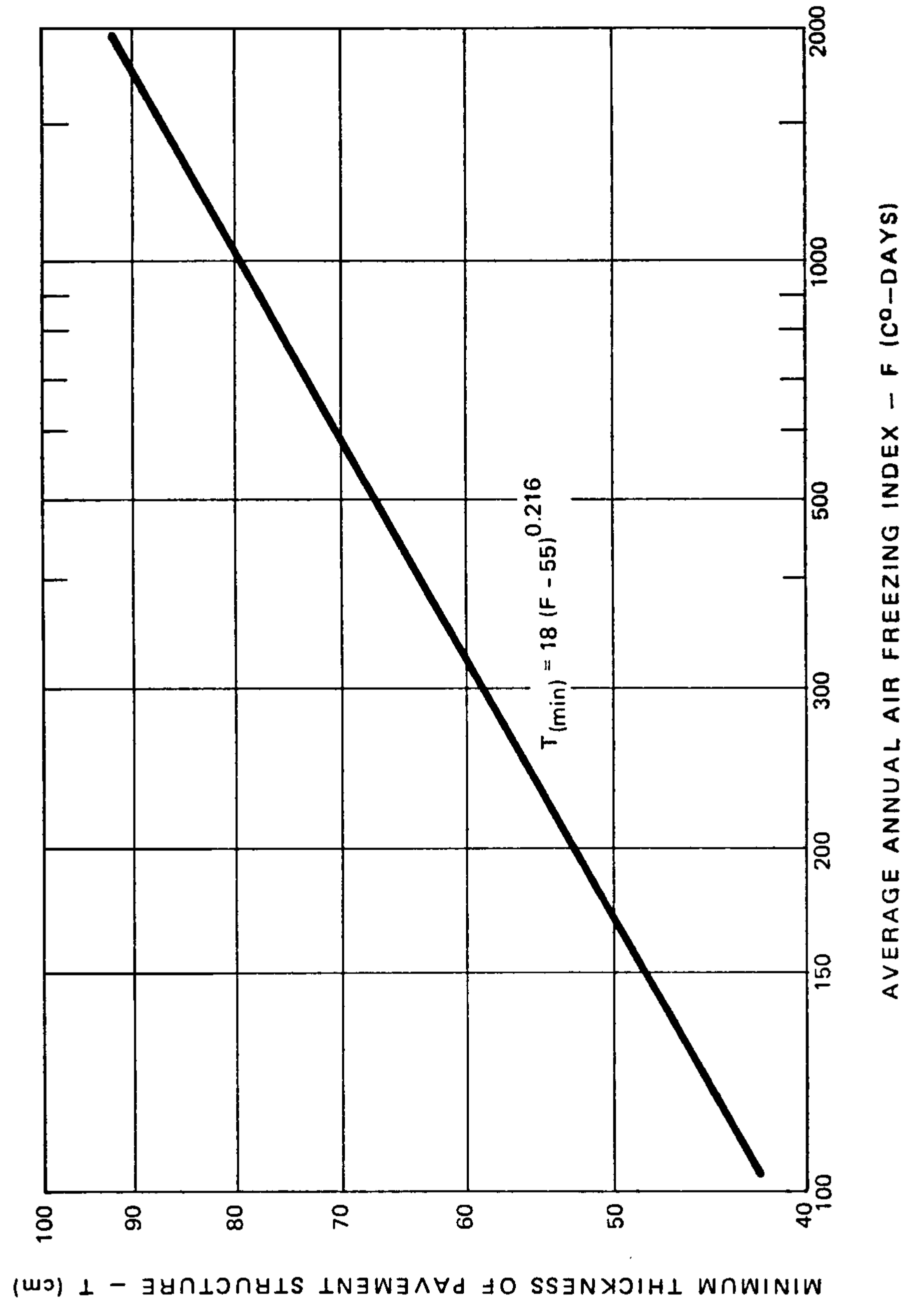


FIGURE 2.9
MINIMUM PAVEMENT THICKNESS FOR FROST PROTECTION



3.0 STRUCTURAL DESIGN THEORY

3.1 DESIGN APPROACHES

A flexible pavement supports traffic by distributing the traffic loads to the subgrade. The design approach for these structures is to provide a thickness of pavement which will limit loads transmitted to the subgrade to acceptable levels.

A rigid pavement utilizes the flexural strength of a Portland cement concrete slab for the support of traffic loads. Structural design is based on providing a thickness of slab sufficient to limit flexural stresses to below failure limits.

This Chapter outlines methods of determining flexible and rigid pavement thicknesses to meet these objectives. Thickness requirements for the separate pavement layers are detailed in Chapter 4.

3.2 FLEXIBLE PAVEMENTS

3.2.1 PLATE LOAD TESTING

Plate load testing consists of applying a load to a pavement through a rigid circular plate and measuring the deflection produced by this load. Starting in 1945 and extending over several years, a major testing program was carried out at Canadian airports utilizing this test procedure. Current structural design procedures for flexible pavements are based on plate load relationships derived from this program.

3.2.2 PLATE LOAD RELATIONSHIP ON SUBGRADE SURFACES

The plate load supported on a pavement subgrade depends on the following three measurement parameters:

- the deflection at which the load is measured;

- the size of the measuring plate;

3.2.2 PLATE LOAD RELATIONSHIP ON SUBGRADE SURFACES (CONT'D)

- the number of load applications.

Whenever a plate bearing value (kN) is quoted, values must also be given for the three test parameters associated with its measurement.

Figure 3.1 gives the average relationship between loads measured on a subgrade surface using test plates of different sizes, and at different deflections. If a subgrade plate bearing value is available measured with a particular plate size and at a given deflection, Figure 3.1 may be used to estimate the plate bearing value which would be measured if the measurement is made using a different plate size, or at a different deflection. An example of this conversion process is shown with Figure 3.1.

Plate bearing values also vary with the number of load applications, and test results show that the accumulated deflection under a given load increases linearly with the log of the number of load applications. Conversely, for a given deflection, the plate bearing value will decrease with the number of load applications, and Figure 3.2 gives an average relationship between these two variables.

3.2.3 PAVEMENT SURFACE VS SUBGRADE LOAD

If a pavement of granular base material is placed over a subgrade, the following equation relates plate bearing values measured at the surface of the pavement and at the surface of the subgrade:

$$P = S \cdot 10^{t/K} \qquad \textbf{(Eq 3.1)}$$

where P = plate bearing value measured on the pavement surface (kN)
S = plate bearing value measured on the subgrade surface (kN)
t = thickness of the granular pavement (cm)
K = a variable dependent on the size of bearing plate being used, as given in Figure 3.3.

3.2.3 PAVEMENT SURFACE VS SUBGRADE LOAD (CONT'D)

Eq. (3.1) is valid only when P and S are measured using the same size of bearing plate, at the same deflection and at the same number of load applications.

The derivation of Eq. (3.1) is outlined in Appendix *B. As* a mathematical model relating the two plate bearing values, P and S, Eq. (3.1) contains inaccuracies when a pavement is very thick or when subgrade bearing strength is very high. However, the equation is sufficiently accurate for use under normal ranges of pavement thickness and subgrade bearing strength.

It should be noted that Eq. (3.1) applies only for a pavement constructed of granular materials. If layers of other materials are present in the pavement structure, such as an asphalt surfacing course, the pavement thickness must be converted to an equivalent granular thickness.

3.2.4 EQUIVALENT GRANULAR THICKNESS

"Equivalent granular thickness" is a term frequently encountered in the design and evaluation of pavement structures. It is the common basis of comparison for flexible pavements with variable thicknesses of materials having different load distribution characteristics.

Table 3.1 lists granular equivalency factors for various pavement construction materials. The granular equivalency factor of a material is the depth of granular material in centimetres considered equivalent to one centimetre of the material on the basis of load distribution considerations. The values listed in Table 3.1 are generally conservative and actual granular equivalencies are normally higher than the values listed.

To determine pavement equivalent granular thickness, the depth of each layer in the pavement is multiplied by the granular equivalency factor for the material in the layer. The sum of these converted layer thicknesses, is the pavement equivalent granular thickness.

3.2.5 EQUIVALENT SINGLE WHEEL LOAD

Design procedures for flexible pavements require that multiple-wheel loadings be converted to an equivalent single wheel load (ESWL). For flexible pavements, equivalent single wheel load is defined as the single wheel load which produces

3.2.5 EQUIVALENT SINGLE WHEEL LOAD (CONT'D)

a maximum normal stress at the subgrade surface equal to that produced by the multiple-wheel loading. The contact pressure of the ESWL is equal to the contact pressure of the wheel configuration it replaces. In practice, the ESWL is not determined strictly in accordance with the above definition but is estimated through the simplified and approximate procedure outlined below.

An equivalent single wheel load chart for a multiple wheel gear loading is illustrated in Figure 3.5. The ESWL is a function of pavement thickness. For a pavement thickness less than a certain value t_1, the ESWL is equal to the load on one wheel of the gear. For a pavement thickness above a value t_2, the ESWL is equal to the total gear load. For a pavement thickness between t_l and t_2, the log of the ESWL is assumed to vary linearly with the log of pavement thickness.

The thicknesses t_1 and t_2 are defined as follows:

t_1= half of the minimum clear distance between any two tire imprints in the gear configuration;

t_2= twice the centre-to-centre distance between the outermost wheel and the wheel closest to the geometric centre of the gear configuration.

The minimum clear distances and the centre-to-centre wheel distances used in calculating t1 and t2 are illustrated in Figure 3.6 for various gear configurations. In drawing a gear configuration, the imprint of a single tire is assumed to be a rectangle with semi-circular ends as shown in Figure 3.6(a). The following equations govern the dimensions of this imprint area:

$$A = 10\frac{P}{Q} \qquad (3.2)$$

$$L = 1.383\sqrt{A} \qquad (3.3)$$

$$W = 0.6L \qquad (3.4)$$

3.2.5 EQUIVALENT SINGLE WHEEL LOAD (CONT'D)

where A = contact area of the tire (cm^2)
P = tire load (kN)
Q = tire pressure (MPa)
L = length of tire imprint (cm)
W = width of tire imprint (cm).

3.2.6 THE DESIGN EQUATION

Equation (3.1), derived from plate load test results, is used as the base equation for determining the equivalent granular thickness of flexible pavement required to structurally support a wheel loading. A direct approach is to assume various pavement thicknesses and calculate the subgrade bearing strength required to support the wheel loading for each of the pavement thicknesses. The t vs. S relationship thus generated may then be used to determine the pavement thickness required for any design value of subgrade bearing strength.

The equation used for the structural design and evaluation of flexible pavements is:

$$S = \frac{1}{R} \cdot F \cdot (ESWL) \cdot 10^{-\frac{t}{K}} \qquad \textbf{(3.5)}$$

where ESWL= equivalent single wheel load of the design vehicle, determined in accordance with Section 3.2.5 (kN)

t = equivalent granular thickness of the pavement structure (cm)

K = a factor dependent on the contact area of the ESWL, as given in Figure 3.3 (cm)

F = a factor dependent on the contact area of the ESWL, as given in Figure 3.4

R = overload ratio as discussed in Section 2.2.3

3.2.6 THE DESIGN EQUATION (CONT'D)

S = subgrade bearing strength (kN) (750 mm plate, 12.5 mm deflection, 10 rep. of loading) required to support the ESWL for pavement thickness t.

Equation (3.5) is easily derived from equation (3.1) by substituting ESWL for P, and adding the factors F and R.

The factor F is included in equation (3.5) to convert the calculated subgrade bearing value from a contact area equal to that of the ESWL, to the contact area of a 750 mm diameter plate, which is the standard plate size for measuring subgrade bearing strength. The function relating F to the ESWL contact area, as given in figure 3.4, is derived from the plate load relationships given in Figure 3.1.

The overload ratio, R, is required when using equation (3.5) for evaluation purposes. In the design situation, R =1.00.

3.2.7 DESIGN FOR AIRCRAFT LOADING

A flexible pavement design-evaluation chart for an aircraft gear loading is illustrated in Figure 3.7. This chart is generated using equation (3.5) as follows:

(i) assume a value of pavement equivalent granular thickness, t.

(ii) calculate the ESWL (kN) of the design aircraft gear loading as outlined in Section 3.2.5.

(iii) compute A = 10 (ESWL)/Q
where A = contact area of ESWL (cm^2)
Q = tire pressure of design aircraft (MPa)

(iv) for this contact area, A, obtain values of K and F from Figures 3.3 and 3.4 respectively.

(v) with these values of ESWL, K and F, use equation (3.5) to compute the subgrade bearing strength required for overload ratios of R = 1.00,1.25, 1.50 and 2.00.

(vi) assume other values of t and repeat steps (ii) to (v) to compute

3.2.7 DESIGN FOR AIRCRAFT LOADING (CONT'D)

corresponding S values.

(vii) plot t vs. S curves for R values of 1.00,1.25, 1.50 and 2.00, as shown in Figure 3.7.

A computer program for these computations is given in Appendix D.

In the design situation, pavement structural thickness requirements are determined from a chart similar to that illustrated in Figure 3.7 using the design value of subgrade bearing strength and the overload ratio R = 1.00 curve. In an evaluation situation, an operation by the aircraft gear loading on a given pavement is evaluated by plotting the point having the pavement t and S values as co-ordinates. The location of this point on the chart with respect to the overload curves indicates whether the operation falls into the unrestricted, limited, marginal or emergency use only category.

3.2.8 DESIGN FOR GROUND VEHICLES

For roads and carparks, subgrade bearing strength was originally defined in terms of the load supported on a 305 mm diameter plate, 5 mm deflection, 10 repetitions of loading. However, mathematically, it can be shown that this measure is equivalent to using design equation (3.5), together with a value of R = 0.625.

Consequently, roads and carparks may be designed using the procedures outlined above, the applicable ground vehicle design loading and a value of R = 0.625. This value of overload ratio R, produces a higher thickness design requirement for road and carpark pavement than for aircraft pavements. In pavement fatigue terms, this higher design requirement reflects the greater number of load repetitions expected on roads, as compared to aircraft pavements. In some situations, where it is known that a road will be subject to infrequent traffic, the pavement may be designed using a value of R = 1.00, corresponding to aircraft pavement design requirements

3.3 RIGID PAVEMENTS

3.3.1 STRESS ANALYSIS OF CONCRETE SLABS

The stress analysis of a concrete pavement slab is based on the theory of thin plates. The following assumptions are made relative to the pavement slab and loading conditions:

(i) the slab consists of a homogeneous, isotropic and elastic material.

(ii) the slab is of uniform thickness, and the range of relative thickness is such that the ordinary theory of thin plates may be applied.

(iii) the load is applied normal to the face of the slab, and is remote from an edge.

(iv) the reaction of the base beneath the slab occurs normal to the slab, and is directly proportional to the slab deflection.

With these assumptions, and for a concentrated load, the following differential equation applies for all of the slab except the point of application of the concentrated load.

$$D\sigma^2\omega + k\omega = 0 \qquad \textbf{(3.6)}$$

Where D is the flexural rigidity of the slab, σ^2 is the Laplace differential operator, ω is the slab deflection and k is the proportionality constant between slab deflection and base reaction. Appendix C provides a more detailed description of the notation involved in Eq. (3.6), and outlines the solution of this differential equation for various loading conditions.

To apply the equations resulting from the solution of Eq. (3.6), values must first be determined for a number of variables. The following values are assumed for the elastic properties of the concrete:

elastic modulus	E = 27,580 MPa
Poissons ratio	μ = 0.15

3.3.1 STRESS ANALYSIS OF CONCRETE SLABS (CONT'D)

The determination of the bearing modulus *k*, and allowable flexural stresses are discussed below.

3.3.2 BEARING MODULUS

In Eq. (3.6), the variable *k* is the proportionality constant between slab deflection and reaction pressure generated on the bottom of the slab by the base course. This variable is called the bearing modulus.

The bearing modulus, *k*, is measured using a 750 mm diameter plate and a single application of load. The bearing plate is loaded to produce a deflection of 1.25 mm, and the plate pressure in kPa is then divided by the deflection, 1.25 mm, to calculate bearing modulus in units of MPa/m.

In practice, bearing modulus is normally not measured directly but is estimated from a design value of subgrade bearing strength, and the thickness of base and sub-base placed between the subgrade and the concrete slab. The equation used for this purpose is:

$$k = 0.474 \times S \times 10^{\frac{t}{165}} \qquad \textbf{(3.10)}$$

where *k* = bearing modulus (MPa/m)
S = subgrade bearing strength (kN)
t = equivalent granular thickness of base and sub-base (cm)

This equation is plotted in Figure 3.8.

Equation (3.10) may be derived from the plate load test relationships given in Sections 3.2.2 and 3.2.3. The selection of a design value for subgrade bearing strength is discussed in Section 2.3.2.

For the design of new concrete pavement structures, the maximum value of bearing modulus is limited to 135 MPa/m. This limitation is placed because very high values of bearing modulus cannot always be relied upon due to such occurrences as differential subgrade settlement, frost heaving, and slab curling caused by thermal effects.

3.3.3 FLEXURAL STRENGTH AND ALLOWABLE STRESSES

Considerations with respect to concrete flexural strength and allowable stresses are an important element in the design and evaluation of concrete pavements. Concrete flexural strength is a function of age as indicated in Figure 3.9. For construction purposes, the strength of a concrete mix is normally specified in terms of a 28 day curing period but as it ages, the concrete will continue to slowly gain strength at a decreasing rate.

Construction specifications and field quality control should ensure an average 28 day flexural strength not less than 4.0 MPa. With good quality aggregates and proper mix design, 28 day flexural strengths in the order of 4.5 to 5.0 MPa are not uncommon. After a few years of curing, the flexural strength of the concrete will usually be unknown, but values of 6.0 to 6.5 MPa are possible.

The selection of allowable stresses is influenced by fatigue considerations. Failure occurs with one application of load producing a stress equal to the flexural strength. Under repeated load applications, however, failure stress decreases linearly with the log of the number of load applications. For a very large, or unrestricted, number of load applications, the allowable stress should be kept below one-half of the flexural strength.

Based on these considerations, the following allowable stresses are normally used in the design and evaluation of concrete pavements.

Criteria for:	Overload Ratio	Allowable Flexural Stress (MPa)
Design	1.00	2.75
Unrestricted Operations	< 1. 25	3.5
Limited Operations	1. 25 - 1. 50	3.5 - 4.1
Marginal Operations	1.50 - 2.00	4.1 - 5.5
Emergency Use Only	> 2.00	5.5

3.3.4 DESIGN FOR AIRCRAFT LOADING

Stress analysis of a concrete slab, based on the equations given in Appendix C is usually performed by computer. A computer program for this purpose is given in Appendix E.

3.3.4 DESIGN FOR AIRCRAFT LOADING (CONT'D)

The output of the computer program given in Appendix E may be used to prepare a design-evaluation chart for a particular aircraft gear loading, as shown in Figure 3.10 where slab thickness is given as a function of bearing modulus for four stress levels: 2.75, 3.5, 4.1 and 5.5 MPa. In the design situation, slab thickness requirements may be determined from the 2.75 MPa stress curve after obtaining a design value for bearing modulus in accordance with Section 3.3.2. In an evaluation situation, an operation by the aircraft gear loading on a given pavement is evaluated by plotting the point having the pavement h and k values. The location of this point on the chart relative to the overload curves indicates whether the operation falls into the unrestricted, limited, marginal or emergency use only category.

3.4 COMPOSITE DESIGN-EVALUATION CHARTS

Design-evaluation charts of the type shown in Figures 3.7 and 3.10 are limited to only one aircraft operating weight. A series of these individual weight charts must be prepared to provide design/evaluation capability over the entire range of an aircraft's operating weights. To reduce the number of charts required, such a series of individual weight charts can be consolidated into one composite design-evaluation chart of the type shown in Figure 3.11 for flexible pavements and Figure 3.12 for rigid pavements.

The composite design-evaluation chart is constructed by first arbitrarily drawing a diagonal reference line, running from bottom left to top right, between the upper and lower horizontal scales. This diagonal is assigned as the reference line for the aircraft at its maximum take-off weight. The information from the individual weight chart for maximum take-off weight is then transposed onto the composite chart to establish the position of the curves reflecting requirements for design, unrestricted, limited, marginal and emergency use only operations. When the position of these curves are established, information from the other individual weight charts may then be incorporated to determine the position of diagonal reference lines for other aircraft operating weights.

Composite design-evaluation charts for present day aircraft are published in AK-68-16 "Pavement Design-Evaluation Charts for Selected Aircraft".

TABLE 3.1 - GRANULAR EQUIVALENCY FACTORS

Pavement Material	Granular Equivalency Factor
Selected granular sub-base	1
Crushed gravel or stone base	1
Waterbound macadam base	1 ½
Bituminous stabilized base	1 ½
Cement stabilized base	2
Asphaltic concrete (good condition)	2
Asphaltic concrete (poor condition)	1 ½
Portland cement concrete (good condition)	3
Portland cement concrete (fair condition)	2 ½
Portland cement concrete (poor condition)	2

NOTE: The equivalent granular thickness of a layer is calculated by multiplying the layer thickness by the granular equivalency factor for the material in the layer.

Example

Given - pavement structure: 8 cm A.C. (good condition) + 25 cm base + 20 cm sub-base
Problem - to determine the equivalent granular thickness

Solution

Layer Component		Granular Equivalency Factor	Equivalent Granular Thickness
8 cm A.C.	x	2	16 cm
25 cm base	x	1	25 cm
20 cm sub-base	x	1	20 cm
			61 cm (total equivalent granular thickness)

FIGURE 3.1
PLATE LOAD RELATIONSHIP ON SUBGRADE SURFACES

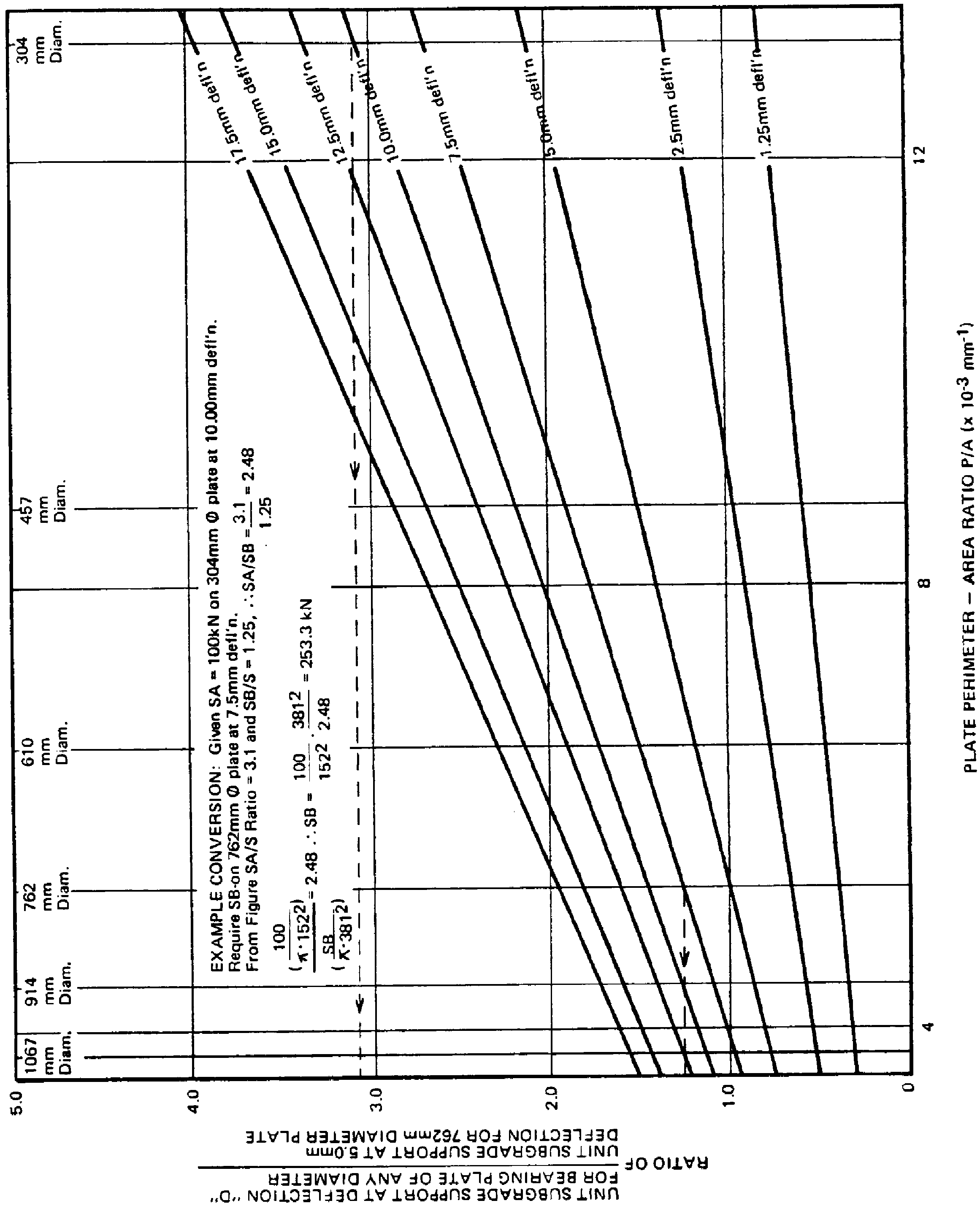


FIGURE 3.2
RATIOS OF LOADS SUPPORTED ON GIVEN BEARING PLATE AT DIFFERENT NUMBERS OF REPETITIONS

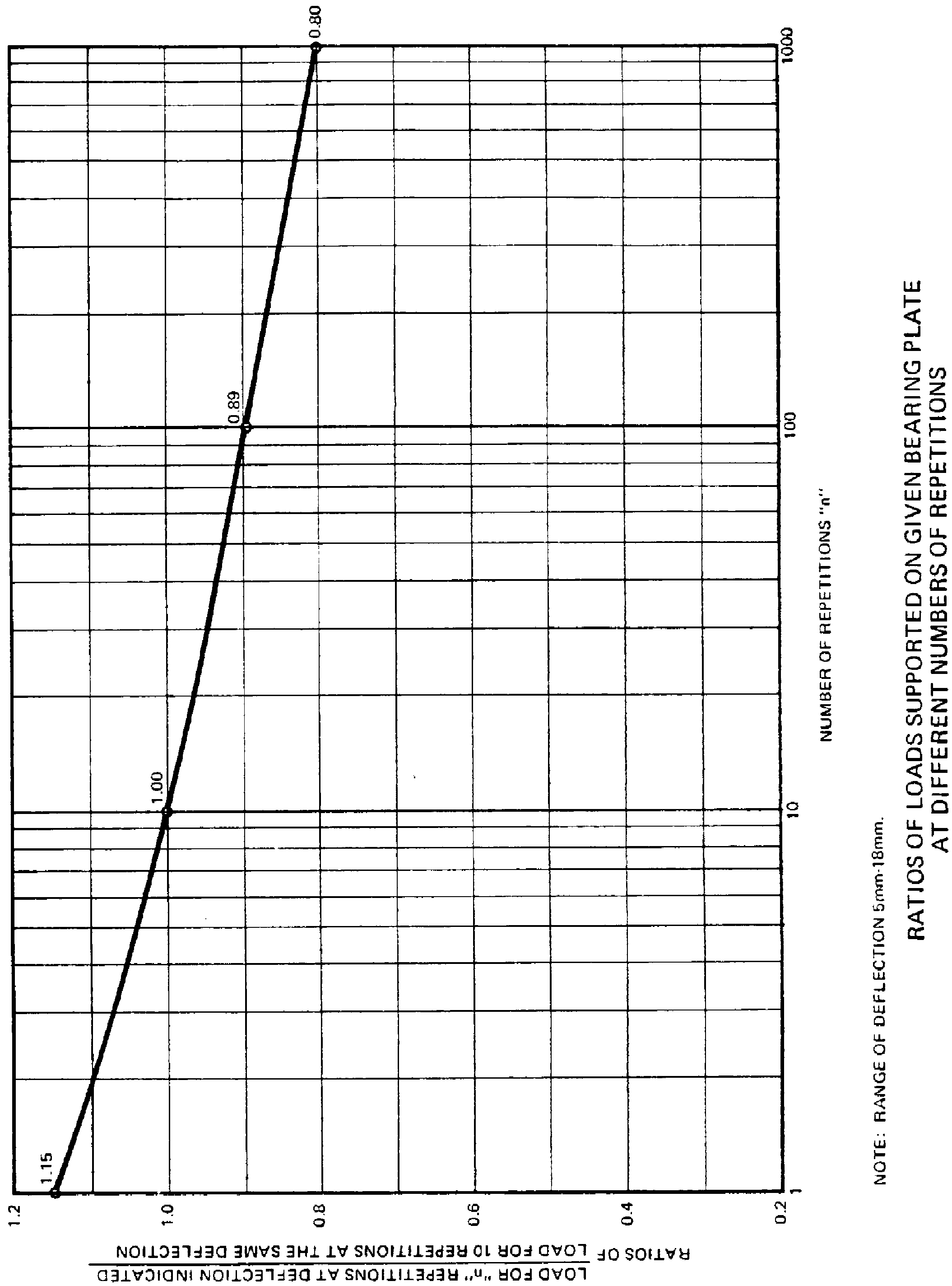


FIGURE 3.3
FLEXIBLE PAVEMENT DESIGN EQUATION - FACTOR K

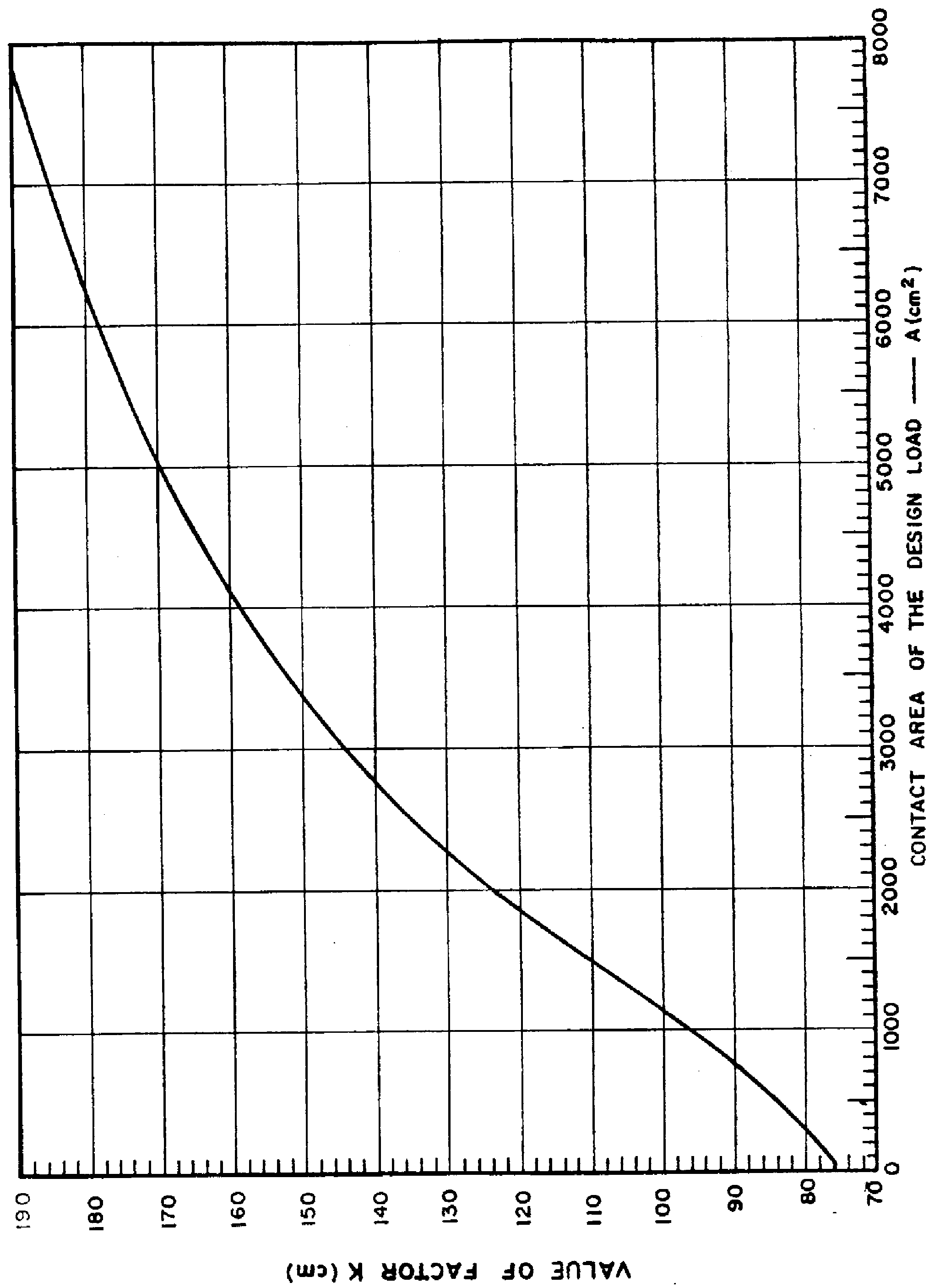


FIGURE 3.4
FLEXIBLE PAVEMENT DESIGN EQUATION - FACTOR F

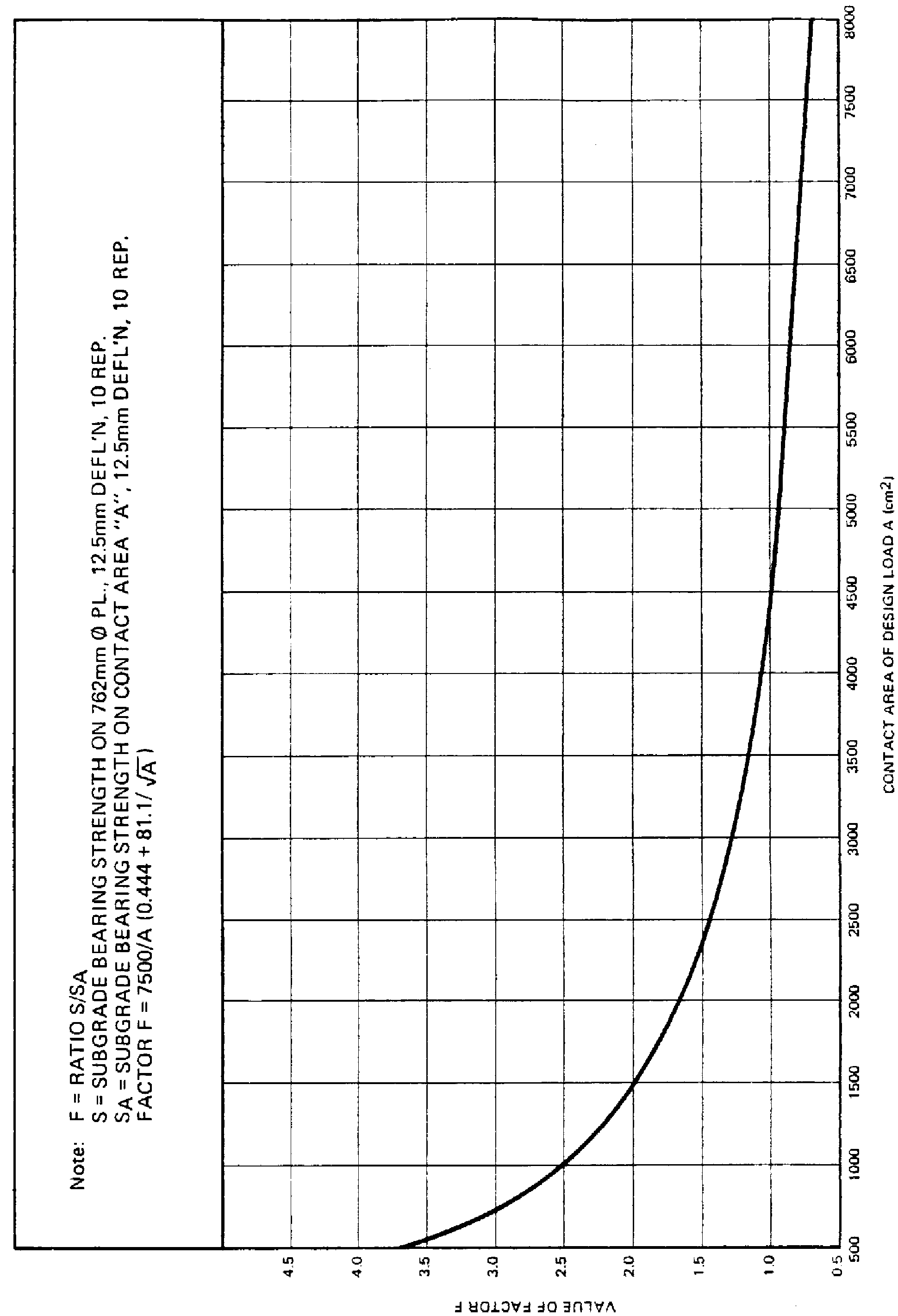


FIGURE 3.5
AIRCRAFT EQUIVALENT SINGLE WHEEL LOAD CHART

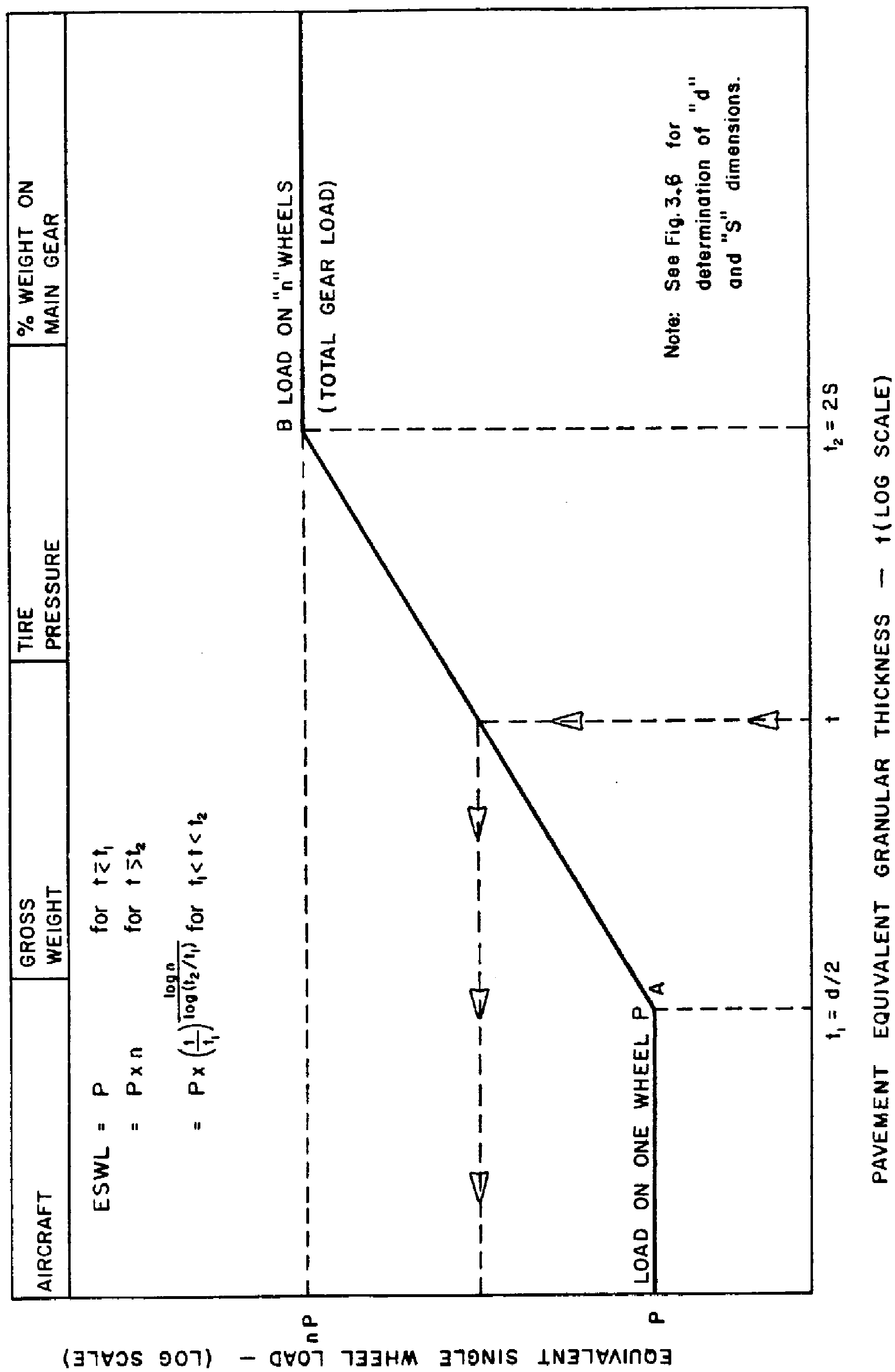


FIGURE 3.6
DIMENSIONS USED FOR DETERMINATION OF EQUIVALENT SINGLE WHEEL LOAD

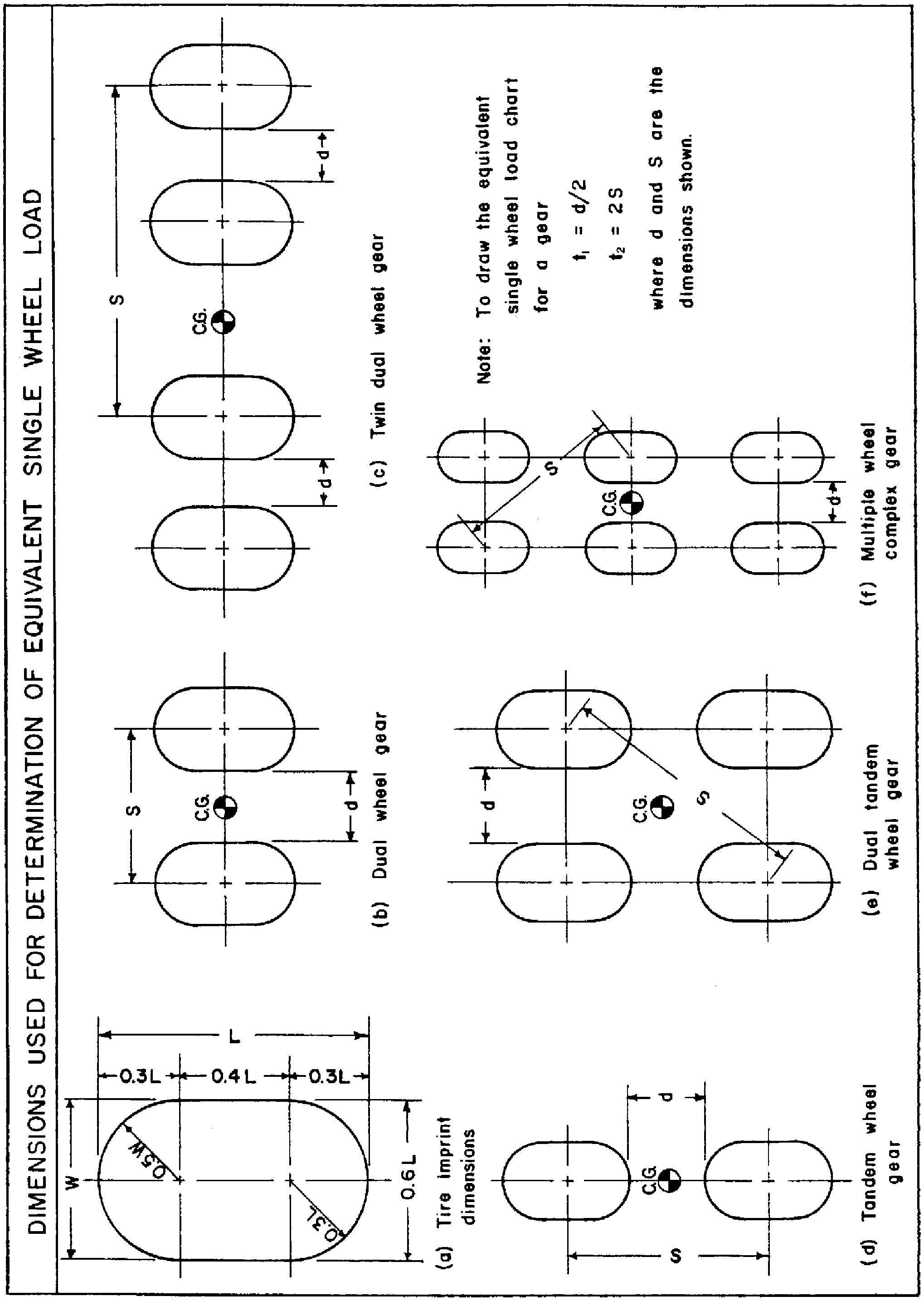


FIGURE 3.7
FLEXIBLE PAVEMENT DESIGN/EVALUATION CHART FOR GIVEN WEIGHT OF AIRCRAFT

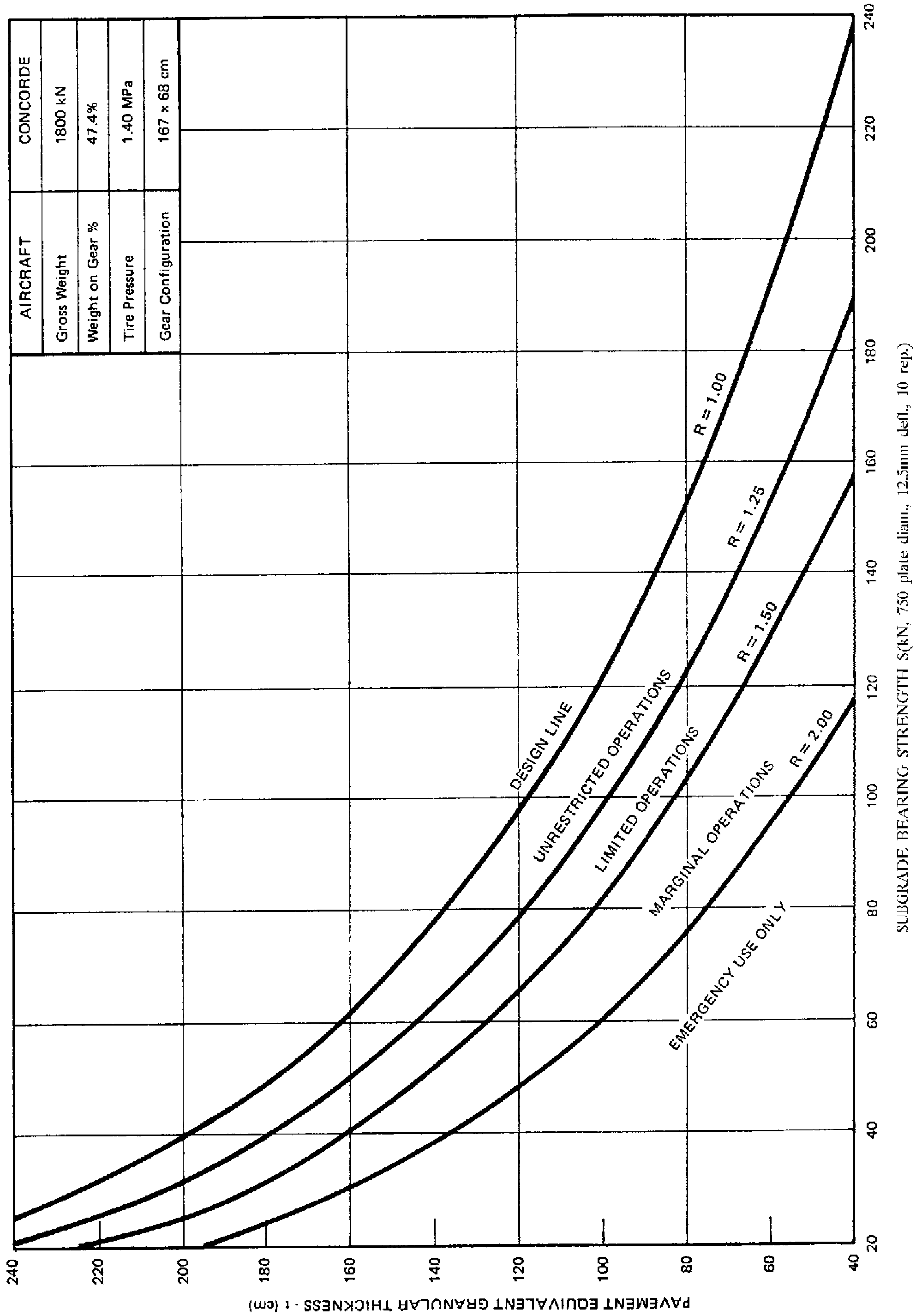


FIGURE 3.8 - BEARING MODULUS k AS A FUNCTION OF S AND t

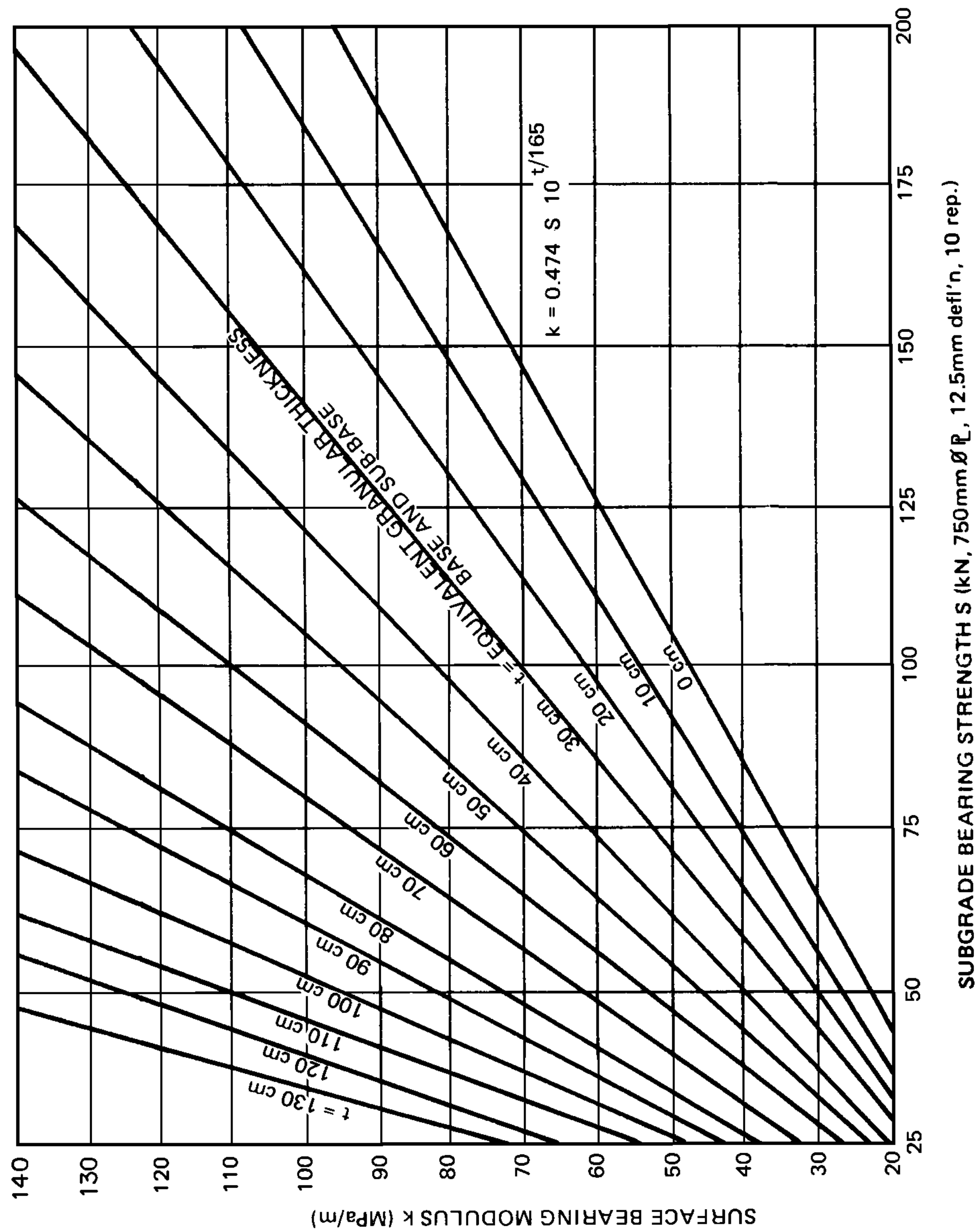


FIGURE 3.9 - VARIATION OF CONCRETE STRENGTH WITH AGE

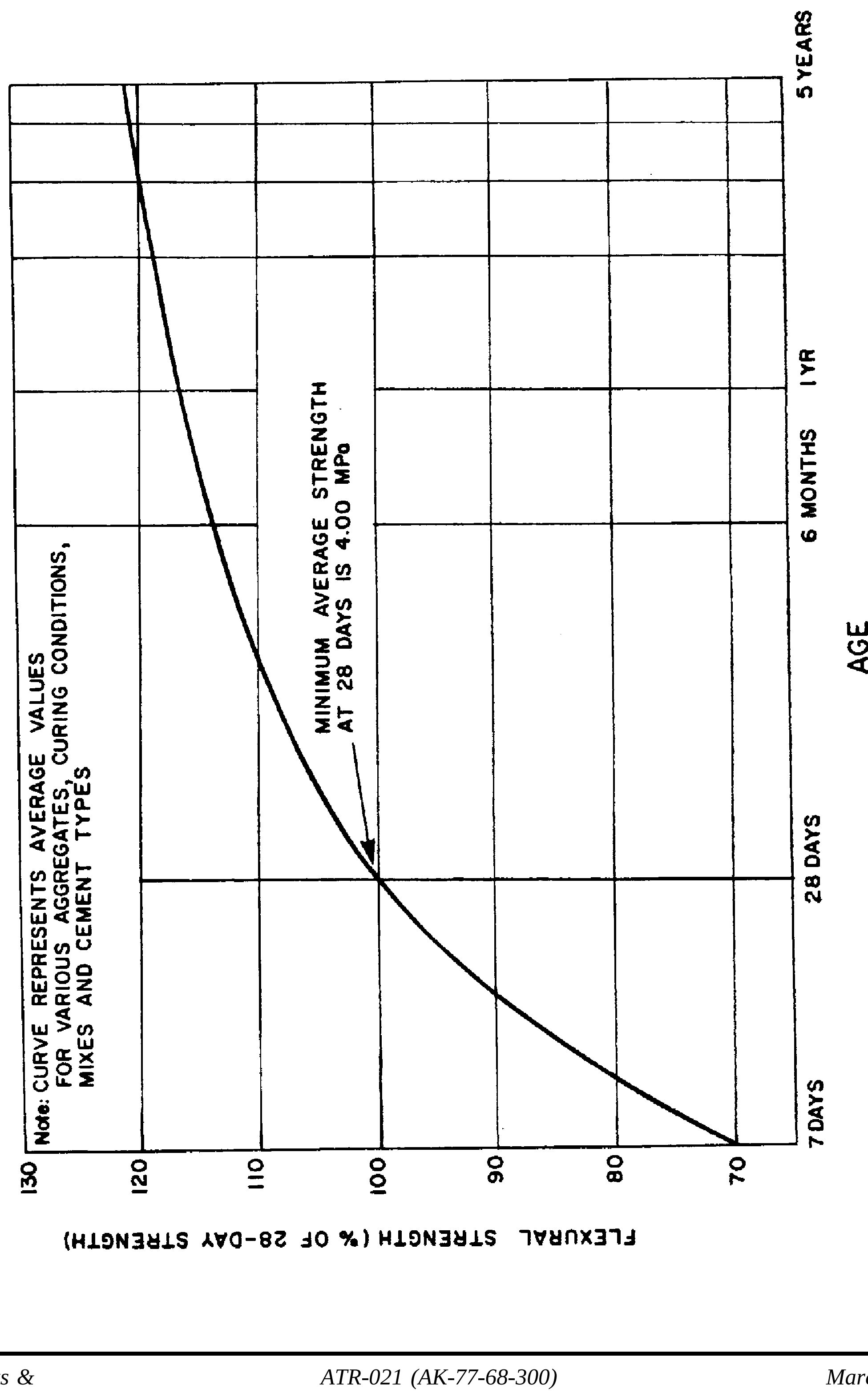


FIGURE 3.10
RIGID PAVEMENT DESIGN/EVALUATION CHART
FOR A GIVEN WEIGHT OFAIRCRAFT

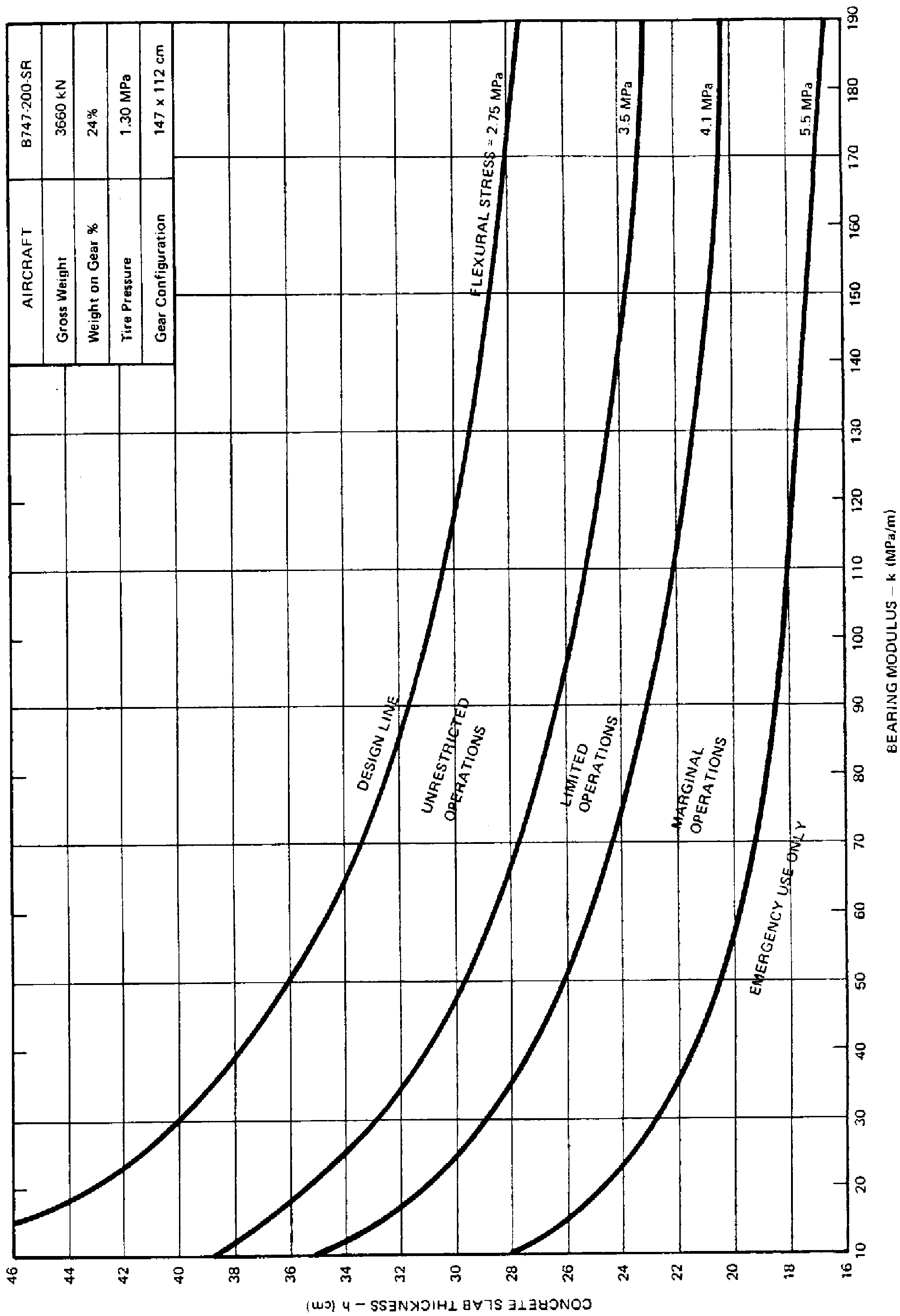


FIGURE 3.11 - FLEXIBLE PAVEMENT DESIGN AND EVALUATION CHART

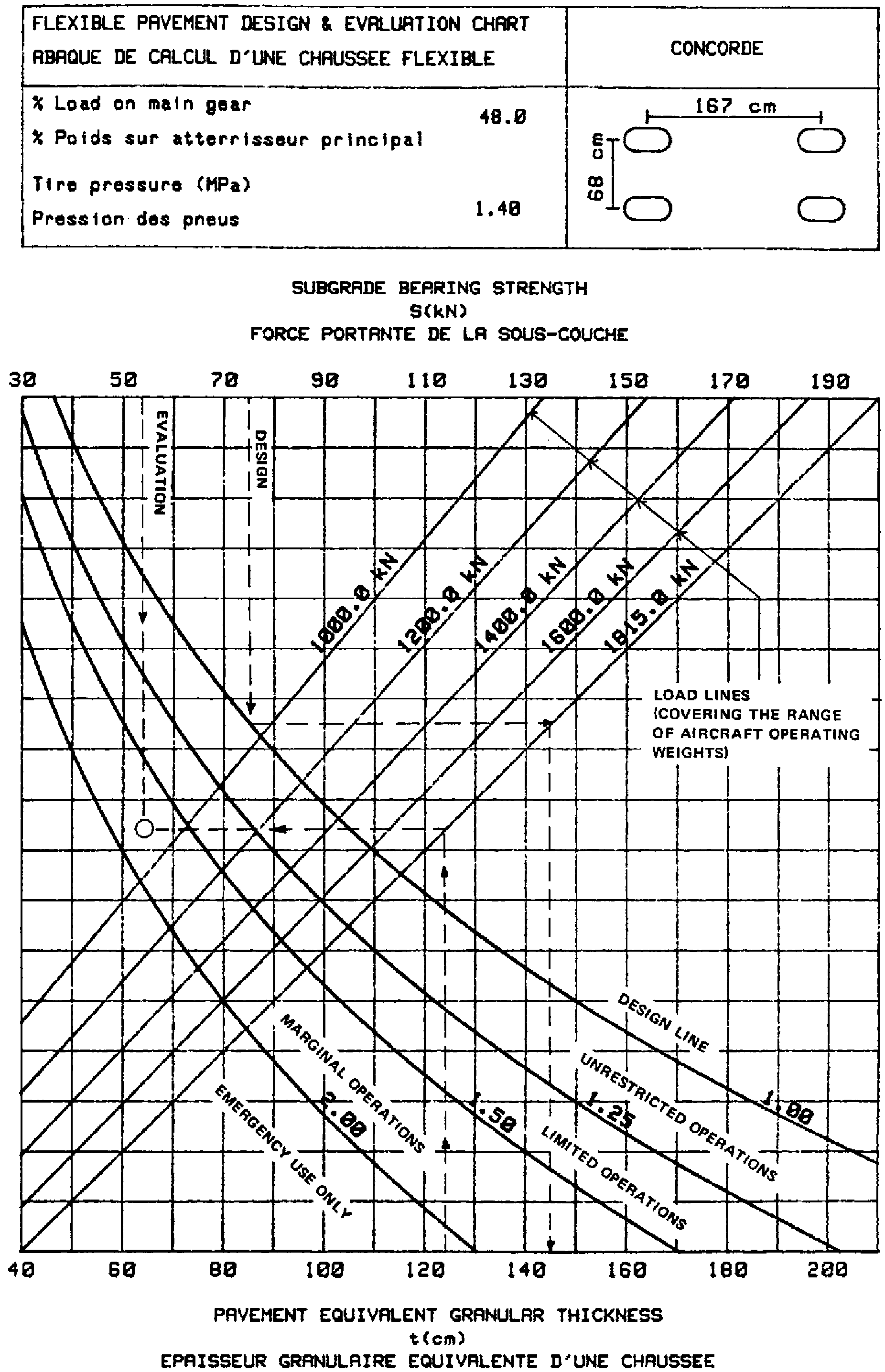
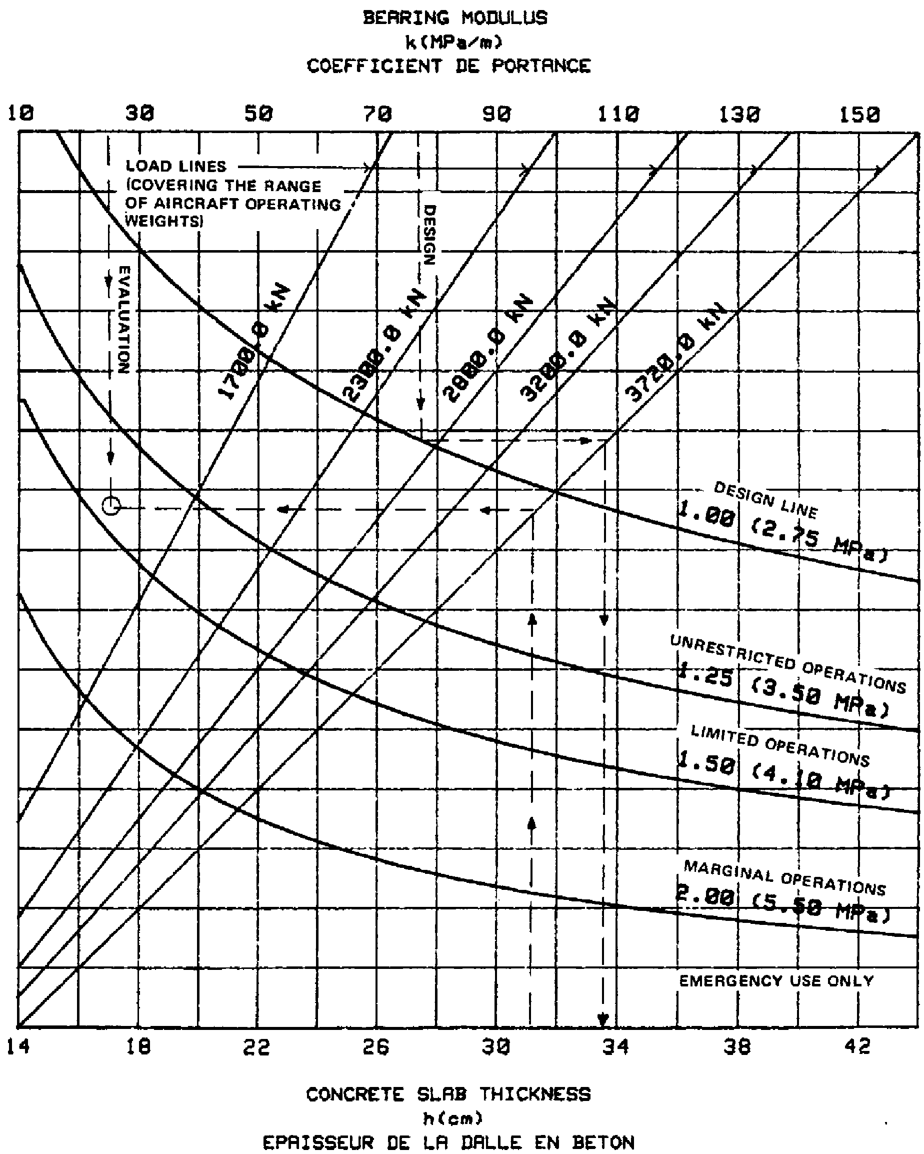


FIGURE 3.12 - RIGID PAVEMENT DESIGN AND EVALUATION CHART

RIGID PAVEMENT DESIGN & EVALUATION CHART ABAQUE DE CALCUL D'UNE CHAUSSEE RIGIDE		B747-200B 200C 200F
% Load on main gear % Poids sur atterrisseur principal	24.0	147 cm 112 cm
Tire pressure (MPa) Pression des pneus	1.35	



4.0 DESIGN STANDARDS

4.1 STANDARD LOADINGS

Standard gear loadings for pavement design were presented in Section 2.2. Application of the design theory of Chapter 3 results in the following charts for these standard loadings.

Figure 4.1 Flexible pavement equivalent granular thickness requirements for aircraft standard gear loadings.

Figure 4.2 Rigid pavement slab thickness requirements for aircraft standard gear loadings.

Figure 4.3 Flexible pavement equivalent granular thickness requirements for ground vehicle standard loadings.

4.2 AIRCRAFT PAVEMENTS

4.2.1 ASPHALT PAVEMENT THICKNESS REQUIREMENTS

The depth of asphalt pavement structure provided is the greater of the:

(i) frost protection requirement given in Section 2.4.3;

(ii) structural thickness requirement for the design standard gear loading as given in Figure 4.1;

(iii) minimum asphalt and base course thicknesses given in Table 4.1.

The depth of pavement structure is divided into layers of asphalt, base and sub-base in accordance with Table 4.1. Note that an asphalt surfaced pavement must be converted to an equivalent granular thickness to check compliance with requirement (ii) above.

4.2.2 GRANULAR PAVEMENT THICKNESS REQUIREMENTS

Frost protection is not normally a requirement for granular surfaced pavement. Consequently the thickness of granular pavement need only meet the structural thickness requirement for the design standard gear loading as given in Figure 4.1. This thickness should be divided into base and sub-base courses with the depth of base course being not less than 15 cm.

4.2.3 CONCRETE PAVEMENT THICKNESS REQUIREMENTS

The total depth of concrete pavement structure provided should be the greater of the:

(i) frost protection requirement given in Section 2.4.3;

(ii) slab thickness required to structurally support the design standard gear loading as given in figure 4.2, plus 15 cm of base course.

The thickness of Portland cement concrete slab required for structural support is determined as follows:

(1) estimate the thickness of slab required and subtract this thickness from the total pavement depth to give the thickness of base and sub-base courses;

(2) determine the bearing modulus, k, at the top of the base course by the methods of Section 3.3.2;

(3) determine the slab thickness required for this bearing modulus using Figure 4.2;

(4) repeat these steps until the slab thickness determined in (3) is equal to the thickness estimated in (1).

The minimum thickness of concrete slab to be provided is 23 cm, and the minimum thickness of base course is 15 cm. At international airports serving heavy aircraft traffic, concrete pavements are generally provided with a 20 cm cement stabilized base course. Subbase thickness is calculated as the difference between total pavement thickness required and slab plus base thickness.

4.2.4 CONCRETE PAVEMENT JOINT AND STEEL DETAILS

Joint and reinforcement design details for aircraft concrete pavements are given in Figures 4.4, 4.5, 4.6 and 4.7.

In general, plain concrete is used for aircraft rigid pavements without the addition of reinforcement, crack control steel, tie bars or load transfer dowelling. The exceptions as shown in Figures 4.6 and 4.7 are the use of tie bars for small irregular shaped panels, reinforcement steel around interior manholes and catchbasins, and crack control steel at locations of mismatched joints.

Because plain concrete is used, joints must be placed at relatively close intervals to avoid cracking caused by thermal expansion and contraction. Longitudinal construction joints and transverse contraction joints are usually located at 6 m intervals, with a construction joint along the centerline of runways and taxiways. Construction joint spacing is increased to 7.5 m on runways and taxiways serving wide-bodied aircraft to avoid the outside support gears of these aircraft tracking along a construction joint.

The outside edge of concrete pavements is an area of concern because water entering through the shoulder frequently causes differential heaving which results in a longitudinal crack along the outside bay. Outside bays adjacent to shoulders should therefore be cut or formed to half bay width. This requirement may be deleted if shoulders are paved to a width not less than 6 m.

4.2.5 BLAST PADS AND SHOULDERS

Figures 4.8 and 4.9 provide some design details for runway blast pads, paved shoulders and the sealing of side drainage on unpaved shoulders.

4.2.6 DESIGN COMPATIBILITY

The design of new aircraft pavements should be compatible with the design of existing pavements at an airport. When a new pavement is constructed that constitutes an expansion of an existing pavement or traffic route, the design of the new pavement should be compatible with the bearing strength of existing pavements which will share the same traffic.

4.3 ROADS AND CARPARKS

4.3.1 ASPHALT PAVEMENT THICKNESS REQUIREMENTS

The depth of asphalt pavement structure to be provided is the greater of the:

(i) frost protection requirement given in Section 2.4.3;

(ii) structural thickness requirement for the design standard loading as given in Figure 4.3;

(iii) minimum asphalt and base course thicknesses given in Table 4.2.

The depth of pavement structure is divided into layers of asphalt, base and sub-base in accordance with Table 4.2. Note that an asphalt surfaced pavement must be converted to an equivalent granular thickness to check compliance with requirement (ii) above.

4.3.2 GRANULAR PAVEMENT THICKNESS REQUIREMENTS

Frost protection is not normally a requirement for granular surfaced pavements. Consequently the thickness of granular pavement need only meet the structural thickness requirement for the standard design loading as given in Figure 4.3. This thickness should be divided into base and sub-base courses with the depth of base course being not less than 15 cm.

4.3.3 CONCRETE PAVEMENT THICKNESS REQUIREMENTS

Rigid pavements for roads and carparks are not designed by the theory outlined in Chapter 3; standard sections are normally used in which slab thicknesses are based on experience. Airport access roads and carparks are usually constructed with flexible pavements and rigid pavement designs are rarely required. If rigid pavement is being considered as an option, the design should be performed according to the recommendations of the Provincial Highway Department or the Portland Cement Association.

TABLE 4.1 - MINIMUM LAYER THICKNESS FOR FLEXIBLE AIRCRAFT PAVEMENTS

Component Layer	DESIGN AIRCRAFT TIRE PRESSURE			
	Less than 0.5 MPa	**0.5 MPa to 0.75 MPa**	**0.75 MPa to 1.0 MPa**	**Greater than 1.0 MPa**
Asphalt Concrete Surface Course (Hot-Mixed)	5.0 cm	6.5 cm	8.0 cm	10.0 cm
Crushed Gravel or Crushed Stone Base Course	15 cm	20 cm	25 cm	30 cm
Selected Granular Sub-base Course	As required in addition to the asphalt and base layers to provide: (a) the total pavement equivalent granular thickness required for structural support. (b) the total pavement depth required for frost protection.			

NOTES:

At grant-in-aid/small airports and other special locations, the pavement required for tire pressures below 0.4 MPa may be designed as a cold-mixed asphalt surfacing. The figures given for hot mix are also the minimum thickness requirements for a cold mix.

In areas of rock cut, the minimum pavement thickness shall be 15 cm of granular base course plus the pavement surface thickness as specified above.

TABLE 4.2 - MINIMUM LAYER THICKNESSES FOR GROUND VEHICLE FLEXIBLE PAVEMENTS

Design Group	Typical Vehicle	Gear Arrangement	Gear Load kN	Wheel Spacing		Tire Pressure MPa	Minimum Pavement Thicknes Requirements
				Dual cm	Tandem cm		
1	<u>Local Airports</u> Cars Light trucks	Single Dual Dual - Tandem	20 24 40	- 30 30	- - 120	0.50 0.50 0.50	6.5cm A.C. 15-20cm Cr.Gr. or St. Base Sub-base as required (see note below)
2	<u>Regional Airports</u> Buses Some trucks Maintenance vehicles Some fuel tankers	Single Dual Dual - Tandem	40 50 80	- 40 30	- - 120	0.70 0.60 0.60	6.5cm A.C. 20cm Cr.Gr. or St. Base Sub-base as required
3	<u>National Airports</u> Heavy trucks Fuel tankers Heavy maintenance	Single Dual Dual - Tandem	70 80 120	- 40 30	- - 130	0.70 0.60 0.70	8.0 cm A.C. 25cm Cr.Gr. or St. Base Sub-base as required
4	<u>International Airports</u> Heavy fuel tankers Heacy service	Single Dual Dual - Tandem	100 110 170	- 40 40	- - 140	0.80 0.70 0.80	8.0 cm A.C. 25cm Cr.Gr. or St. Base Sub-base as required

Notes:

(1) For small airports with low traffic volumes, the flexible pavement minimum thickness requirements for Design Group 1 may be reduced to 5cm A.C. + 15cm Cr. Gr. or St.Base.

(2) Sub-base thickness is the greater of:
- thickness required to provide total pavement equivalent granular thickness for structural support; or
- thickness required for frost protection.

FIGURE 4.1
FLEXIBLE AIRFIELD PAVEMENT STRUCTURAL THICKNESS REQUIREMENTS

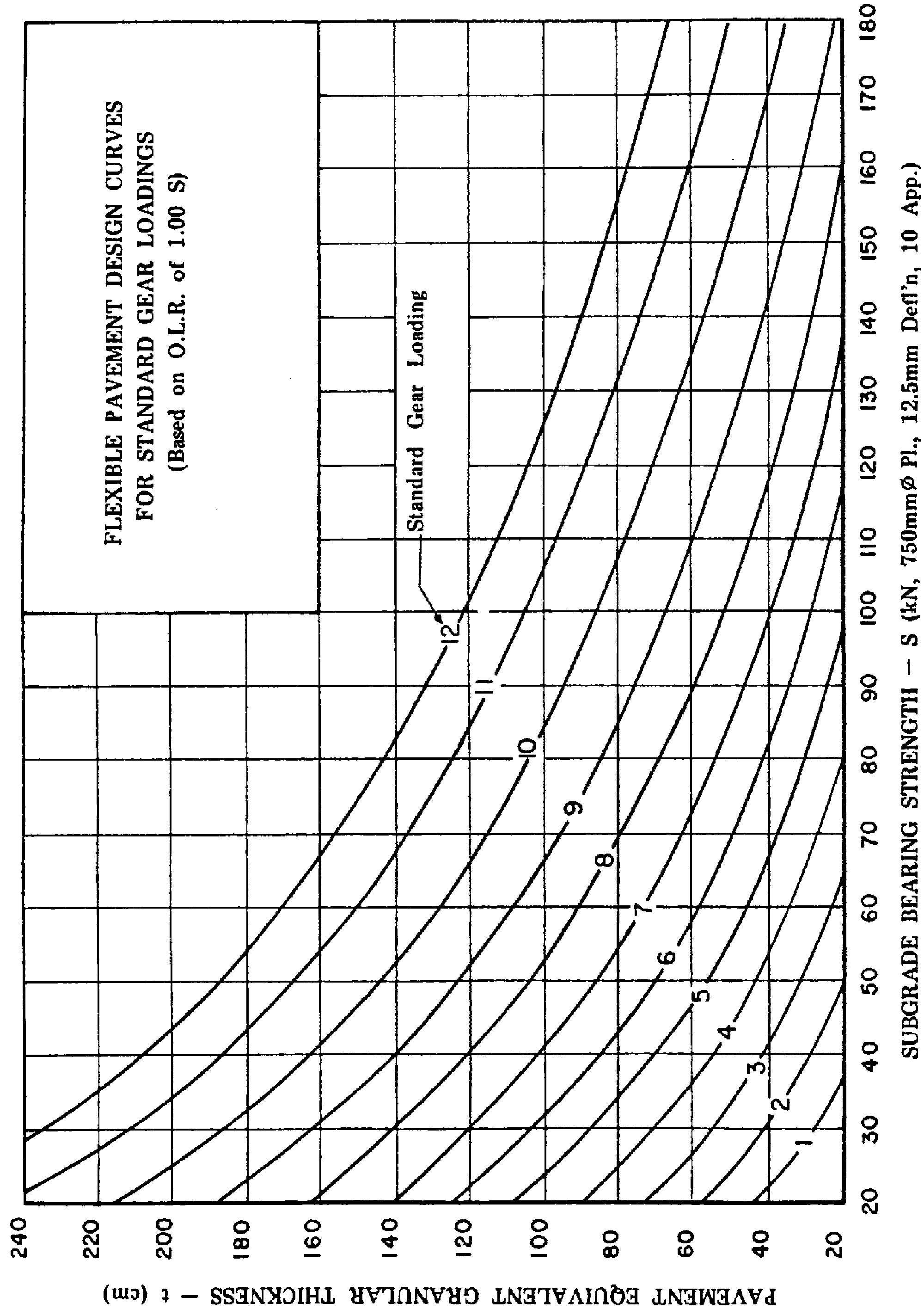


FIGURE 4.2
RIGID AIRFIELD PAVEMENT SLAB THICKNESS REQUIREMENTS

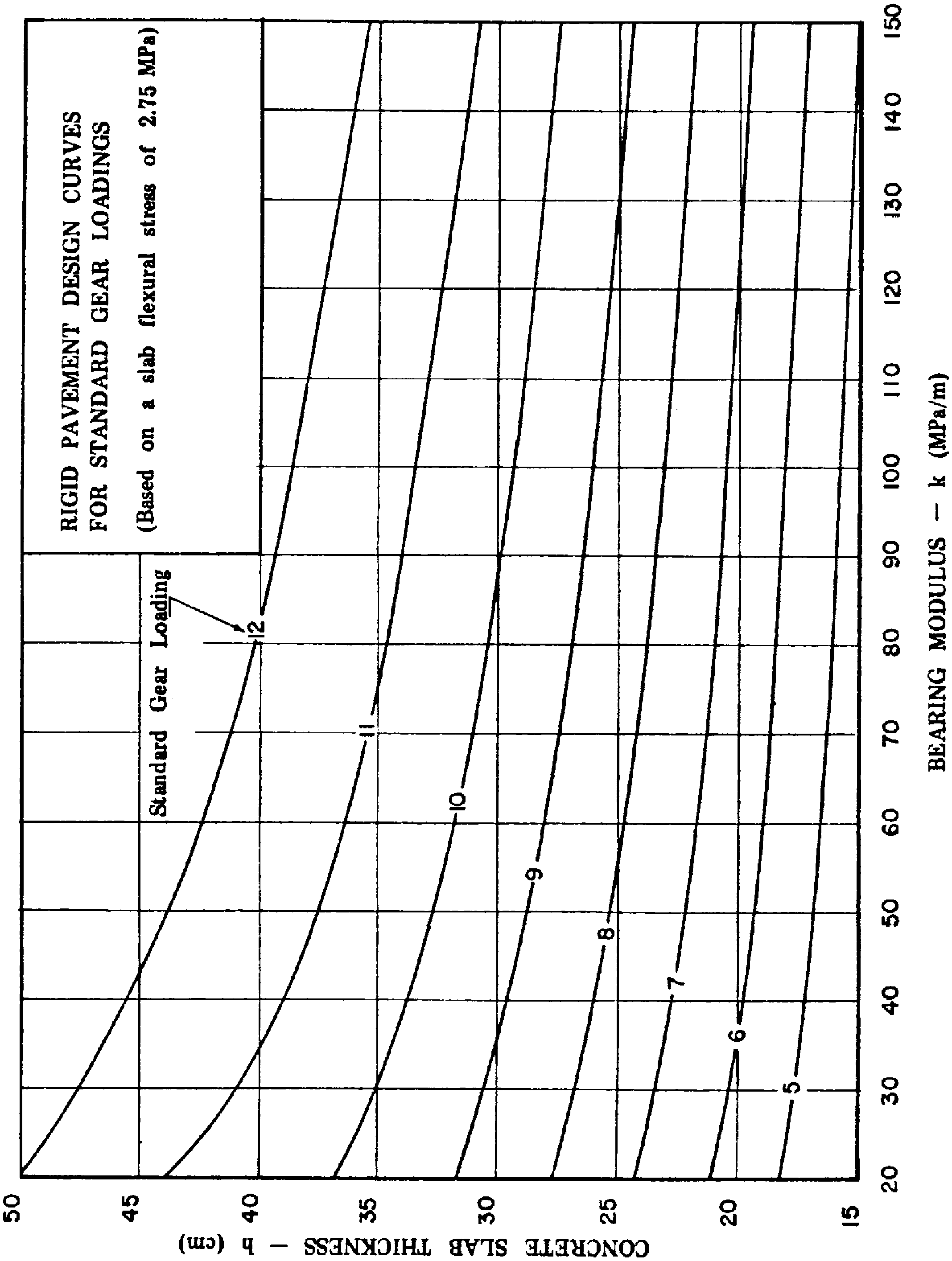


FIGURE 4.3
FLEXIBLE ROAD AND CAR-PARK PAVEMENTS
STRUCTURAL THICKNESS REQUIREMENTS

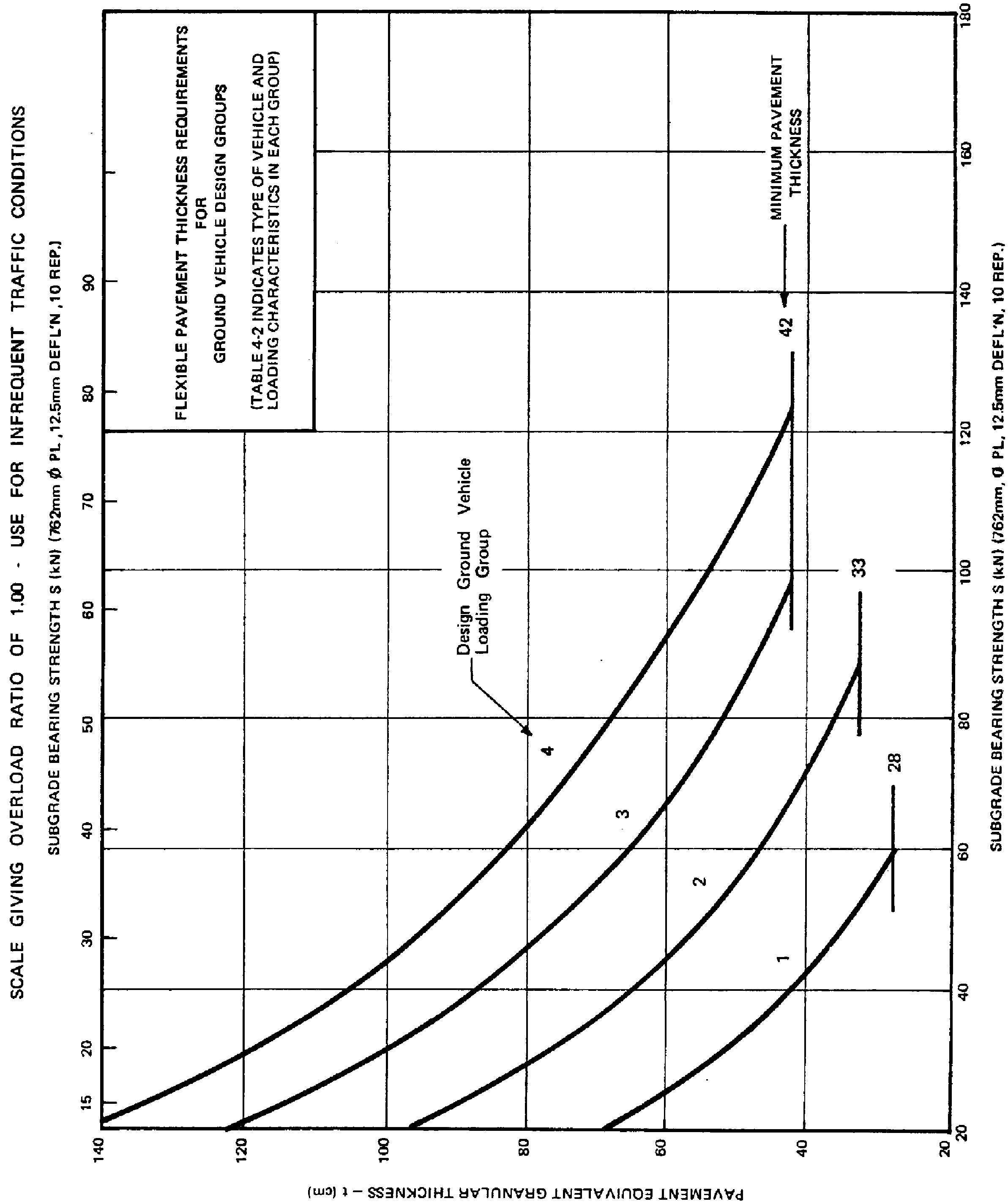
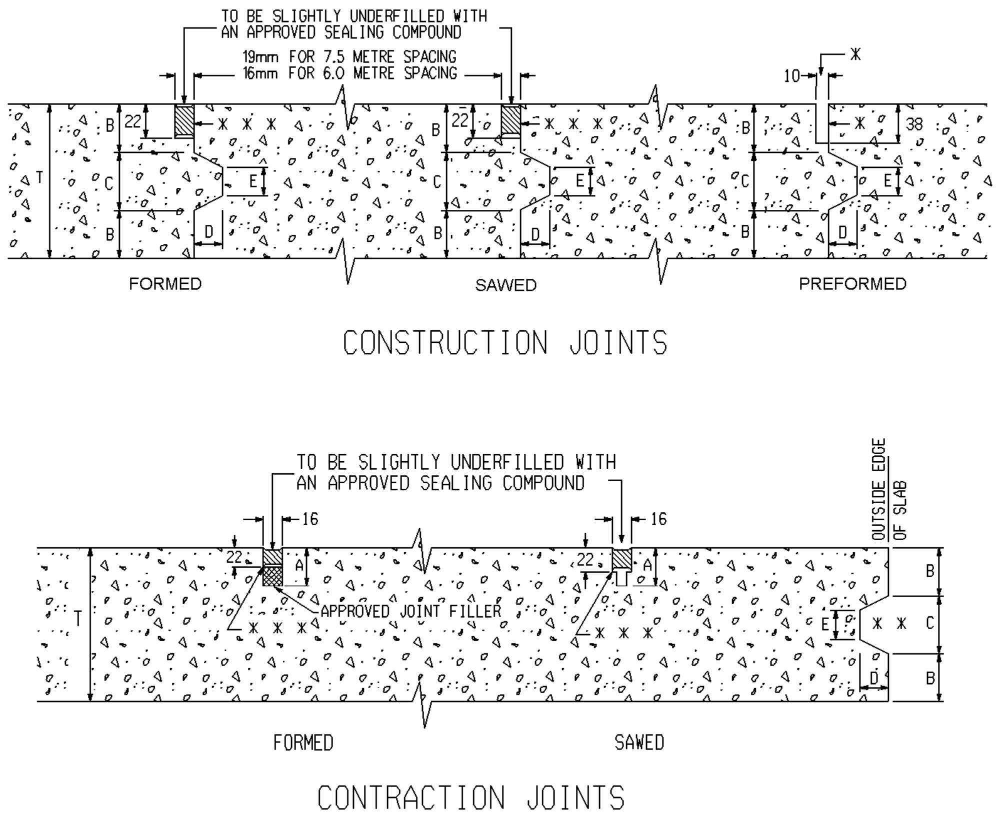


FIGURE 4.4
CONCRETE JOINTS - CONSTRUCTION DETAIL NO. 1



JOINT DIMENSIONS					
T	A	B	C	D	E
150	44	B = 0.40 T	C = 0.20 T	D = 0.10 T	E = 0.15 T
175	50				
200	57				
225	64				
250	70				
275	75				
300	82				
325	89				
350	95				
375	100				
400	108				
425	115				

* PREFORMED NEOPRENE SEAL, LUBRICANT ADHESIVE AND METHOD OF INSTALLATION SUBJECT TO PRIOR APPROVAL OF THE ENGINEER.

* * A MALE OR FEMALE KEYWAY SHALL BE FORMED ALONG THE OUTSIDE OF ALL EXTERIOR SLABS.

* * * SUITABLE BACK-UP TAPE TO BE APPROVED BY ENGINEER PRIOR TO USE.

NOTE: ALL DIMENSIONS IN MILLIMETRES

FIGURE 4.5
CONCRETE JOINTS - CONSTRUCTION DETAILS NO. 2

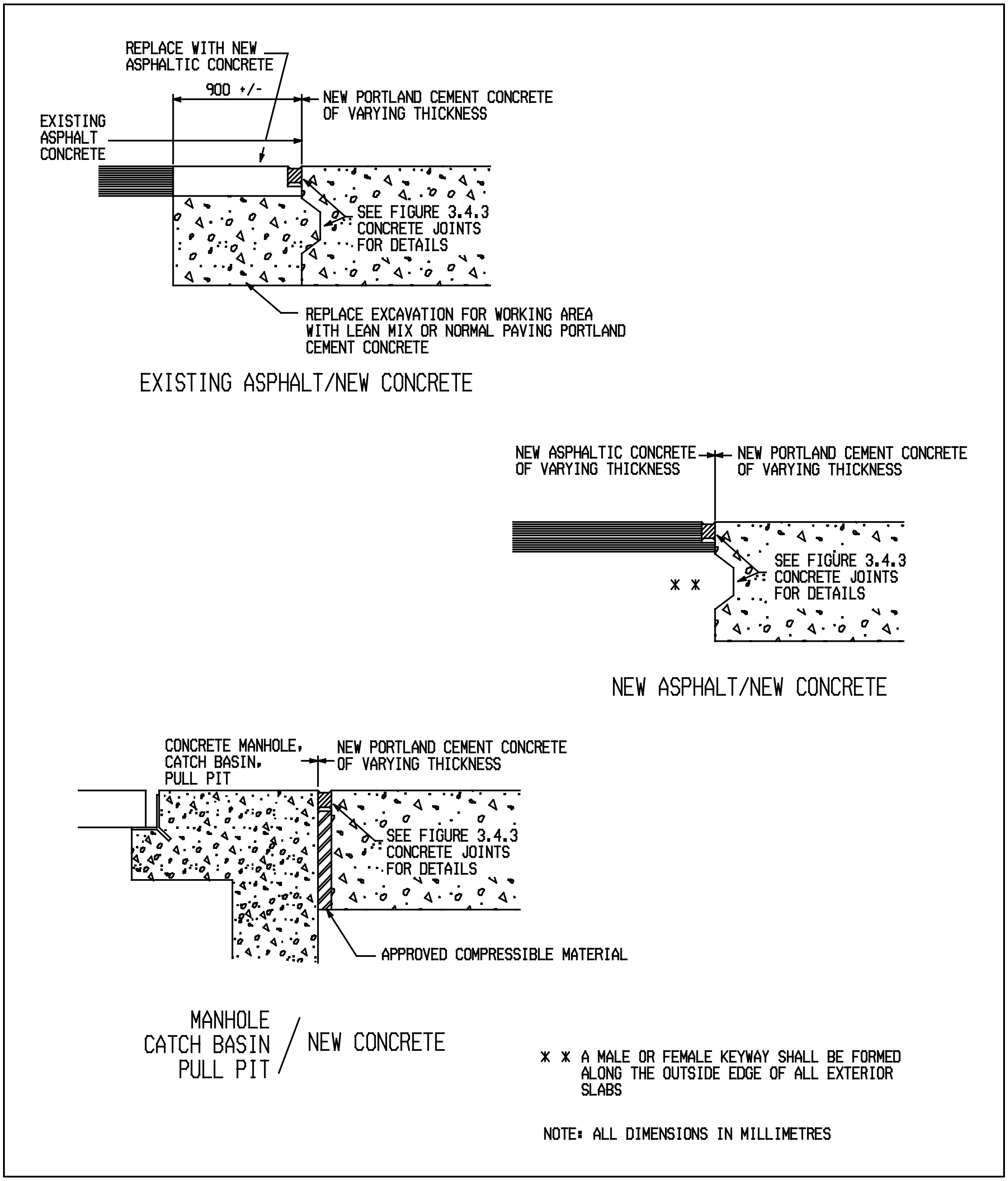


FIGURE 4.5 (CONT'D)
CONCRETE JOINTS - CONSTRUCTION DETAILS NO. 2

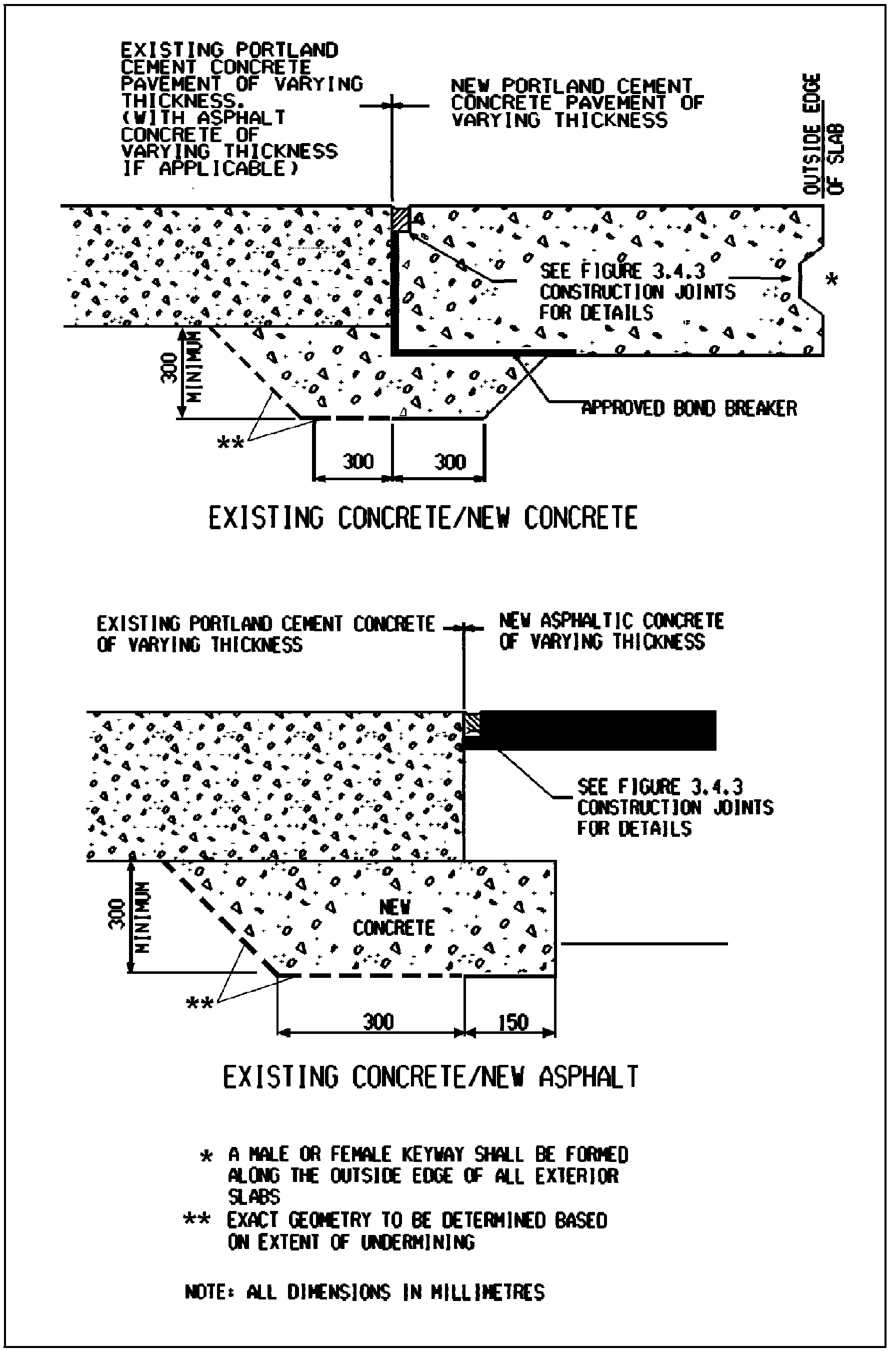


FIGURE 4.6
CONCRETE JOINTS - CONSTRUCTION DETAILS NO. 3

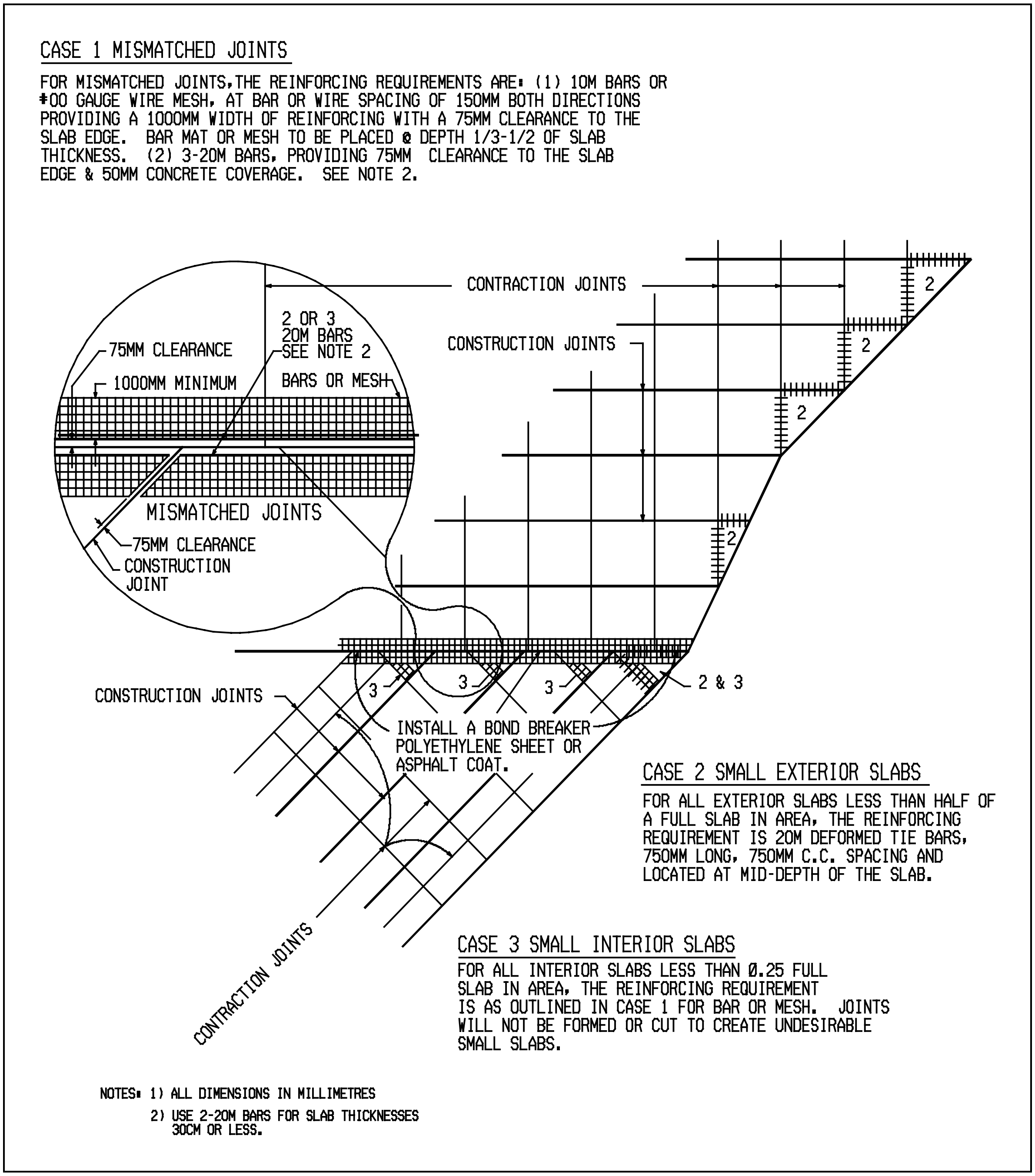
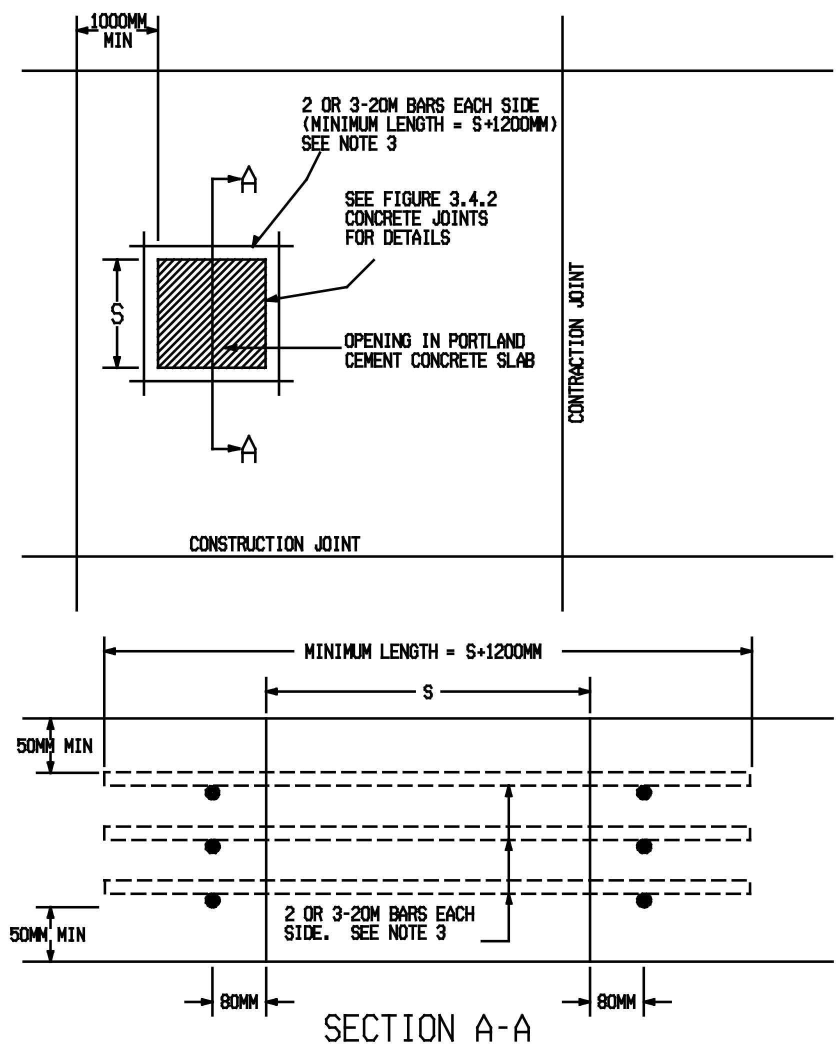


FIGURE 4.7
CONCRETE SLAB REINFORCEMENT AROUND INTERIOR MANHOLES AND CATCH BASINS



NOTES:
1) ALL DIMENSIONS ARE IN MILLIMETRES.
2) ABOVE DETAIL APPLIES WHEN LOCATING OF MANHOLES AND CATCH BASINS IN INTERIOUR OF SLAB CANNOT BE AVOIDED. PREFERED LOCATION WOULD BE AT SLAB CORNER
3) USE 2-20M BARS FOR SLAB THICKNESS 30 CM OR LESS

FIGURE 4.8
STANDARD DETAILS FOR AIRFIELD PAVEMENT SHOULDERS

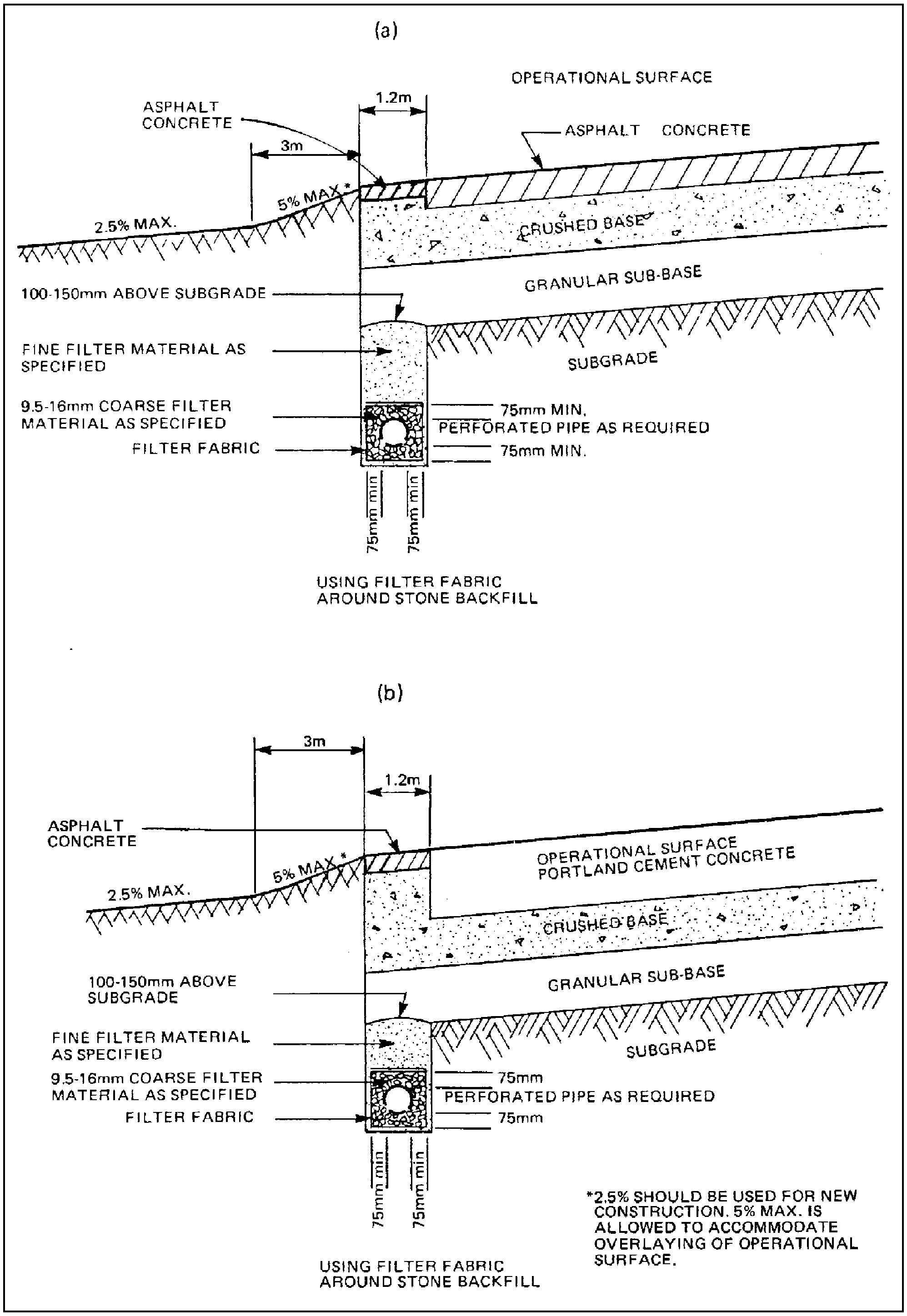
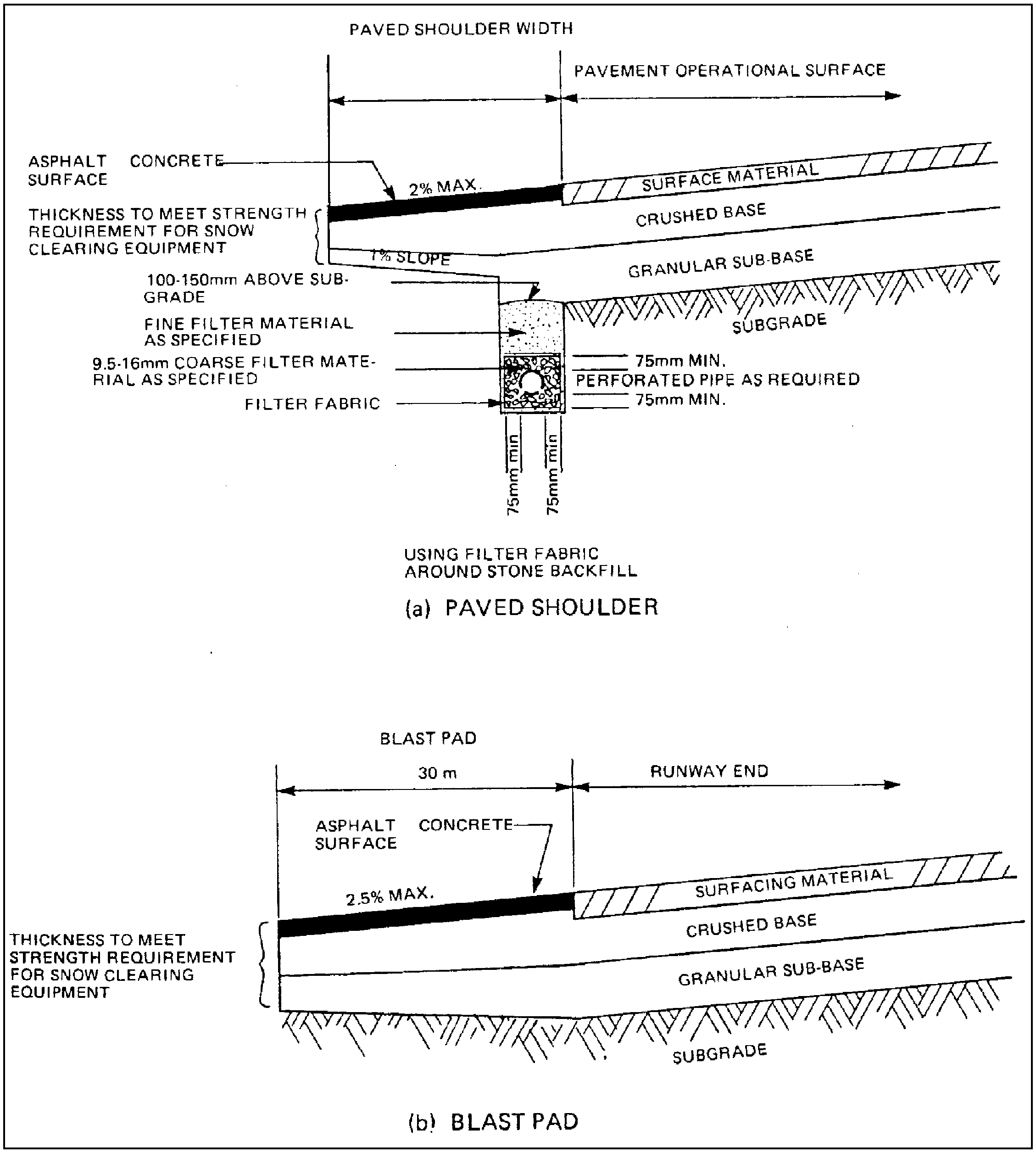


FIGURE 4.9
TYPICAL SECTIONS FOR PAVED SHOULDERS AND BLAST PADS



5.0 PAVEMENT RESTORATION

5.1 ASPHALT PAVEMENTS

5.1.1 RESTORATION ALTERNATIVES

Alternatives that may be considered for the restoration of asphalt surfaces include the following:

(i) Recycling - central plant hot mixed recycling of the existing asphalt surface or portion thereof. When bearing strength increases are not required, recycling may be the low cost option, although disruption to traffic may be greater than in the case of an overlay.

(ii) Overlay - overlays result in the least disruption to traffic. An overlay is the most usual method of restoration when strengthening is required and may be cost competitive with recycling in other cases.

(iii) Reconstruction - reconstruction is significantly more costly than other restoration methods and is usually undertaken only when subsurface deficiencies exist, and the restored pavement will not perform satisfactorily unless these deficiencies are corrected. ln some situations, reconstruction may also be required because of grade restrictions.

(iv) Seal Coat - seal coats should be considered as a possible restoration method only for low volume roads (AADT < 2000). Slurry seals may be considered as a temporary (1 to 3 years) corrective measure for airfield pavements when sufficient funds are not immediately available for more permanent restoration measures.

No structural design procedures are required for recycling since it consists simply of removing and replacing an existing layer; however, attention must be given to grades and asphalt mix design. The design of overlays is discussed below and some additional considerations for overlays of flexible construction are given in Section 5.3. For reconstruction, design considerations are the same as for new pavements.

5.1.2 FLEXIBLE OVERLAY DESIGN

Pavement bearing strength is the first consideration in the design of a flexible overlay for a flexible pavement. Equivalent granular thickness requirements for the design aircraft loading should be determined from Figure 4.1, and the depth of overlay placed should result in a pavement structure meeting these requirements. For pavement thicknesses deficient with respect to frost protection requirements, additional overlay thickness to meet these requirements should not be considered unless the existing pavement has experienced frost heaving problems.

If an increase in bearing strength is not required, and the only purpose of the overlay is to restore surface characteristics, the overlay should consist of one or two lifts of asphaltic concrete. One lift of asphaltic concrete, not less than 5 cm in thickness, may be used for pavements which serve light aircraft and which are in reasonably good structural condition. Two lifts of asphaltic concrete, not less than 8 cm in total thickness, should be used for other pavements.

5.1.3 RIGID OVERLAY DESIGN

A concrete slab overlay on an asphalt pavement is designed according to requirements for a new concrete pavement. The bearing modulus is computed at the top of the existing pavement and slab thickness is then determined from Figure 4.2.

5.2 CONCRETE PAVEMENTS

5.2.1 RESTORATION ALTERNATIVES

Alternatives that may be considered for the restoration of concrete surfaces include the following.

(i) Asphalt Overlay - as it usually results in the least cost and least disruption to traffic, an asphalt overlay is the usual method adopted for the restoration of a concrete surface.

(ii) Concrete Overlay - a concrete overlay on a concrete surfaced pavement

5.2.1 RESTORATION ALTERNATIVES (CONT'D)

may be adopted in lieu of an asphalt overlay when it is desirable that the pavement surface remain concrete (e.g. apron gate surfaces at large airports).

(iii) Reconstruction - restoration by reconstruction may be considered when subsurface deficiencies must be corrected, or when grade restrictions preclude the use of an overlay.

Design methods for asphalt and concrete overlays are given below. Reconstructed pavements are designed to meet new pavement requirements as outlined in Chapter 4.00.

5.2.2 FLEXIBLE OVERLAY DESIGN

A flexible overlay on a rigid slab is assumed to result in a rigid pavement structure if the depth of overlay does not exceed the thickness of the slab, or 25 cm. For this case, the thickness of asphalt overlay required is computed by Eq. (5.1).

$$t = 1.67(F \cdot h_d - h) \quad \textbf{(5.1)}$$

where t = asphalt overlay thickness required (cm). If a granular layer is to be included in the overlay, multiply the thickness of the granular layer by 0.67 to determine it's equivalent asphalt thickness.

F = a factor dependent on the bearing modulus of the existing slab as given in Figure 5.1.

h_d = thickness of slab required for a new concrete pavement (cm) given in figure 4.2.

h = existing slab thickness (cm).

Note: If $t + h < 14$, the t value obtained from equation 5.1 may have to be adjusted upward to meet $t + h \geq 14$.

Eq. (5.1) is plotted in Figure 5.1.

5.2.2 FLEXIBLE OVERLAY DESIGN (CONT'D)

If the thickness of the overlay exceeds the thickness of the existing slab, or exceeds 25 cm, the pavement structure is considered to be a flexible system. In this case, the overlay is designed by determining the thickness necessary to provide a pavement equivalent granular thickness as required by figure 4.1 for a new flexible pavement.

5.2.3 RIGID OVERLAY DESIGN

A concrete slab overlay on a concrete pavement may be placed without a separation course if the existing slab is in relatively good structural condition with little or no cracking. The surface of the existing slab should be thoroughly cleaned, and roughened by milling, to promote bond with the overlay slab. Also, reinforcement or mesh should be incorporated in the overlay slab for crack control, and joints in the overlay slab should be offset by 75 mm to 100 mm from those in the underlying slab for load transfer.

The thickness of overlay slab without separation course, and with a granular separation course not exceeding 15 cm, is computed from Equations (5.2) and (5.3) respectively.

Without separation course:

$$h_o = \sqrt[1.4]{h_d^{1.4} - Ch^{1.4}} \tag{5.2}$$

With separation course not exceeding 15 cm:

$$h_o = \sqrt{h_d^2 - Ch^2} \tag{5.3}$$

where h_o = overlay slab thickness (cm)

h_d = thickness of slab required for a new concrete pavement (cm) as given in Figure 4.2

h = existing slab thickness (cm)

5.2.3 RIGID OVERLAY DESIGN (CONT'D)

C = 1.00 if existing slab is in very good condition
= 0.75 if existing slab has minor cracking
= 0.35 if existing slab has major cracking

Equations (5.2) and (5.3) are plotted in Figure 5.1. The minimum thickness of overlay slab to be placed is 15 cm.

If a separation course is used which exceeds 15 cm in thickness, the upper slab is considered to act independently of the lower slab. The bearing modulus is calculated at the top of the separation course (converting the existing slab to an equivalent granular thickness) and the overlay slab thickness is then determined from Figure 4.2. The bearing modulus used should not exceed 250 MPa/m.

5.3 ADDITIONAL CONSIDERATIONS

The following considerations apply when designing an overlay of flexible construction.

(a) Preference should be given to full depth asphalt overlays. If a thick overlay is required for strengthening or grade purposes, consideration may be given to a sandwich overlay (granular lift followed by asphalt) if a significant cost saving can be demonstrated.

(b) When the transverse grade of a runway is less than permitted by geometric design standards, tapering of the overlay towards the runway edges should be considered for improved surface drainage and reduction of asphalt quantities.

(c) When an overlay is comprised of two or more lifts of asphalt, any grade corrections or levelling required should be effected in the lower lift.

(d) When a runway is to remain operational during overlay construction, design should observe the temporary ramping requirements given in Figure 5.2.

(e) Prior to placement of an overlay, any requirements for major maintenance should be satisfied, such as the repair of localized failed areas, and the sealing (with hot poured sealant) and levelling of major cracks. Cold pour crack sealant on the pavement surface or in wider cracks should be removed prior to the placing of an asphalt overlay.

FIGURE 5.1
EQUIVALENT SINGLE SLAB THICKNESS OF OVERLAID CONCRETE SLAB

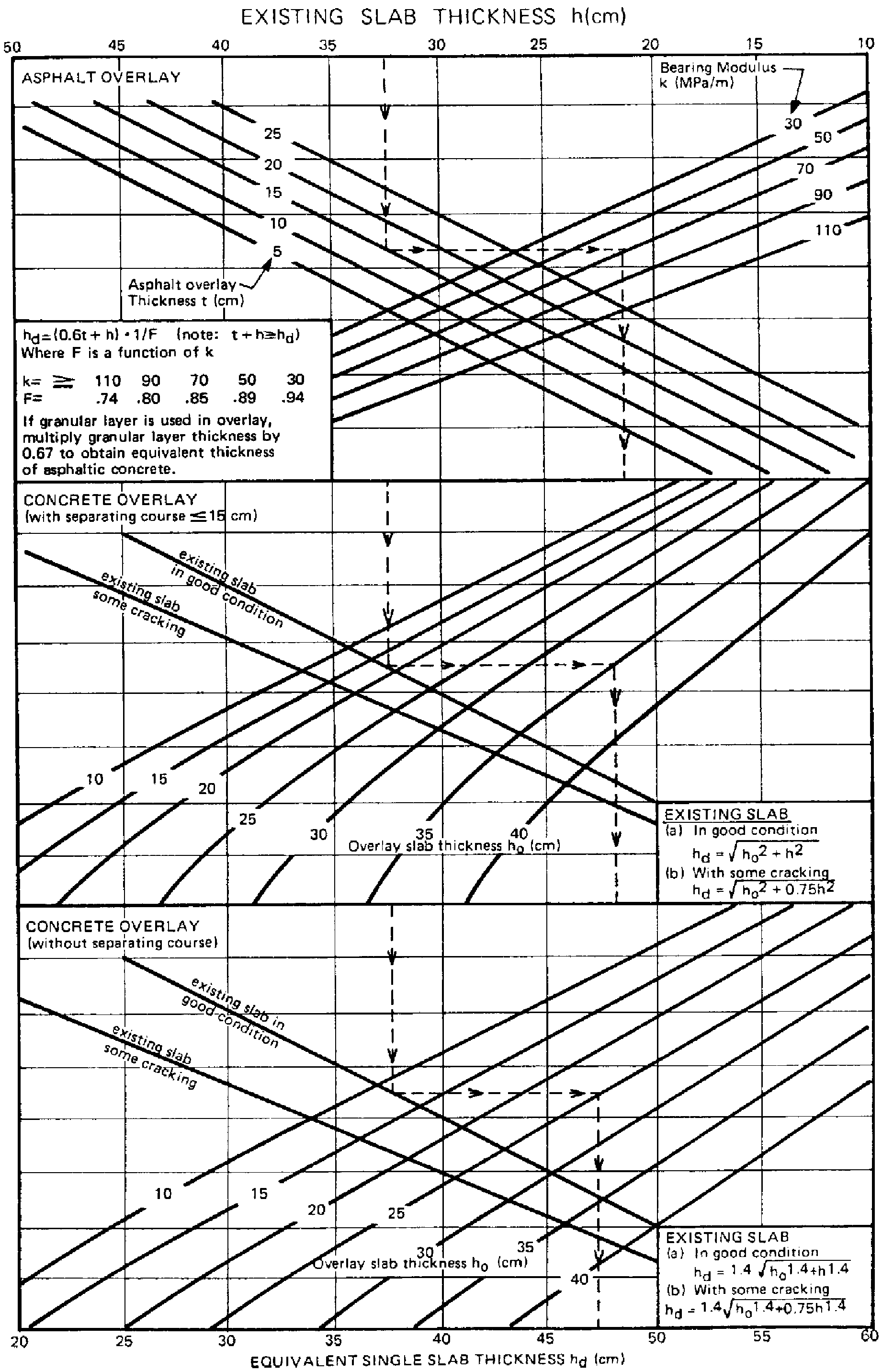
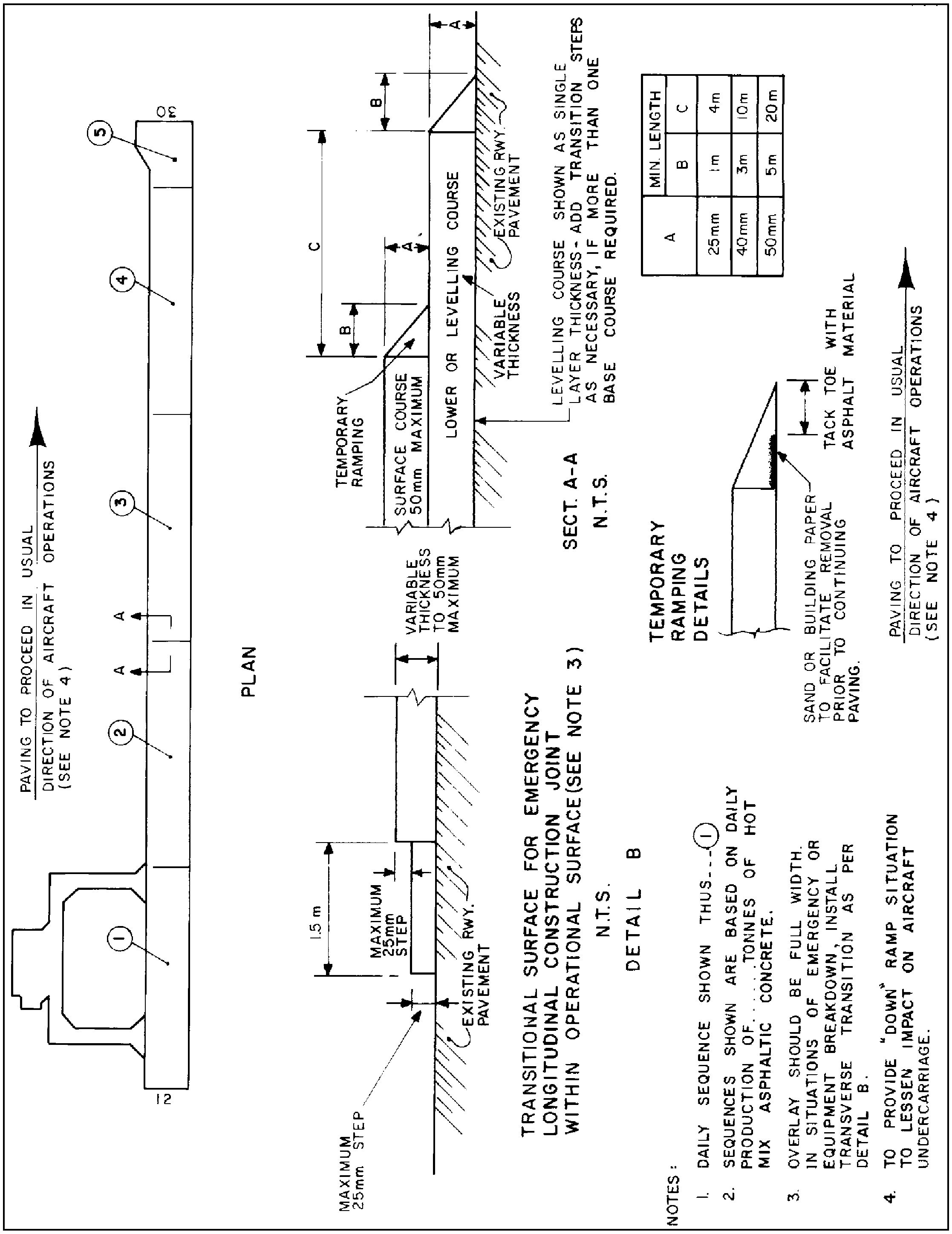


FIGURE 5.2
CONSTRUCTION DETAILS FOR OVERLAYING OPERATIONAL RUNWAYS



6.0 PLANNING AND PROGRAMMING

6.1 PROJECT JUSTIFICATION AND SCHEDULING

Capital work pavement projects fall into two broad categories. The first category consists of new pavement construction projects, which represent an expansion of the present system. The second category consists of pavement restoration projects, where the work is needed to maintain the existing system in an operational condition, and no increase in pavement inventory results.

The justification for new pavement facilities is established through master planning activities. The National Airports Plan and Area Master Plans identify the need for new airport sites. The Airport Master Plan provides justification for the expansion of facilities at an existing airport. In general, justification is based on a capacity analysis of existing facilities, and the construction of new facilities is scheduled when traffic projections indicate that demand will exceed capacity.

The need for pavement restoration is established through pavement evaluation activities which monitor such pavement characteristics as structural condition, bearing strength, roughness and skid resistance. The main evaluation activity used for the justification and scheduling of restoration is pavement condition surveys performed in accordance with AK-68-32 "Pavement Evaluation: Condition Surveys". When a pavement is newly constructed, the restoration year is estimated by adding the average service life for the type of construction involved to the year of construction. As the pavement matures and the rate of deterioration is established through periodic condition surveys, restoration scheduling is modified to the year in which it is estimated that normal maintenance will not be sufficient to keep the pavement operational.

In project justification and scheduling for new pavement facilities, the master plan providing justification for the project should be referenced and be available for study, and include a demand/capacity and a cost/benefit analysis. The latest condition survey report should be attached to project justification.

6.2 DESIGN ALTERNATIVES AND SELECTION

In most design situations, alternatives exist with respect to the type of pavement to be provided and design details. It is not the designers function to choose between these alternatives, although a recommendation should be given. The major responsibility of the designer is to assist management in reaching a decision by outlining the alternatives available along with their costs and operational implications.

The following guidelines apply generally to alternatives and selection in pavement design:

(a) All types of pavement structure satisfying operational requirements should be considered. The operational requirements should come from, or at least be approved by, the facility operator.

(b) Selection between design alternatives for new pavements should be based on minimum life cycle costs as discussed in Section 6.3. For restoration projects, disruption of traffic also becomes a factor in the selection between design alternatives.

(c) Aircraft pavements intended to provide year round uninterrupted service should generally be surfaced with asphaltic or Portland cement concrete, unless technical or economic reasons exist for a lower quality pavement structure.

(d) New aircraft pavements subject to turning movements, such as aprons, holding areas, and runway buttons, should be surfaced with Portland cement concrete if the traffic consists of heavy aircraft with tire pressures exceeding 1.0 MPa.

(e) Aprons surfaced with asphaltic concrete should be provided with a coal tar slurry seal in refuelling areas.

6.3 LIFE CYCLE COSTING

Cost analysis for the comparison of pavement design alternatives should be performed in accordance with AK-76-06 "Life Cycle Costing Procedures". For a comparison of relative costs, a present value is calculated for each design alternative according to Eq. (6.1).

$$P_V = C + \sum_{i=1}^{n} \frac{R_i}{(1+r)^i} - \frac{V_n}{(1+r)^n} \qquad \textbf{(6.1)}$$

6.3 LIFE CYCLE COSTING (CONT'D)

where Pv = present value of the facility ($)

n = analysis period (years)

C = initial construction cost ($)

Ri = restoration or maintenance cost in year i

Vn = residual value of the facility at the end of the analysis period

r = discount rate applied to future costs or values.

An analysis period of 25 to 30 years is normally used for pavement construction projects. With an analysis period of this duration, the residual value discounted to a present value is small and can be assumed equal for all alternatives. Under these circumstances, residual value can be eliminated from equation (6.1) when Pv is being calculated only for relative comparison purposes.

All costs in Eq. (6.1) are calculated in terms of present day dollar value. The application of a discount rate to these costs when they are expended in the future reflects the advantages of delaying expenditures. These advantages include the average difference between interest and inflation rates, possible productivity gains in the future, and more accurate assessments of future requirements as time progresses.

The discount rate normally applied to future expenditures and values is 10 percent. Additional calculations at 5 and 15 percent may be made to determine the sensitivity of the decision process to this factor.

The present value of design alternatives bears little relationship to the actual costs of the facility over its life cycle; present value is simply a relative measure for comparison purposes.

6.4 DESIGN BRIEF

A design brief is a concise statement of the design parameters for a project, the design options studied, their costs and operational consequences. An example is given in Table 6.1.

Program approval documents need-only provide the project design parameters, summary

6.4 DESIGN BRIEF (CONT'D)

of design options, and costs for the recommended option. However, a design brief should be available for examination in the event that the recommendation is challenged.

6.5 PAVEMENT SERVICE LIFE

The service life of a pavement is the time period in years between construction and restoration of the pavement surface. This variable is important in the programming of restoration measures, and for the life cycle cost comparison of different design options.

Some distributions of service life experienced at Canadian airports are given in Figures 6.1, 6.2 and 6.3 for various types of construction.

For planning purposes service lives corresponding to the 50 percentile value should generally be used; a value closer to the 75 percentile may be used for light traffic conditions. Values less than the 50 percentile should be used if the pavement is deficient with respect to construction materials, frost protection or bearing strength. A recycled or replaced asphalt surface may be assumed to have a service life equal to a new asphalt pavement.

TABLE 6.1 - DESIGN BRIEF SUMMARY (EXAMPLE)

Project:

Restoration of Runway

The following example of life cycle cost analysis applies to an airport where the riding quality of the runways has declined over the years due to increased surface roughness caused by frost action and the introduction of heavier aircraft.

Design Alternatives:

Alternative "A" Provision of a 75mm hot mix overlay for the center 12m of the existing surface, tapering to approximately 38mm on the shoulders. Expected life 10 years. Capital Cost $2,229,000.00.

Alternative "B" Replacement of the central slabs 12 m wide with 380mm Portland Cement Concrete, maintaining the original design. Expected life 25 years. Capital Cost $4,877,000.00.

Alternatives will be compared over a 30 year period using a discount rate of 10%.

Maintenance costs are not known but it is assumed that they will differ very little between alternatives.

Calculation of present value:

Alternative A = $3,421,000
Alternative B = $5,104,000

Sensitivity Analysis performed for discount rates of 5% and 10%

@5%	Alternative A = $4,438,000	@15%	A = $2,916,000
	Alternative B = $5,415,000		B = $4,964,000

Conclusions:

Alternative "A" is more economical under these circumstances.

FIGURE 6.1
NEW ASPHALT PAVEMENTS - DISTRIBUTION OF SERVICE LIFE

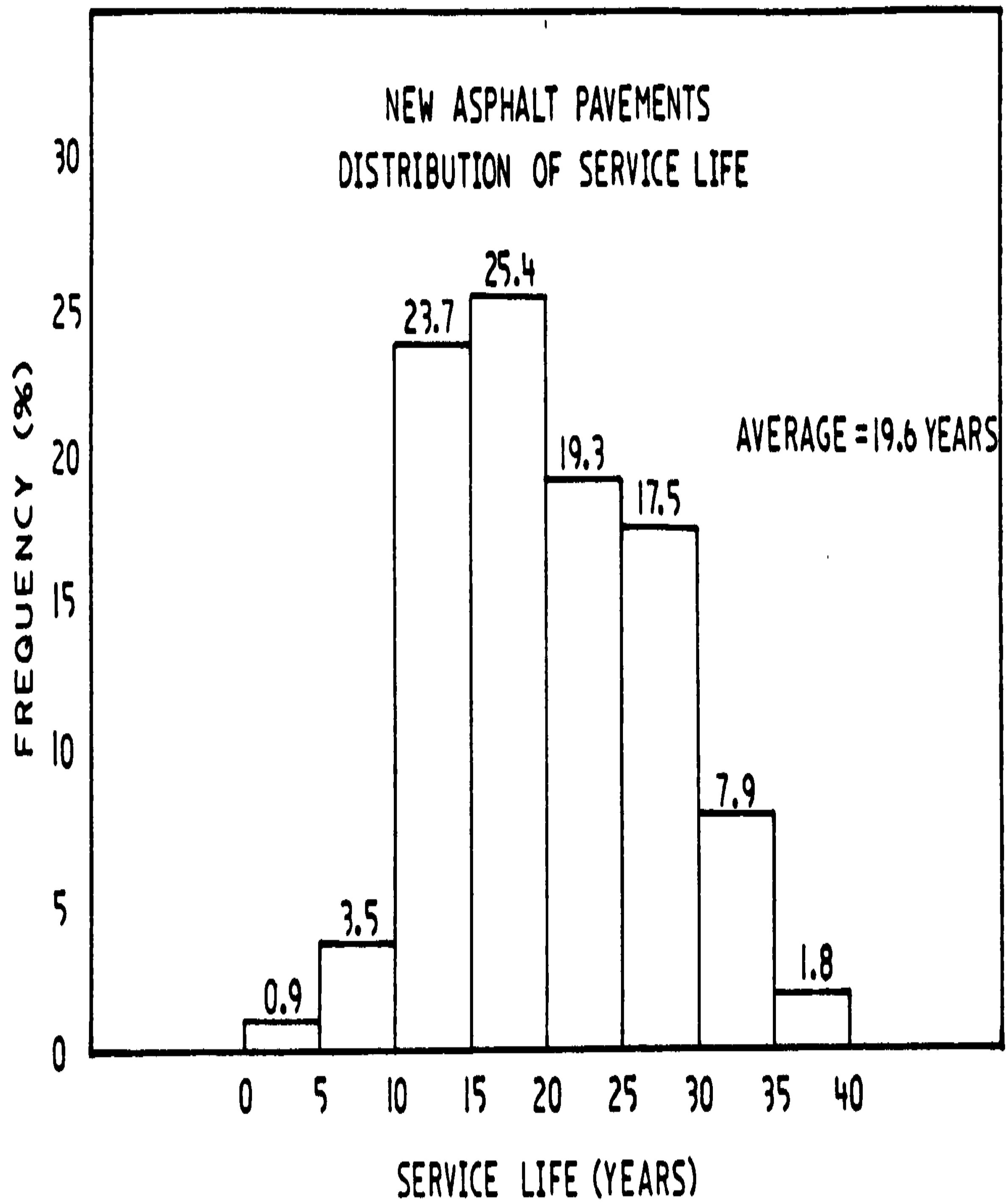


FIGURE 6.2
NEW P.C.C. PAVEMENTS - DISTRIBUTION OF SERVICE LIFE

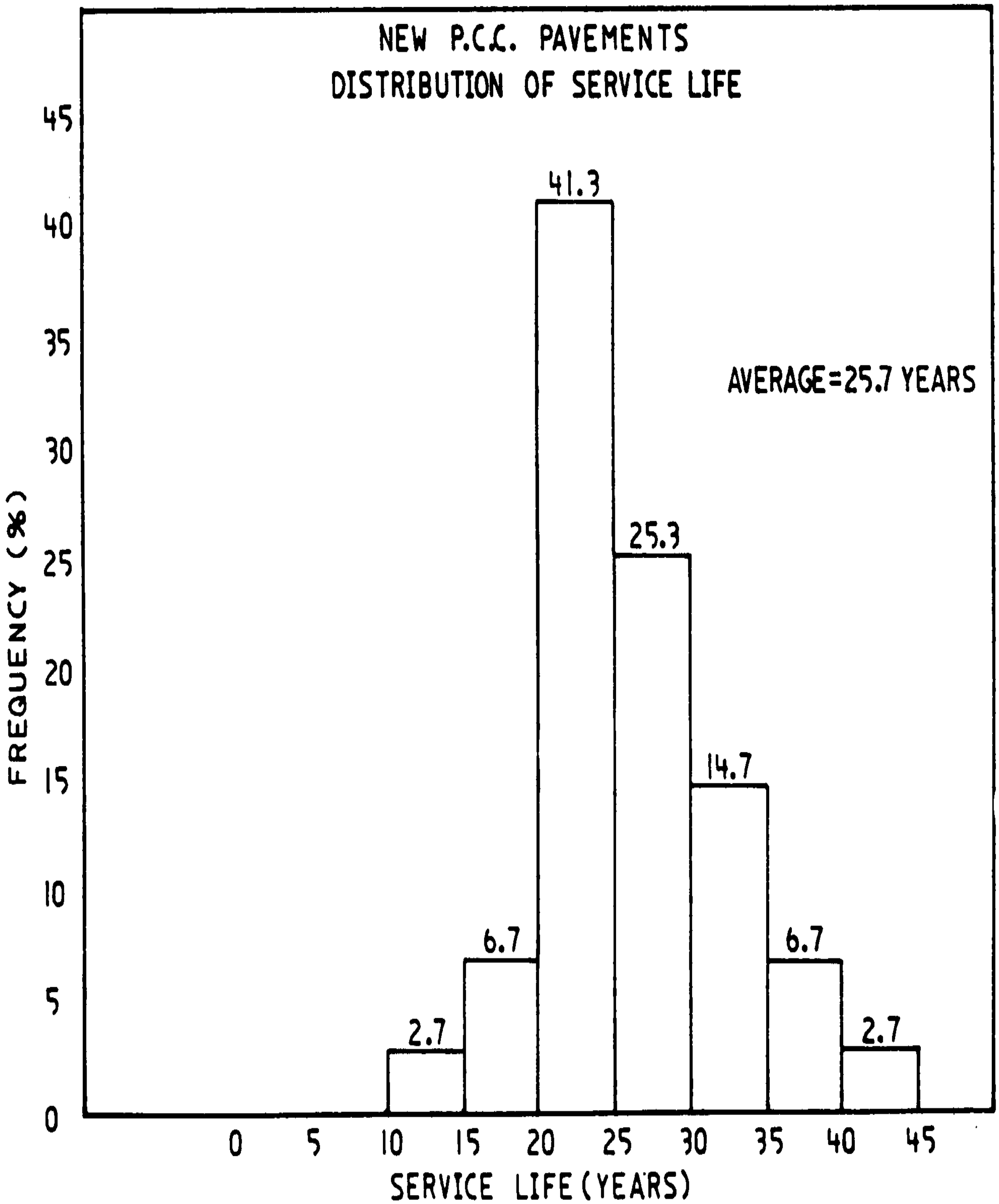
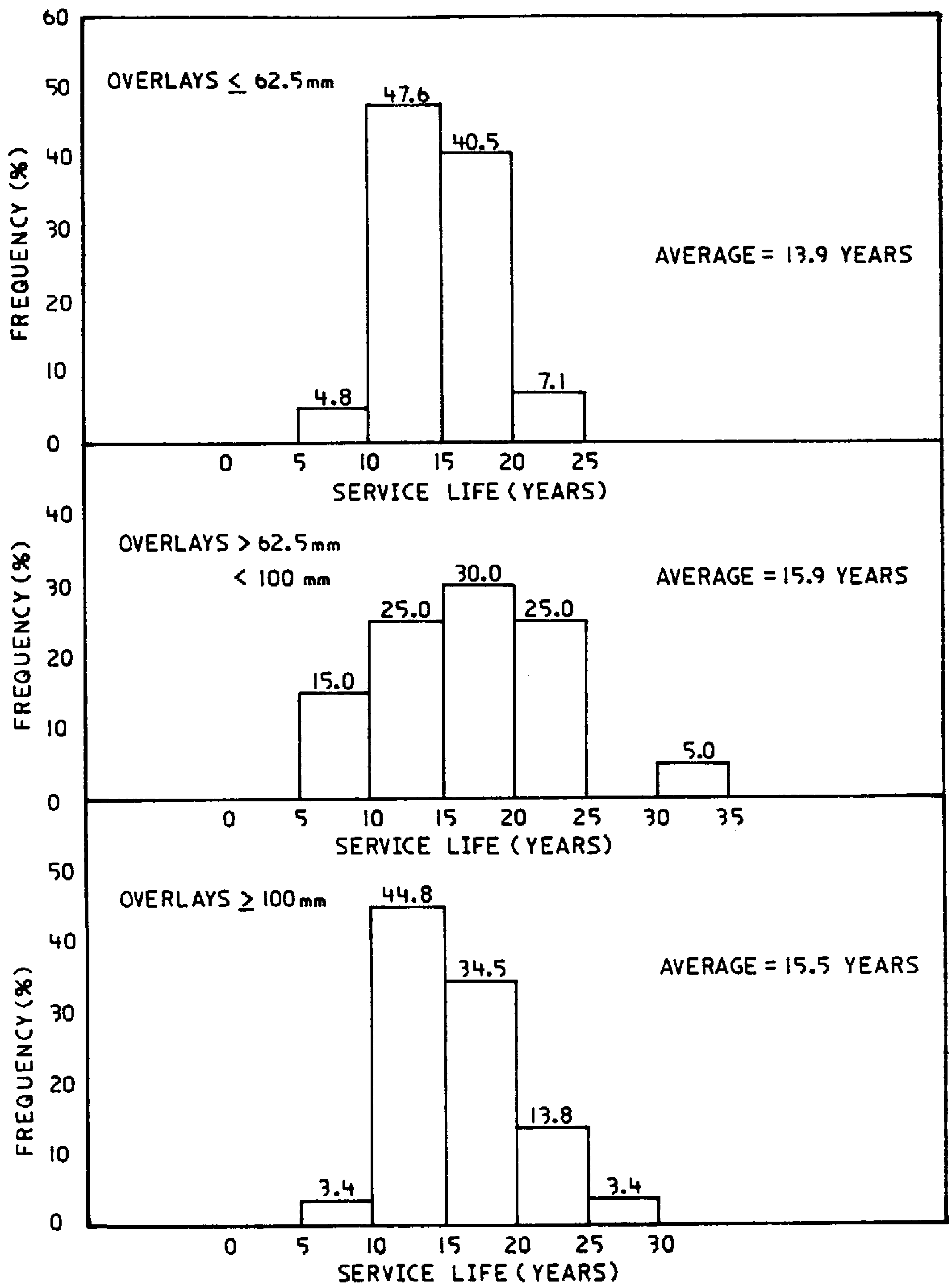


FIGURE 6.3
ASPHALT OVERLAYS - DISTRIBUTION OF SERVICE LIFE



7.0 MISCELLANEOUS DESIGN TOPICS

7.1 PAVEMENTS ON PERMAFROST

Subgrade soil conditions are a critical element for airfield site selection in permafrost areas. Fine-grained subgrade soils with high ice contents are to be avoided as they are very unstable during thaw, and large settlements are likely to occur. The best subgrade soils for pavement construction in northern Canada are granular materials with low ice content. The availability of construction materials may also be critical at some sites. Soil and material survey methods to be followed for permafrost areas are outlined in AK-77-68-600 "Geotechnical Surveys - Training Manual".

In northern permafrost areas where the active layer is not too deep, the normal approach to pavement design is to provide a pavement and embankment thickness such that thaw does not reach the existing in-situ material. In southern permafrost areas where deeper active layers render this approach uneconomical, pavement design is based on strength considerations using a subgrade bearing strength estimated for the thawed subgrade soil. Pavement insulation may also be a feasible design alternative for permafrost areas.

When the active layer penetrates the subgrade soil, substantial movements can be expected in the pavement structure after construction as the subsurface permafrost regime adjusts to a new equilibrium state. It is preferable to have the surface unpaved, as irregularities can be corrected more easily and economically with gravel surfaces. Where paving is an operational necessity, a requirement for resurfacing courses can be expected at five to ten-year intervals unless subgrade soil conditions are exceptionally favourable.

Drainage is also an important consideration for northern airfield pavements. Water acts as a heat sink and changes to the surface drainage pattern should be minimized as they will frequently result in permafrost degradation and large settlements. Pavement subsurface drainage is difficult as pipes located at depth will provide subsurface drainage for only a short period of the year. A double layer of pipe may be considered i.e. an upper pipe for drainage during the early thaw period and a lower pipe for drainage toward the end of the thaw period.

7.2 PROOF ROLLING

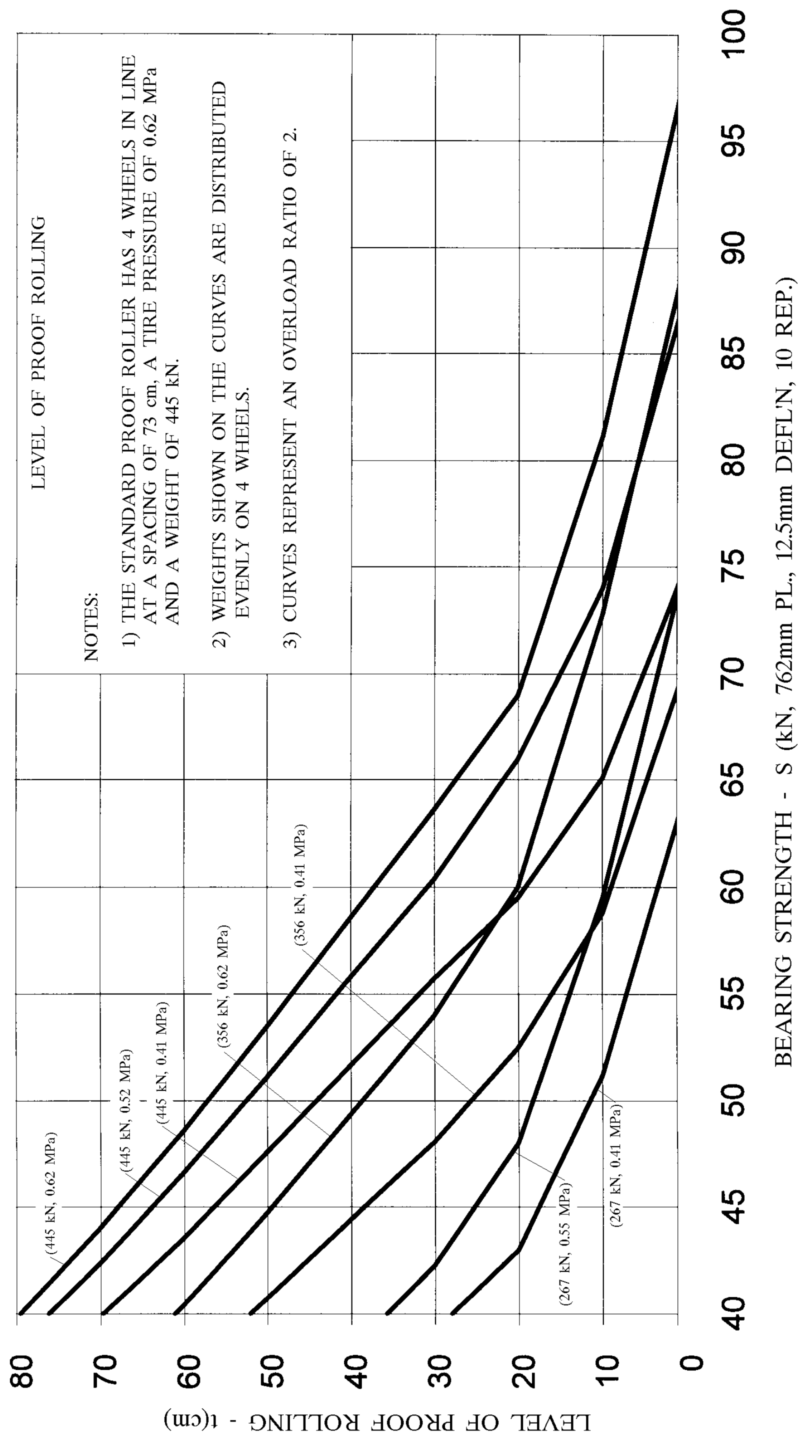
During the construction of a pavement, proof rolling is conducted at some level in the sub-base or base course for the purpose of checking the uniformity of subgrade bearing strength. Isolated weak areas identified by proof rolling are corrected to increase the significant strength and uniformity of the total area. As a side benefit, proof rolling provides additional compaction for the pavement structure.

The standard vehicle used for proof rolling is a rubber-tired roller having four wheels abreast with a maximum centre-to-centre wheel spacing of 92 cm, tire inflation pressure of 0.62 MPa, and a total weight of 445 kN. The level for proof rolling chosen by the designer should create a subgrade overload ratio of two using the standard proof rolling equipment. Figure 7.1 shows the required pavement depth as a function of subgrade bearing strength.

In the case of strong subgrades where the roller cannot provide an overload ratio of two, proof rolling is carried out on the first lift of sub-base. In the case of weak subgrades and thinner pavements where the standard roller gives an overload ratio greater than two, proof rolling is carried out on the surface of the base course at a reduced roller weight which gives an overload ratio of two. Where proof rolling is on a sub-base material unstable under a tire pressure of 0.62 MPa, tire pressures should be reduced.

Contractors may request to use alternative proof rolling equipment. The designer should prepare a design-evaluation chart for the alternative proof rolling equipment to determine the level at which proof rolling should be carried out.

FIGURE 7.1 - LEVEL OF PROOF ROLLING



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APPENDIX A

AIRCRAFT LOADING CHARACTERISTICS

AIRCRAFT LOADING CHARACTERISTICS

Aircraft	Op. Weight (kN)		% Load	Tire	Wheel Spacing (cm)	
	Max.	Min.	On Gear	Press (MPa)	Dual	Tandem
AERO COMMANDER GRAND, TURBO	40	25	47.5	0.55	--	--
AERO COMMANDER, JET COMMANDER	75	55	47.5	0.93	--	--
AIRBUS A300-B2, B4	1540	900	47.3	1.30	91	140
AIRBUS A300-C4	1627	1216	47.3	1.24	95	146
AIRBUS 310-200	1303	1064	46.6	1.12	95	140
ANTONOV AN-24	207	130	47.5	0.42	58	--
ARGOSY AW650	410	250	47.5	O.55	71	--
B707-120B	1150	700	47.0	1.17	86	142
B707-320, 320B, 320C, 420	1500	800	47.0	1.24	88	142
B720, 720B	1045	700	47.5	1.00	81	124
B727-100, 100C	760	400	45.4	1.25	86	--
B727-200 (St/Ad)	935	500	47.0	1.25	86	--
B737-100, 200	450	250	46.5	1.00	78	--
B737-200, 200C	575	300	46.5	1.20	78	--
B737-300	603	323	45.9	1.34	78	--
B747-1OOB, SR	2330	1600	24.0	1.04	112	147
B747-SP	3130	1500	23.0	1.35	110	137
B747-100, 100B, SR	3350	1700	23.5	1.55	112	147

AIRCRAFT LOADING CHARACTERISTICS

Aircraft	**Op. Weight (kN)**		**% Load**	**Tire**	**Wheel Spacing (cm)**	
	Max.	**Min.**	**On Gear**	**Press (MPa)**	**Dual**	**Tandem**
B747-200B, 200C, 200F	3720	1700	24.0	1.35	112	147
B747-300	3720	1715	22.7	1.30	--	--
B757-200	1075	560	45.2	1.17	86	114
B767-200	1410	783	46.3	1.31	114	142
B767-200 ER, 300	1566	800	46.3	1.21	114	142
BAC-111-Srs 400, 500	465	250	45.0	1.05	53	--
BAE-146-100	366	225	46.0	0.80	71	--
BAE-146-100	366	225	46.0	0.52	71	--
BAE-146-200	398	225	47.1	0.88	71	--
BAE-146-200	398	225	47.1	0.61	71	--
BANDEIRANTE	58	35	47.5	0.62	--	--
BEECH BONANZA 35, 36	17	10	47.5	0.28	--	--
BEECH BARON 55, 58	28	15	47.5	0.38	--	--
BEECH KING AIR 90 Srs	49	26	47.5	0.38	--	--
BEECH KING AIR B100, SUPER 200	56	32	47.5	0.73	29	--
BEECH QUEEN AIR 65, 70 80 Srs, 88	40	24	47.5	0.33	--	--
BRITTANIA 300	825	400	47.5	1.00	F51 R76	122
C5A GALAXY (Lockheed)	3400	1500	23.5	0.77	86	F165 R165

AIRCRAFT LOADING CHARACTERISTICS

Aircraft	Op. Weight (kN)		% Load On Gear	Tire Press (MPa)	Wheel Spacing (cm)	
	Max.	Min.			Dual	Tandem
CANADAIR CL44 (Yukon)	940	500	47.5	1.12	F51 R76	122
CANADAIR CL215	194	130	47.5	0.55	--	--
CANADAIR CL 600, 601 (Challenger)	188	85	46.0	1.50	38	--
CARAVELLE-3, 6, 12	549	312	46.0	F0.80 R1.24	F38 R41	114
CARAVELLE-10, 11R SUPER 8	510	285	46.3	F0.75 R1.17	F45 R40	115
CESSNA CUTLASS, SKYHAWK	12	7	47.5	0.19	--	--
CESSNA SKYLANE, SKYWAGON	15	8	47.5	0.27	--	--
CESSNA CENTURION	18	10	47.5	0.38	--	--
CESSNA CHANCELLOR, MODEL 402C	31	20	47.5	0.48	--	--
CESSNA 421 GOLDEN EAGLE	34	21	47.5	0.55	--	--
CESSNA CONQUEST	45	26	47.5	0.59	--	--
CESSNA CONQUEST 11 (Model 441)	44	26	47.5	0.66	--	--
CESSNA CITATION I	54	30	47.5	0.69	--	--
CESSNA CITATION II	60	32	47.0	0.69	--	--
CESSNA CITATION III	90	48	47.0	1.03	27	--
COMET 4, 4B, 4C	725	400	47.7	1.07	F49 R41	114
CONCORDE	1815	1000	48.0	1.40	68	167

AIRCRAFT LOADING CHARACTERISTICS

Aircraft	**Op. Weight (kN)**		**% Load**	**Tire**	**Wheel Spacing (cm)**	
	Max.	**Min.**	**On Gear**	**Press (MPa)**	**Dual**	**Tandem**
CONVAIR 240	190	125	46.0	0.64	55	--
CONVAIR 340, 440, 540	220	140	47.0	0.47	62	--
CONVAIR 580	260	140	47.0	0.50	62	--
CONVAIR 600	210	140	45.8	0.73	54	--
CONVAIR 640	285	180	45.8	0.52	61	--
CONVAIR 880	860	400	46.6	1.03	55	114
CONVAIR 990	1135	600	48.5	1.28	61	118
DART HERALD	200	120	45.0	0.43	48	--
DASSAULT FALCON 10	84	50	47.5	0.93	24	--
DASSAULT FALCON 20	128	75	47.5	0.92	24	--
DASSAULT FALCON 50	173	90	47.5	0.93	38	--
DC-3	147	80	46.8	0.31	--	--
DC-4	335	200	46.8	0.53	74	--
DC-6, 6B	480	300	44.0	0.73	78	--
DC-7 (All Models)	640	400	47.5	0.89	78	--
DC-8-10, 20 Srs	1240	600	47.5	1.01	76	140
DC-8-43, 55, 61, 71	1470	800	47.5	1.26	76	140
DC-8-61F, 62F, 63F	1557	1001	47.5	1.35	76	140
DC-8-62, 63, 72, 73	1600	800	48.0	1.35	81	140
DC-9-15	407	300	46.2	0.90	61	--

AIRCRAFT LOADING CHARACTERISTICS

Aircraft	Op. Weight (kN)		% Load	Tire	Wheel Spacing (cm)	
	Max.	Min.	On Gear	Press (MPa)	Dual	Tandem
DC-9-21, 32	485	300	47.2	1.10	64	--
DC-9-41, 51	545	300	47.0	1.15	66	--
DC-10-10	1971	1032	46.9	1.31	137	163
DC-10-15	2037	1032	46.7	1.34	137	163
DC-10-20, 20CF, 30CF	2482	1637	34.9	1.14	137	163
DC-10-30, 40	2638	1217	37.9	1.24	137	163
DH104 DOVE, DEVON	42	30	45.0	0.32	--	--
DHC1 CHIPMUNK	10	7	47.5	0.21	--	--
DHC2 BEAVER	25	14	47.5	0.17	--	--
DHC3 OTTER	36	20	47.5	0.20	--	--
DHC4 CARIBOU	130	90	43.0	0.28	51	--
DHC5 BUFFALO	187	115	47.5	0.41	51	--
DHC6 TWIN OTTER	56	35	45.5	0.26	--	--
DHC7 DASH 7	197	120	46.8	0.74	42	--
DHC8 DASH 8	136	90	47.5	0.44	49	--
F27 FRIENDSHIP	200	125	47.5	0.54	45	--
F28 FELLOWSHIP	325	175	47.0	0.76	55	--
FAIRCHILD FH227	205	105	47.5	0.73	48	--
GATES LEARJET 25D, LONGHORN 29	69	34	47.5	0.79	25	--

AIRCRAFT LOADING CHARACTERISTICS

Aircraft	**Op. Weight (kN)**		**% Load On Gear**	**Tire Press (MPa)**	**Wheel Spacing (cm)**	
	Max.	**Min.**			**Dual**	**Tandem**
GATES LEARJET 35A, 36A	82	42	47.5	0.79	28	--
GATES LEARJET 55, 56	93	49	47.5	0.80	32	--
GULFSTREAM COMMANDER	50	30	47.5	0.48	--	--
GULFSTREAM G159	156	100	47.5	0.83	42	--
GULFSTREAM II	294	150	47.5	1.03	46	--
GULFSTREAM III	306	150	47.5	1.21	46	--
HERCULES C130, L100-20-30, L382	695	400	47.5	0.74	--	154
HS 125-700 (BAe) (DOMINIE)	112	60	45.5	0.83	32	--
HS 748-2B (BAe)	210	120	43.6	0.59	48	--
HS TRIDENT 3B, SUPER 3B, TRIDENT 3, SUPER 3, TRIDENT 2E	707	400	47.0	1.17	2D @ 30 Pairs @ 95	--
ILYUSHIN IL-18	625	350	47.5	0.80	77	105
ILYUSHIN IL-62, 62M	1648	651	47.0	1.08	80	165
ILYUSHIN IL-76T	1677	822	47.0	0.64	2DT Pairs (62 x 258) @ 144	--
ILYUSHIN IL-86	2054	1089	31.2	0.88	125	149
JETSTAR L329, C140 (Lockheed)	190	100	42.5	1.52	34	
L1011-1 TRISTAR,-385-1	1925	1400	47.5	1.33	132	178
L1011-100, 200, 500 TRISTAR	2215	1400	46.8	1.25	132	178

AIRCRAFT LOADING CHARACTERISTICS

Aircraft	**Op. Weight (kN)**		**% Load**	**Tire**	**Wheel Spacing (cm)**	
	Max.	**Min.**	**On Gear**	**Press (MPa)**	**Dual**	**Tandem**
L1049 SUPER CONSTELLATION	625	300	48.2	0.85	71	--
L188 ELECTRA	515	350	47.5	1.00	66	--
L649	418	250	47.5	0.55	71	--
L749/749A	476	300	47.5	O.59	71	--
MD-81,87	627	325	47.9	1.17	--	--
MD-82	669	349	47.6	1.27	--	--
MD-83	716	355	47.4	1.34	--	--
MERCURE-DASSAULT	559	471	47.5	0.97	65	--
MITSUBISHI MU-2	52	34	47.5	0.44	--	--
MITSUBISHI DIAMOND 1A	72	40	47.5	0.83	--	--
PIPER CUB	8	5	47.5	0.13	--	--
PIPER SEMINOLE	18	11	47.5	0.25	--	--
PIPER APACHE, COMMANCHE, SENECA	21	13	47.5	0.29	--	--
PIPER AZTEC/NAVAJO	30	18	47.5	0.42	--	--
PIPER CHEYENNE I/II	43	22	47.5	0.55	--	--
PIPER CHEYENNE III	50	28	47.5	0.69	--	--
SAUNDERS ST27	60	35	47.5	0.43	--	--
SHORTS SKYVAN SC7	56	35	41.0	0.28	--	--
SHORTS 330	102	66	47.5	0.55	--	--

AIRCRAFT LOADING CHARACTERISTICS

Aircraft	Op. Weight (kN) Max.	Op. Weight (kN) Min.	% Load On Gear	Tire Press (MPa)	Wheel Spacing (cm) Dual	Wheel Spacing (cm) Tandem
SHORTS 360	256	155	47.5	0.76	--	--
STARLIFTER LOCKHEED C141	1415	600	46.7	1.25	82	122
SWEARINGEN METRO II, IIA and MERLIN IIIB, IIIC, IVA	59	36	47.5	0.69	29	--
SWEARINGEN METRO III and MERLIN IVC	65	36	47.5	0.69	29	--
TUPOLEV TU104	765	400	45.0	0.98	F 95 R 100	120
TUPOLEV TU 134A	467	288	45.6	0.83	56	99
TUPOLEV TU 154, 154B	961	525	45.1	0.93	62	F103 R98
VANGUARD 950 Srs	655	400	47.5	0.83	74	--
VC10-1100 Srs	1395	700	47.8	0.84	86	155
VC10-1150 SUPER	1490	800	48.2	1.01	86	155
VISCOUNT 700, 800	335	200	46.0	0.88	48	--
YS11(NIHON)	245	160	47.5	0.52	52	--

Revised: May 30,1986

APPENDIX B

DEVELOPMENT OF FLEXIBLE PAVEMENT DESIGN EQUATION

FLEXIBLE LOAD PROPORTIONALITY

Plate Load Proportionality

Based on the many tests conducted at Canadian airports during the initial years of plate load testing, it was observed that for a given thickness of base course placed over subgrade, the plate bearing value at the surface of the base tended to be directly proportional to the bearing value at the surface of the subgrade. In mathematical terms:

$$P \propto S$$

OR

$$P = C \times S \qquad \textbf{(B-1)}$$

where P = plate bearing value at the surface of the base course
S = plate bearing value at the surface of the subgrade
C = constant of proportionality between P and S

This statement of proportionality is valid only when P and S are measured with the same size of bearing plate and at the same deflection and number of load repetitions.

Development of McLeod Equation

The McLeod equation relating plate bearing values at the surface of base course and subgrade is developed by dividing the base course into layers of unit thickness and applying the assumption of proportionality outlined above.

In Figure B-1, the base course t units in thickness is divided into levels 1, 2, 3, ..., t with the thickness between each level being 1 unit. P_1 designates the plate bearing value measured on the surface of the i^{th} level. Applying the assumption of proportionality given in eq. B-1,

$$P_1 = C \times S$$

OR

$$C = \frac{P_1}{S}$$

Considering the surface of level 1 to be a "new" subgrade surface:

$$P_2 = C \times P_1 = (\frac{P_1}{S}) \times P_1 = (\frac{P_1}{S})^2 \times S$$

Considering the surface of level 2 to be a "new" subgrade surface:

$$P_3 = C \times P_2 = (\frac{P_1}{S})^3 \times S$$

Continuing in this manner until the surface of the base course is reached,

$$P = P_t = (\frac{P_1}{S})^t \times S$$

or

$$t = \frac{1}{\log(\frac{P_1}{S})} \times \log(\frac{P}{S})$$

The value 1/[log (P_1/S)] is designated as K and is assumed to be independent of the type of base course material. McLeod's equation is thus stated as:

$$t = K \cdot \log(\frac{P}{S}) \qquad \textbf{(B-2)}$$

or

$$P = S \times 10^{\frac{t}{K}} \qquad \textbf{(B-3)}$$

McLeods Constant K

The constant K in Eq. B-2 is a measure of the increase in bearing strength per unit thickness of base course. For Eq. B-2 to be balanced dimensionally, K has to have the same dimensions as t.

From various geotechnical and foundation design theories, the value of the constant K has to be dependent on the size of the bearing plate used in measurement. The function of K versus size of bearing plate given in Figure 3.3 was determined from field plate bearing tests using different sizes of bearing plates.

Comparison with Layered Elastic Theory

Elastic theory applied to a two layer system representing a base course over subgrade suggests that the load ratio P/S is a function of the thickness ratio t/a and the modulus ratio E1/E2, where t is the thickness of base course, a is the radius of the bearing plate and E1 and E2 are the elastic moduli of the base course and subgrade respectively. The functional relationship between these variables as derived from elastic theory is shown in Figure B-2. Superimposed on Figure B-2 is the McLeod relationship of load ratio P/S as a function of thickness ratio t/a.

The elastic model has some deficiencies when applied to plate load testing because pavement deflection contains a plastic as well as elastic component, and modulus or stiffness values of pavement materials vary with stress and strain levels. However, the comparison in Figure B-2 serves to illustrate some limitations of the McLeod model. The equation $P = S \times 10^{t/K}$ suggests that the base surface load P will continue to increase exponentially with increasing base thickness t, but actually at high values, P will asymptotically approach a limiting value equal to the bearing value measured on an infinite depth of base course material. Similarly, the McLeod equation indicates that base course placed on subgrade will provide an increase in bearing strength regardless of the value of the subgrade bearing strength. This effect does not occur if the subgrade has a very high bearing value; in the extreme, one only has to consider the case of placing base material over rock subgrade. Despite these limitations, the McLeod model is sufficiently accurate for most pavement conditions encountered and its usefulness has been demonstrated over many years of experience.

As illustrated in Figure B-2, McLeod’s model corresponds to the layered elastic model for a modular ratio of about 5, for usual thicknesses of pavement structures.

The Design/Evaluation Equation

Equation B-3 is adapted to a design equation by substituting the equivalent single wheel load (ESWL) of the design vehicle for the surface plate bearing value P. The resulting equation may be written as:

$$S = (ESWL) \times 10^{-\frac{t}{K}} \qquad \textbf{(B-4)}$$

where S is the subgrade bearing strength required to support the ESWL for a pavement thickness

t. With the equation in this form, the subgrade bearing strength variable, S, and the variable, K, correspond to a contact area equal to that of the ESWL.

From the plate load interrelationships given in Figure 3.1, it can be shown that two plate loads P_1 and P_2, giving a deflection of 12.5 mm when applied through plates of contact area A_1 and A_2 respectively, are related by:

$$P_1 = P_2 \times \frac{A_1}{A_2} \times \frac{0.41 + \frac{81.9}{\sqrt{A_1}}}{0.41 + \frac{81.9}{\sqrt{A_2}}} \qquad \textbf{(B-5)}$$

If P_1 is taken as the standard measure of subgrade bearing strength, S_s, obtained with a 75 cm diameter plate (A_1 = 4418 cm^2), and P_2 is a subgrade bearing strength S measured on a variable contact area, A, then

$$S_s = S \times \frac{7.3 \times 10^3}{A(0.41 + \frac{81.9}{\sqrt{A}}} \qquad \textbf{(B-6)}$$

Substituting Eq. B-6 into Eq. B-4:

$$S_s = F \times (ESWL) \times 10^{-\frac{t}{K}} \qquad \textbf{(B-7)}$$

where F = $\dfrac{7.3 \text{ x } 10^3}{A(0.41 + 81.9/\sqrt{A})}$

Ss = standard measure of subgrade bearing strength (kN, 750 mm diam plate, 12.5 mm defl'n, 10 rep. of loading)

ESWL = design vehicle equivalent single wheel load (kN) determined as given in Section 3.2.5

A = contact area of the ESWL (cm^2)

t = pavement thickness (cm)

K = variable depending on the contact area of the ESWL, as given in Figure 3.3

For evaluation purposes, Eq. B-7 is further modified by the addition of an overload ratio, R, to produce the design/evaluation equation given in Section 3.2.6.

FIGURE B-1 - DEVELOPMENT OF McLEOD EQUATION

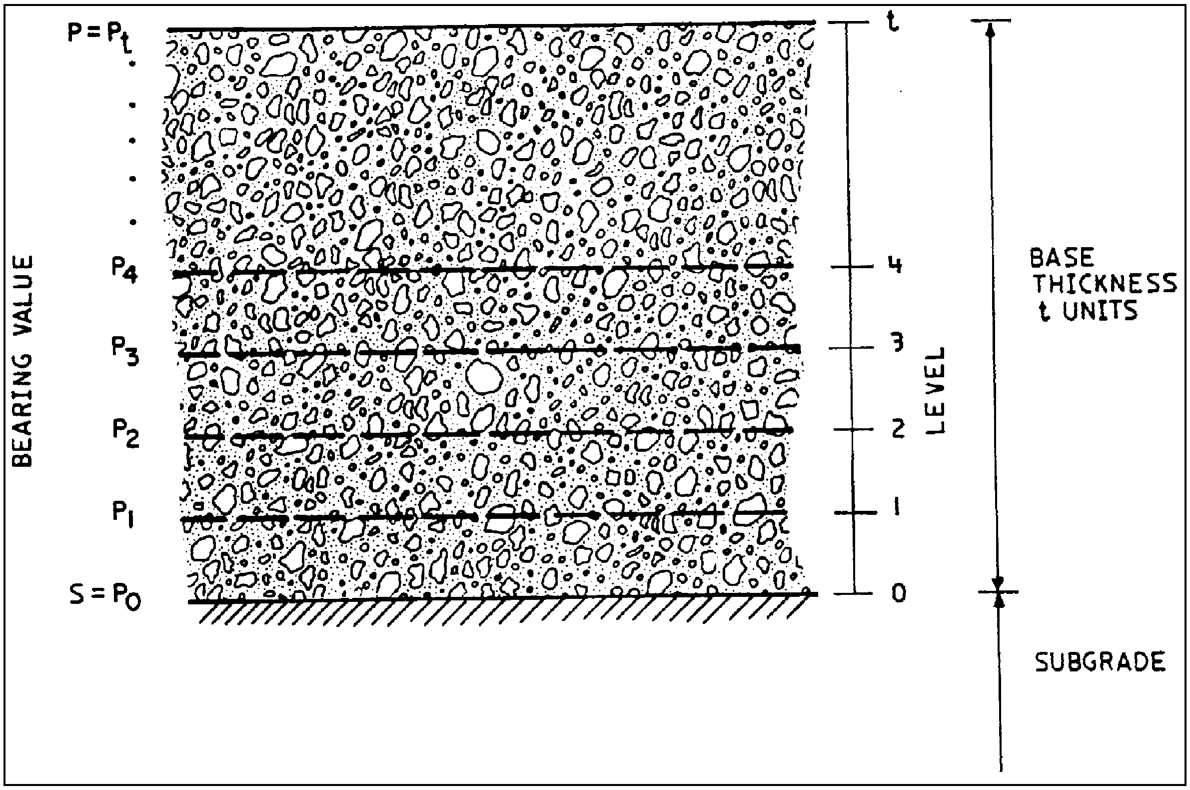
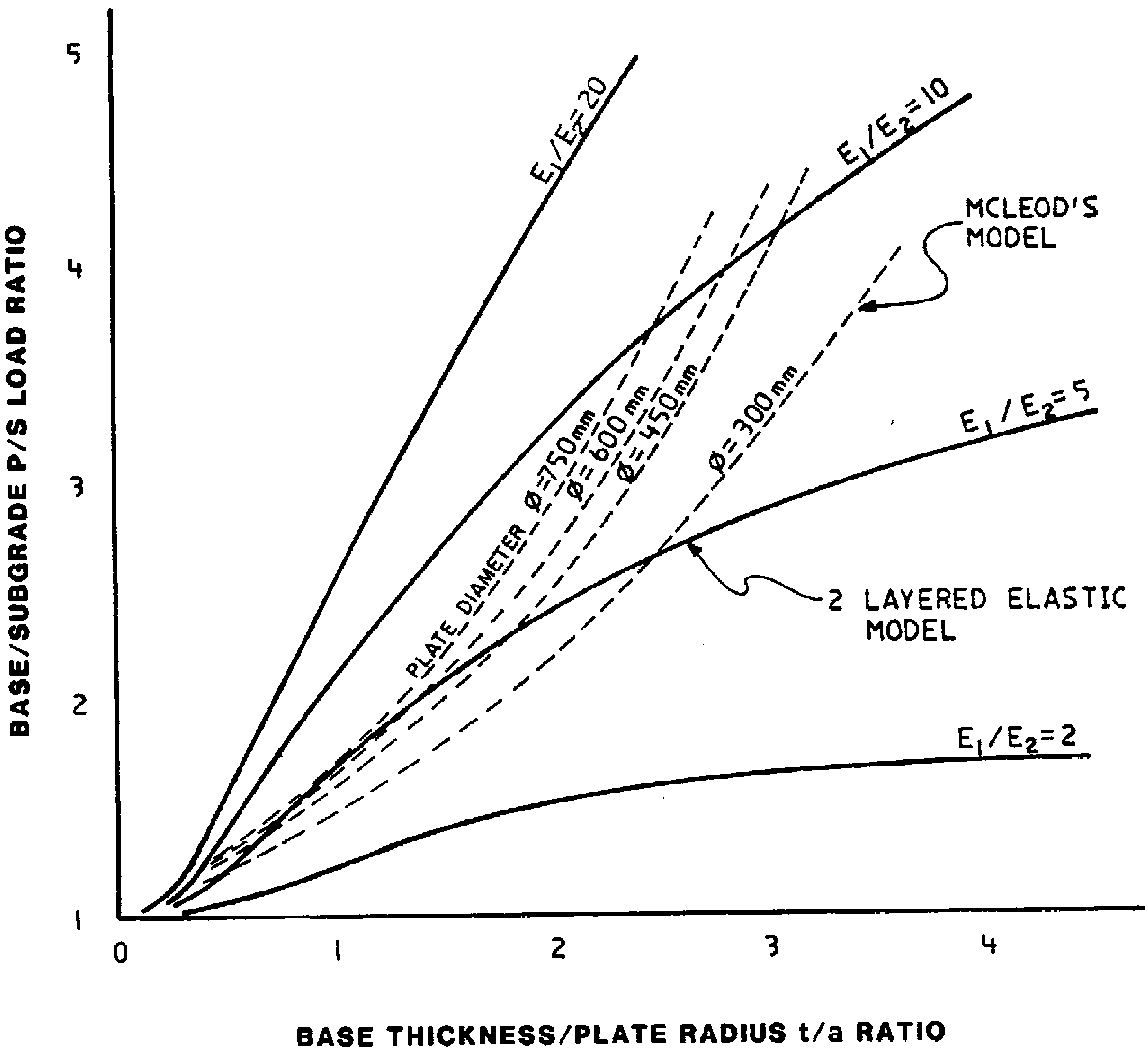


FIGURE B-2
COMPARISON OF TWO LAYERED ELASTIC AND McLEOD'S MODELS



APPENDIX C

WESTERGAARD STRESS ANALYSIS

FOR INTERIOR LOADING OF CONCRETE SLAB

1.0 REFERENCES

(1) Pickett, Gerald, Milton E. Raville, William C. James, Frank J. McCormick. Deflections, Moments and Reactive Pressures for Concrete Pavements. Kansas State College, Bulletin No. 65, 1951.

(2) Computer Program "RIGID" for Design and Evaluation of Airport Rigid Pavements.

2.0 WESTERGAARD ANALYSIS

In the analysis, the following assumptions are made regarding the concrete slab:

(1) the slab consists of homogeneous, isotropic, and elastic material;

(2) the slab is of uniform thickness;

(3) the loads on the top and on the bottom of the slab occur in a direction normal to these surfaces;

(4) the range of relative thicknesses is such that the theory of thin plates may be applied.

Based on these assumptions, the slab deflection must satisfy the following differential equation:

$$D\sigma^2\omega = q - p \qquad \textbf{(C-1)}$$

where σ^2 = Laplace Differential Operator

= $\delta^2/\delta r^2 + 1/r\ \delta/\delta r + 1/r^2\ \delta^2/\delta\Theta^2 + \delta^2/\delta z^2$

D = Flexural Rigidity = $Eh^5/[12(1-\mu^2)]$

E = Young's modulus for slab (27,580 MPa assumed)

μ = Poisson's ratio for slab (0.15 assumed)

h = thickness of slab

ω	=	slab deflection
q	=	intensity of slab loading
p	=	intensity of reactive pressure between slab and subgrade

In order to obtain a solution for Eq. (C - 1), the relation between p and ω must be either assumed or derived from assumptions regarding the subgrade. If the subgrade is assumed to have the properties of a dense liquid, then the following relation applies:

$$p = k \cdot \omega \qquad \textbf{(C-2)}$$

where k is the modulus of subgrade reaction.

An indirect approach is used to solve the differential equation. If the problem of a concentrated load is considered. then Eq. (C - 1) becomes

$$D\sigma^2\omega + p = 0 \qquad \textbf{(C-3)}$$

for all the slab except the point of application of the load.

Substituting the value of p from Eq.(C - 2), the differential equation becomes

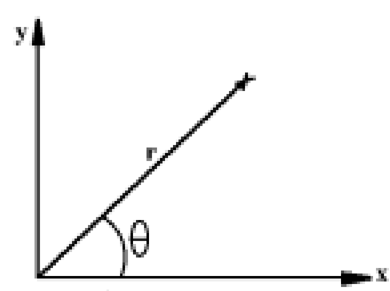
$$D\sigma^2\omega + k\omega = 0 \qquad \textbf{(C-4)}$$

This equation can now be solved if the slab is assumed to be of infinite extent. The solution is developed in reference (1).

For the following loading conditions:

a) Concentrated Load

Fig. C-1



Deflection ω at the origin and moment M at the origin in the direction of the X axis are given by:

$$\omega = \frac{Pl^2}{4D} \cdot Re[H_s^I(\frac{r\sqrt{i}}{l})] \tag{C-5}$$

$$M = \frac{P}{8} \cdot Re[(1+\mu) i \cdot H_s^I(\frac{r\sqrt{i}}{l}) + (1-\mu)(i \cdot H_s^I(\frac{r\sqrt{i}}{l}) - \frac{2l\sqrt{i}}{r} \cdot H_1^I(\frac{r\sqrt{i}}{l}))\cos 2\theta \tag{C-6}$$

where P = concentrated load on slab

l = $(D/k)^{1/4}$

Re = "the real part of"

i = √-1

r = distance from the load

H^I_s, H^I_1 = Hankel functions of order zero and one

b) Uniformly Loaded Sector

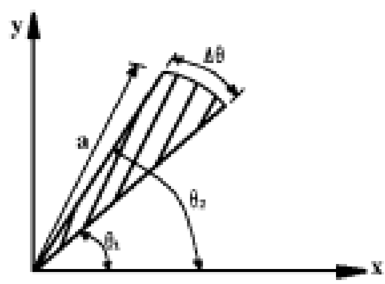


Fig. C-2

For a uniformly loaded sector as shown, concentrated load P is replaced by uniform load q acting on the differential area drda, and the above equations are integrated over r = Θ to a and Θ = Θ_1 to Θ_2.

$$\omega = \frac{ql^4}{D}(\frac{\theta_2 - \theta_1}{2\pi})[1 + \frac{\pi a}{2l} I_m \sqrt{i} H_1^I(\frac{a\sqrt{i}}{l})] \tag{C-7}$$

where I_m = "the imaginary part of"

$$M=\frac{ql^2}{8}R_e[(1+\mu)(\theta_2-\theta_1)\frac{a\sqrt{i}}{l}H_1^I(\frac{a\sqrt{i}}{l})+(1-\mu)(\sin 2\theta_2-\sin 2\theta_1)(\frac{a}{2l}\sqrt{i}H_1^I(\frac{a\sqrt{i}}{l})+H_s^I(\frac{a\sqrt{i}}{l})-0.5)]$$

(C-8)

The tensile stress at the bottom of the slab associated with this moment is given by:

$$f_c=\frac{6M}{h^2}$$ **(C-9)**

For purposes of computer program development, Eq. (C - 8) is stated in the form:

$$M=\frac{ql^2}{8}[1.15\Delta\theta f_1(\frac{a\sqrt{i}}{l})+1.7\sin\Delta\theta\cos 2\theta f_2(\frac{a\sqrt{i}}{l})]$$ **(C-10)**

$$\textit{where} \quad \Delta\theta=\theta_2-\theta_1 \qquad \theta=(\frac{\theta_1+\theta_2}{2})$$

$$f_1(\frac{a\sqrt{i}}{l}=R_e[\frac{a\sqrt{i}}{l}H_1^I(\frac{a\sqrt{i}}{l})]=R_e[2x\sqrt{i}H_1^I(2x\sqrt{i})] \qquad (\textit{where}\, x=\frac{a}{2l})$$

$$=-4x^2(\frac{\ln x+\gamma-1/2}{\pi})+\frac{x^4}{2}+x^6(\frac{lnx+\gamma-5/3}{3\pi})-\frac{x^8}{144}-x^{10}(\frac{lnx+\gamma-131/60}{720\pi})$$

$$+\frac{x^{12}}{86400}+x^{14}(\frac{lnx+\gamma-353/140}{907200\pi})\ldots$$

$$f_2\left(\frac{a\sqrt{i}}{l}\right)=R_e\left[\frac{a\sqrt{i}}{2l}H_1^I\left(\frac{a\sqrt{i}}{l}\right)+H_s^I\left(\frac{a\sqrt{i}}{l}\right)-0.5=R_e\left[x\sqrt{i}H_1^I(2x\sqrt{i})+H_s^I(2x\sqrt{i})-0.5\right]\right.$$

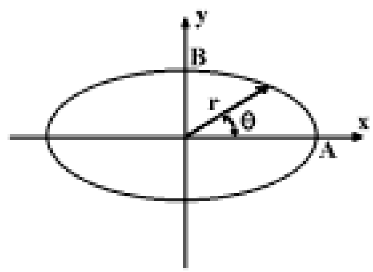
$$=-\frac{x^2}{\pi}+\frac{x^4}{8}+x^6\left(\frac{lnx+\gamma-19/12}{9\pi}\right)-\frac{x^8}{384}-x^{10}\left(\frac{lnx+\gamma-259/120}{1800\pi}\right)$$

$$+\frac{x^{12}}{207360}+x^{14}\left(\frac{lnx+\gamma-527/210}{2116800\pi}\right)\ldots$$

3.0 LOADING CONDITIONS

The load is applied to the concrete slab through the aircraft tires. The shape of the tire imprint is assumed to be an ellipse as shown below.

Fig. C-3



The general equation for an ellipse is given by:

$$\frac{x^2}{A^2}+\frac{y^2}{B^2}=1 \quad or \quad r^2=\frac{1}{\frac{\sin^2\theta}{B^2}+\frac{\cos^2\theta}{A^2}} \qquad \textbf{(C-11)}$$

where A = half of the major axis
B = half of the minor axis

It is assumed that length of the tire imprint is related to imprint area by (see Figure 3.6

of manual text):

$$imprint\ length = 2A = 1.383\sqrt{area} = 1.383\sqrt{P/Q} \qquad \text{(C-12)}$$

where P = tire load
Q = tire pressure

For a contact area of elliptical shape, Eq.(C - 12) requires that

$$B = 0.6655A \qquad \text{(C-13)}$$

To apply the moment equation (C - 10) for this loading condition,the co-ordinates of 72 points along the perimeter of the ellipse are determined. These points are located by dividing the ellipse into 72 segments each subtended by an angle of ϖ/72 radians at the centre of the ellipse. The co-ordinates of these points may be calculated as:

$$\begin{aligned} &For\ n = 1,...,72 \\ &x_n = A[1 + 1.25775\sin^2(n \times 0.087266)]^{-1/2}\cos(n \times 0.087266) \\ &y_n = A[1 + 1.25775\sin^2(n \times 0.087266)]^{-1/2}\sin(n \times 0.087266) \end{aligned} \qquad \text{(C-14)}$$

If the tire imprint is centred at the point (X.,Y.) as shown below rather than at the origin Or the co-ordinate system then the coordinates are defined by:

$x_n = x_n + X_s$ for n = 1, ... , 72

$y_n = y_n + Y_s$ for n = 1, ... , 72

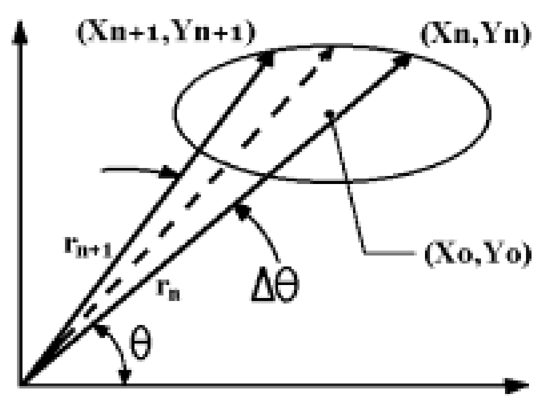


Fig. C-4

4.0 MOMENT DUE TO GEAR LOADING

To calculate the moment at the origin in the direction of the X axis due to a single wheel load with the tire pressure q, as illustrated in Figure C-4, the moment equation(C -10) is summed for 72 loaded sectors:

$$M=\sum_{n=1}^{72}\frac{ql^2}{8}[1.15\Delta\theta_{(n)}f_{1(n)}+1.7\sin\Delta\theta_{(n)}cos2\theta(n)f_{2(n)}] \quad \textbf{(C-16)}$$

Each sector is defined by two radial lines from the origin to two consecutive points (as defined previously) along the perimeter of the ellipse as shown in Figure C-4. For each sector

$$a_{(n)}=\frac{r_n+r_{n+1}}{2}=\frac{\sqrt{X_n^2+Y_{n+1}^2}+\sqrt{X_{n+1}^2+Y_{n+1}^2}}{2}$$

$$\cos2\theta_{(n)}=\frac{X_n\cdot X_{n+1}-Y_n\cdot Y_{n+1}}{r_n\cdot r_{n+1}} \quad \textbf{(C-17)}$$

$$\sin\Delta\theta_{(n)}=\frac{Y_{n+1}\cdot X_n-Y_n\cdot X_{n+1}}{r_n\cdot r_{n+1}}$$

The summation progresses around the perimeter Or the ellipse in a counterclockwise direction. When the origin is located outside the imprint area as in Fig. C-4, $\Delta\Theta$ is positive and the sector adds to the moment along the top portion of the ellipse. Along the bottom portion of the ellipse, $\Delta\Theta$ is negative and the sector subtracts from the moment. When the summation is completed around the entire perimeter, the resulting moment calculated is that due to the load on the wheel imprint area.

For a multiwheeled gear loading of T wheels, the moments for each wheel determined as above are added.

$$M_T=\sum_{m=1}^{T}M_m \quad \textbf{(C-18)}$$

With moment determined, flexural stress at the bottom of the slab is calculated using Eq.(C - 9).

5.0 MAXIMUM MOMENT DUE TO GEAR LOADING

a) Rotation of Axis

The maximum moment developed by a multiwheeled gear loading may not occur in the direction of the X-axis. To determine the maximum moment and stress, the axis is rotated by an angle Φ as shown below.

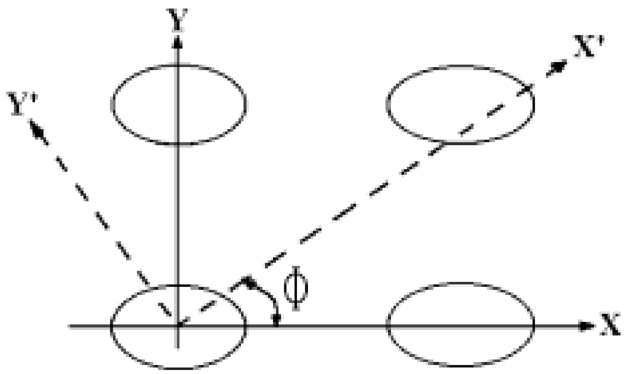


Fig. C-5

The moment about the X axis for a gear consisting of T tires is:

$$M_T^{/}=\sum_{m=1}^{T}\sum_{n=1}^{72}\frac{ql^2}{8}[1.15\Delta\theta_{(n,m)}f_{1(n,m)}+1.7\sin\Delta\theta_{(n,m)}(\cos2\theta_{(n,m)}\cos2\Phi-\sin2\theta_{(n,m)}\sin2\Phi)f_{2(n,m)}] \quad \textbf{(C-19)}$$

$$Let\ S_1=\sum_{m=1}^{T}\sum_{n=1}^{72}1.15\Delta\theta_{(n,m)}f_{1(n,m)}$$

$$S_2=\sum_{m=1}^{T}\sum_{n=1}^{72}1.7\sin\Delta\theta_{(n,m)}\ \sin2\theta_{(n,m)}f_{2(n,m)}$$

$$S_3=\sum_{m=1}^{T}\sum_{n=1}^{72}1.7\sin\Delta\theta_{(n,m)}\ \sin2\theta_{(n,m)}f_{2(n,m)}$$

$$Thus \qquad M_T^{/} = \frac{ql^2}{8}[S_1 + S_2 cos2\Phi - S_3 \sin 2\Phi] \qquad \textbf{(C-20)}$$

To find the angle Φ that will result in the maximum (and minimum) moments, the derivative of M'_T with respect to Φ is set to zero.

$$\frac{\delta M_T^{/}}{\delta \Phi} = \frac{ql^2}{8}(-2S_2 \ \sin 2\Phi - 2S_3 \ \cos 2\Phi) = 0$$

$$\tan 2\Phi = \frac{-S_3}{S_2}$$

S_2 and S_3 can be either positive or negative.

$$For\ all\ cases\ ,\ the\ maximum\ moment\ = \frac{ql^2}{8}(S_1 + \sqrt{S_2^2 + S_3^2})$$

$$If\ S_2\ is\ negative,\ then\ 2\Phi\ = \pi + \tan^{-1}(\frac{-S_2}{S_3})$$

$$If\ S_2\ is\ positive,\ then\ 2\Phi\ = \tan^{-1}(\frac{-S_2}{S_3})$$

(b) Displacement of Axis

The moment due to a multiwheeled gear loading is calculated at the center of the wheel closest to the center of gravity of the gear loading. This practice has long been followed in the traditional method of determining moments using influence charts. Actually, the maximum moment is displaced slightly off the center of this wheel toward the center of gravity or the gear loading. This displacement is usually ignored because of past practice and because the difference in moments and stresses is small.

APPENDIX D

FLEXIBLE PAVEMENT DESIGN

COMPUTER PROGRAM

"FLEXIBLE" is a BASIC program written using Microsoft QuickBasic 4.5 and can be used on any IBM-PC computer. The program may be modified for use with other machines or input/output modes. Refer to the following pages for an example program run and output which is briefly described below.

Once the program has been loaded into the system, it will then prompt the user to enter the necessary data.

INPUT 1: Allows the user to identify the aircraft or ground vehicle with a maximum of 30 characters.

INPUT 2: Aircraft gross weight in kN.

INPUT 3: The percent of the gross weight on the gear in question.

INPUT 4: The number of wheels in the gear.

INPUT 5: The tire pressure in MPa.

INPUT 6: Allows the user to differentiate between an aircraft or a ground vehicle run.

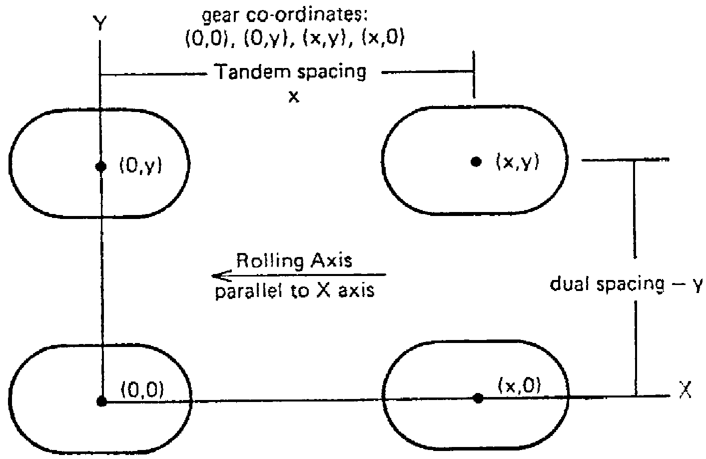
INPUT 7: The program will then prompt the user to determine whether a hardcopy printout of the results is required.

INPUT 8: The gear wheel co-ordinates. The (X,Y) co-ordinates in cm of the wheel centres inputed one pair at a time. In giving the wheel co-ordinates, the gear must be oriented so that its rolling axis is parallel to the X-axis (Figure D-1). Neither the order in which the wheels are identified nor the location of the origin of the axes is critical. However, the wheel co-ordinates will be identified in the same manner in the output.

Normally the gear in question will be one of the main gears. If the gear load is known, it may be used in place of gross weight and 100% used as percent of load on the main gear.

By pressing F10 the program should now execute and produce the output shown in the following pages. At the end of the run, the user may re-run the program with a new gross weight but with the other input values remaining the same.
For the design/evaluation of roads and carparks, the ground vehicle option is chosen in input 6. The output will then contain the subgrade bearing strength values required for overload ratios of 0.625, 1.00, 1.25, 1.50 and 2.00 as shown by the example in the following pages.

FIGURE D-1 - ORIENTATION OF AIRCRAFT GEAR



"FLEXIBLE" PROGRAM RUN AND OUTPUT

• At the dos prompt type A:\FLEXIBLE

REQUEST Run Identification
INPUT 1 B720

REQUEST Gross Weight (KN)
INPUT 2 1045

REQUEST % Load on Gear
INPUT 3 47.5

REQUEST Number of Wheels
INPUT 4 4

REQUEST Tire Pressure (MPA)
INPUT 5 1.00

REQUEST Type of Vehicle (Ground (G)/Air (A))
INPUT 6 A

REQUEST To Printer or Screen (P/S)
INPUT 7 S

REQUEST Wheel Coordinates (CM)
INPUT 8 0,0
0,81
124,81
124,0

INPUT 9 Press F10 to Calculate.

REQUEST Another Weight? (Y/N)
INPUT 10 N

The input screen and program output are shown on the following pages.

```
                         FLEXIBLE PAVEMENT DESIGN
   Run Identification : B720
     Gross Weight (KN): 1045          % Load on Gear: 47.5
      Number of Wheels: 4       Tire Pressure (MPA) : 1.00
      Type of Vehicle (Ground (G)/Air (A)): A  To Printer Or Screen(P/S)

                       Wheel Coordinate (CM): Wheel Num: ___  X: 0    Y: 64
                                              1:       0        0
                                              2:       0        81
                                              3:       124      81
                                              4:       124      0

                  [SF4]-Quit     [F10]-Calculate    [Esc]-Reset
```

INPUT SCREEN

PROGRAM OUTPUT (AIRCRAFT LOADING)

```
                           FLEXIBLE PAVEMENT DESIGN
**********************************************************************
 RUN IDENTIFICATION : B720
 Gross Weight (KN)  :  1045.0
 % Load on Gear     :    47.5
 Tire Load (KN)     :   124.1
 Tire Pressure (MPA):     1.00


 Wheel Coords (CM) :   Wheel #      X     Y

                         1          0     0
                         2          0     81
                         3          124   81
                         4          124   0

 Pavement                    Subgrade Bearing Strength (KN)
 Thickness                   Required For Over Load Ratio Of
   (CM)                      1.00     1.25     1.50     2.00
                         ======================================
    10                     218.70   174.96   145.80   109.35
    20                     175.13   140.11   116.76    87.57
    30                     148.05   118.44    98.70    74.02
    40                     134.24   107.39    89.49    67.12
    50                     121.07    96.86    80.71    60.53
    60                     108.90    87.12    72.60    54.45
    70                      97.80    78.24    65.20    48.90
    80                      87.74    70.19    58.49    43.87
    90                      78.66    62.93    52.44    39.33
   100                      70.48    56.38    46.98    35.24
   110                      63.12    50.49    42.08    31.56
   120                      56.51    45.21    37.68    28.26
   130                      50.59    40.47    33.73    25.29
   140                      45.28    36.22    30.19    22.64
   150                      40.53    32.42    27.02    20.26
   160                      36.27    29.02    24.18    18.14
   170                      32.47    25.98    21.65    16.23
   180                      29.07    23.25    19.38    14.53
   190                      26.03    20.82    17.35    13.01
   200                      23.31    18.65    15.54    11.66
   210                      20.88    16.71    13.92    10.44
   220                      18.71    14.97    12.48     9.36
   230                      16.78    13.42    11.18     8.39
   240                      15.04    12.03    10.03     7.52
   250                      13.49    10.79     8.99     6.75
   260                      12.11     9.68     8.07     6.05
   270                      10.87     8.69     7.24     5.43
   280                       9.76     7.80     6.50     4.88
```

PROGRAM OUTPUT (GROUND VEHICLE LOADING)

```
                         FLEXIBLE PAVEMENT DESIGN
**********************************************************************
RUN IDENTIFICATION : CRASH RESCUE VEHICLE
Gross Weight (KN)  : 66.0
% Load on Gear     : 28.0
Tire Load (KN)     : 18.5
Tire Pressure (MPA):  0.31

Wheel Coords (CM) : Wheel #              X         Y

                                         0         0

Pavement                  Subgrade Bearing Strength (KN)
Thickness                 Required For Over Load Ratio Of
  (CM)                  0.625    1.00     1.25     1.50     2.00
                   ==============================================
   10                  75.62    47.26    37.81    31.51    23.63
   20                  57.89    36.18    28.95    24.12    18.09
   30                  44.32    27.70    22.16    18.46    13.85
   40                  33.92    21.20    16.96    14.14    10.60
   50                  25.97    16.23    12.98    10.82     8.12
   60                  19.88    12.42     9.94     8.28     6.21
   70                  15.22     9.51     7.61     6.34     4.76
```

"FLEXIBLE" PROGRAM LISTING

```
'*********************************************************************
'*                                                                   *
'* Program Name: FLEXIBLE.BAS                                        *
'* Purpose.....: This program is for flexible pavement design according *
'*               to Transport Canada practices.  Questions regarding   *
'*               this program should be directed to AKPB.            *
'* Author......: AKPB                                                *
'* Date........: Feb 1987                                            *
'* Language....: Hewlett Packard Basic                               *
'*                                                                   *
'*********************************************************************
'* Compile Instructions:                                             *
'*                                                                   *
'* BC D:\QB40\SRC\FLEXIBLE.BAS /E/X/O;                               *
'* Link /EX/NOE FLEXIBLE , D:\EXE\FLEXIBLE.EXE, , ALL.LIB;           *
'*                                                                   *
'*********************************************************************
'*                                                                   *
'* Modification History:                                             *
'*                                                                   *
'* Description of Change:                                            *
'*                                                                   *
'* July 88 - Capt R.H.J. Boisjoli                                    *
'*                                                                   *
'*          Air Command Headquarters Winnipeg 895-5869               *
'*                                                                   *
'*                      Translated to Microsoft Quick Basic 4.0.     *
'*                      This will allow the program to run on MSDOS  *
'*                      computers.                                   *
'*                                                                   *
'* February 92 - Marc Turpin                                         *
'*                                                                   *
'*              PWC/A&ES/AIR TRANSPORTATION HQ 990-3780              *
'*                                                                   *
'*                       Upgraded to Microsoft Quick Basic 4.5.      *
'*                       Corrected Errors (in SUB Calculate):        *
'*                                                                   *
'*                               -Change Xd% to Xd# in line 35       *
'*                               -Change Xs% to Xs# in line 36       *
'*                               -Change NumWhls% to N1% in line 62  *
'*                               -Change "<" to ">" in line 66       *
'*                                                                   *
'*********************************************************************

CONST IDRow = 5, IDCol = 24, IDLen = 30 ' Scrn row and col and len for
Ident$
CONST GWRow = 7, GWCol = 24, GWLen = 6  ' Scrn row and col and len for
GRWght#
CONST LGRow = 7, LGCol = 55, LGLen = 5  ' Scrn row and col and len for
PcntLoad#
CONST NWRow = 9, NWCol = 24, NWLen = 2  ' Scrn row and col and len for
NumWhls%
CONST TPRow = 9, TPCol = 55, TPLen = 6  ' Scrn row and col and len for
TirePress#
CONST VTRow = 11, VTCol = 44, VTLen = 1 ' Scrn row and col and len for
VehType$
CONST WXRow = 15, WXCol = 49, WXLen = 4 ' Scrn row and col and len for
WheelX%
```

```
CONST WYRow = 15, WYCol = 58, WYLen = 4 ' Scrn row and col and len for
WheelY%
CONST PSRow = 11, PSCol = 76, PSLen = 1 ' Scrn row and col and len for
PrintScrn
CONST ReportFileName = "REPORT.FIL"     ' Temp report file name

DECLARE SUB Calculate (Ident$, GRWght&, PcntLoad#, NumWhls%, TirePress#,
VehType$)
DECLARE SUB Credit ()
DECLARE SUB DrawScreen ()
DECLARE SUB EditFld (CurrFld$, ValidChars$, StRow%, StCol%, FldType%,
FldLen%, ExitKey$)
DECLARE SUB Frame (ULRow%, ULCol%, LRRow%, LRCol%, LineType%)
DECLARE SUB InputData (Ident$, GRWght&, PcntLoad#, NumWhls%, TirePress#,
VehType$, ExitKey$)
DECLARE SUB Page ()

DIM SHARED Esc AS STRING * 1           'The Escape key
DIM SHARED BS AS STRING * 1            'The back space key
DIM SHARED ABORT AS STRING * 2         'The shift F4 key
DIM SHARED Retrn AS STRING * 1         'The Return or Enter key
DIM SHARED CrsrRight AS STRING * 2     'The right arrow key
DIM SHARED CrsrLeft AS STRING * 2      'The left arrow key
DIM SHARED CrsrDown AS STRING * 2      'The down arrow key
DIM SHARED CrsrUp AS STRING * 2        'The up arrow key
DIM SHARED PF10 AS STRING * 2
DIM SHARED PrtScrn AS STRING * 1
DIM SHARED WheelX%(1 TO 12)
DIM SHARED WheelY%(1 TO 12)
DIM SHARED SBRarray#(1 TO 70)
DIM SHARED SBR.625array#(1 TO 70)
DIM SHARED SBR1.25array#(1 TO 70)
DIM SHARED SBR1.50array#(1 TO 70)
DIM SHARED SBR2.00array#(1 TO 70)
DIM SHARED GRWght&
DIM SHARED Ident$
DIM SHARED PcntLoad#
DIM SHARED TireLoad#
DIM SHARED TirePress#
DIM SHARED NumWhls%
DIM SHARED ReportFile AS STRING
DIM SHARED FileNum AS INTEGER
DIM SHARED PageLen AS INTEGER

'
'************************************************************************
'*                                                                      *
'*  Main line.                                                          *
'*                                                                      *
'************************************************************************


BS = CHR$(8)
Esc = CHR$(27)
ABORT = CHR$(0) + CHR$(87)
Retrn = CHR$(13)
CrsrRight = CHR$(0) + CHR$(77)
CrsrLeft = CHR$(0) + CHR$(75)
CrsrUp = CHR$(0) + CHR$(72)
CrsrDown = CHR$(0) + CHR$(80)
PF10 = CHR$(0) + CHR$(68)
```

```
ExitKey$ = Esc
PrtScrn = "S"                 ' Set report to screen
Credit
ON ERROR GOTO ErrHandler
DO
   FileNum = FREEFILE
   InputData Ident$, GRWght&, PcntLoad#, NumWhls%, TirePress#, VehType$,
ExitKey$
   IF ExitKey$ = PF10 THEN
      IF PrtScrn = "S" THEN
         CLS
         ReportFile = "SCRN:" + ReportFileName
         PageLen = 23
      ELSE
         ReportFile = "LPT1:"' + ReportFileName
         PageLen = 54
      END IF
      Calculate Ident$, GRWght&, PcntLoad#, NumWhls%, TirePress#, VehType$
      IF PrtScrn = "S" THEN
         LOCATE 25, 2
         PRINT "Press any key to continue...";
         WHILE INKEY$ = ""
         WEND
         DrawScreen
      END IF
      LOCATE 23, 1
      PRINT "Another Weight ? (Y/N)";
      LOCATE 23, 27, 1
      Ans$ = ""
      WHILE Ans$ = ""
         Ans$ = INKEY$
         IF UCASE$(Ans$) <> "Y" AND UCASE$(Ans$) <> "N" THEN
            Ans$ = ""
         END IF
      WEND
      IF UCASE$(Ans$) = "Y" THEN
         ExitKey$ = ""
         GRWght& = 0
         LOCATE GWRow, GWCol
         PRINT "_____ ";
         LOCATE 23, 1
         PRINT "                      ";
      END IF
   END IF
LOOP UNTIL GRWght& > 0 OR ExitKey$ = ABORT
CLS
END

ErrHandler:
Errr% = ERR
LOCATE 22, 1
BEEP
SELECT CASE Errr%
   CASE 24, 25
      PRINT "Printer Not Ready. Please Check It.";
   CASE 27
      PRINT "Printer Out Of Paper.  Please Reload.";
   CASE ELSE
      PRINT "Unknown Error." + STR$(Errr%)
END SELECT
LOCATE 23, 1
```

```
PRINT "  Press any key to continue...";
WHILE INKEY$ = ""
WEND
LOCATE 22, 1
PRINT "                                    ";
LOCATE 23, 1
PRINT "                                 ";
IF ((Errr% = 25) OR (Errr% = 27) OR (Errr% = 24)) THEN
   Errr% = 0
   RESUME
ELSE
   RESUME NEXT
END IF
END

'
'*************************************************************************
'*                                                                       *
'*  This procedure calculates and prints the appropriate values.  Many  *
'*  of the variables do not have meaningful names.  The names used in   *
'*  in the original Hewlett-Packard program were retained since there   *
'*  was no way of telling what they stood for.                          *
'*                                                                       *
'*************************************************************************
'
SUB Calculate (Ident$, GRWght&, PcntLoad#, NumWhls%, TirePress#, VehType$)

'*************************************************************************
'*                                                                       *
'*  Calculate tire load and print titles.                               *
'*                                                                       *
'*************************************************************************
'
   TireLoad# = GRWght& * PcntLoad# / (100 * NumWhls%)
   FileNum = FREEFILE
   OPEN ReportFile FOR OUTPUT AS FileNum
   Page
   NumLines% = 16 + NumWhls%
'
'*************************************************************************
'*                                                                       *
'*  Multiple wheel centre - geometric.                                  *
'*                                                                       *
'*************************************************************************
'
   IF PrtScrn = "P" THEN
      LOCATE 23, 1
      PRINT "Working...";
   END IF
   Xd# = 1000
   Xs# = 0
   N1% = NumWhls% - 1
   IF N1% > 0 THEN
      Xg% = 0
      Yg% = 0
      FOR Count% = 1 TO NumWhls%
         Xg% = Xg% + WheelX%(Count%)
         Yg% = Yg% + WheelY%(Count%)
      NEXT Count%
      Xg% = Xg% / NumWhls%
      Yg% = Yg% / NumWhls%
```

```
      Ref# = 1000#                ' Closest wheel
      FOR Count% = 1 TO NumWhls%
         Z# = SQR((Xg% - WheelX%(Count%)) ^ 2 + (Yg% - WheelY%(Count%)) ^ 2)
         IF Ref# > Z# THEN
            Ref# = Z#
            Xref% = WheelX%(Count%)
            Yref% = WheelY%(Count%)
         END IF
      NEXT Count%
      FOR Count% = 1 TO NumWhls%   ' C/C spacing
         Z# = SQR((Xref% - WheelX%(Count%)) ^ 2 + (Yref% - WheelY%(Count%))
^ 2)
         IF Xs# < Z# THEN
            Xs# = Z#
         END IF
      NEXT Count%
      FOR Count% = 1 TO N1%   ' Clear spacing
         N2% = Count% + 1
         FOR Count2% = N2% TO NumWhls%
            Z# = SQR((WheelX%(Count%) - WheelX%(Count2%)) ^ 2 +
(WheelY%(Count%) - WheelY%(Count2%)) ^ 2)
            IF (Xd# - Z#) > 0 THEN
               Xd# = Z#
               Yy% = WheelY%(Count%) - WheelY%(Count2%)
            END IF
         NEXT Count2%
      NEXT Count%
      Xd# = Xd# - .8298 * SQR(10# * TireLoad# / TirePress#)
      IF Yy% = 0 THEN
         Xd# = Xd# - .5532 * SQR(10# * TireLoad# / TirePress#)
      END IF
      Z# = NumWhls%               ' EWSL
      M% = 1
   END IF
   Count% = 10
'
'************************************************************************
'*                                                                      *
'*  This section calculates and prints the subgrade bearing strength.   *
'*                                                                      *
'************************************************************************
'
   DO
      T# = Count%
      IF T# - (Xd# / 2#) <= 0 THEN
         Xp# = TireLoad#          ' for T < D / 2
      ELSE
         IF T# - (2# * Xs#) >= 0 THEN
            Xp# = Z# * TireLoad#  ' for T > 2S
         ELSE                     ' D/2 < T < 2S
            Xp# = TireLoad# * (2# * T# / Xd#) ^ ((LOG(Z#) / LOG(10#)) /
(LOG(4# * Xs# / Xd#) / LOG(10#)))
         END IF
      END IF
      Area# = 10 * Xp# / TirePress#
      IF Area# < 100 THEN  'Area# > 8000# OR
         Count% = 710
         PRINT #FileNum, "     Contact Area Outside of Empirical
Relationship"
         NumLines% = NumLines% + 1
      ELSE
```

```
         Aa# = Area# / 1000
         P1# = 76.547155# + 4.7796366# * Aa# + 25.752346# * Aa# ^ 2 -
12.913974# * Aa# ^ 3
         P2# = 3.0618698# * Aa# ^ 4 - .39427499# * Aa# ^ 5 + 26517.766# *
(Aa# / 10) ^ 6
         Xka# = P1# + P2# - 7310.5616# * (Aa# / 10#) ^ 7
         Xk# = 1# / Xka#
         Cf# = 7500 / (Area# * (.444 + 81.1 / SQR(Area#)))
         SBRarray#(M%) = Xp# * Cf# * 10# ^ (-T# * Xk#)
         SBR.625array#(M%) = SBRarray#(M%) / .625
         SBR1.25array#(M%) = SBRarray#(M%) / 1.25
         SBR1.50array#(M%) = SBRarray#(M%) / 1.5
         SBR2.00array#(M%) = SBRarray#(M%) / 2
         IF UCASE$(VehType$) = "G" THEN
            PRINT #FileNum, "     ";
            PRINT #FileNum, USING "######"; T#;
            PRINT #FileNum, "              ";
            PRINT #FileNum, USING "#####.##"; SBR.625array#(M%);
SBRarray#(M%); SBR1.25array#(M%); SBR1.50array#(M%); SBR2.00array#(M%)
         ELSE
            PRINT #FileNum, "     ";
            PRINT #FileNum, USING "######"; T#;
            PRINT #FileNum, "                  ";
            PRINT #FileNum, USING "######.##"; SBRarray#(M%);
SBR1.25array#(M%); SBR1.50array#(M%); SBR2.00array#(M%)'; Area#
         END IF
         NumLines% = NumLines% + 1
         IF SBRarray#(M%) - 10# > 0 THEN
            M% = M% + 1
         ELSE
            Count% = 710
         END IF
      END IF
      Count% = Count% + 10
      IF NumLines% > PageLen THEN
         IF PrtScrn = "P" THEN
            PRINT #FileNum, CHR$(12)
         ELSE
            LOCATE 25, 1
            PRINT "Press Any Key To Continue ...";
            WHILE INKEY$ = ""
            WEND
            Page
         END IF
         NumLines% = 16 + NumWhls%
      END IF
   LOOP UNTIL Count% > 700
   PRINT #FileNum,
   IF PrtScrn = "P" THEN
      PRINT #FileNum, CHR$(12)
   END IF
   CLOSE #FileNum

END SUB

SUB Credit

   CLS
   Frame 1, 20, 25, 59, 2
   Frame 3, 26, 5, 53, 2
   LOCATE 4, 28
```

```
   PRINT "FLEXIBLE PAVEMENT DESIGN"
   Frame 12, 26, 16, 53, 2
   LOCATE 7, 28
   PRINT "MICROSOFT QUICKBASIC 4.5"
   LOCATE 13, 30
   PRINT "PUBLIC WORKS CANADA"
   LOCATE 14, 34
   PRINT "A&E SERVICES"
   LOCATE 15, 31
   PRINT "AIR TRANSPORTATION"
   LOCATE 18, 33
   PRINT "FEBRUARY 1992"
   LOCATE 23, 25
   PRINT "Press any key to continue...";
   WHILE INKEY$ = ""
   WEND
END SUB

'
'************************************************************************
'*                                                                      *
'*  This procedure displays the input screen.                           *
'*                                                                      *
'************************************************************************
'
SUB DrawScreen

   CLS
   PRINT "      "; SPACE$(22); "FLEXIBLE PAVEMENT DESIGN"
   Frame 3, 1, 13, 80, 2
   LOCATE 5, 4
   PRINT "Run Identification: ______________________________"
   LOCATE 7, 5
   PRINT "Gross Weight (KN): _____"; SPACE$(10); "% Load on Gear: _____"
   LOCATE 9, 6
   PRINT "Number of Wheels: __"; SPACE$(8); "Tire Pressure (MPA): ______"
   LOCATE 11, 6
   PRINT "Type of Vehicle (Ground (G)/Air (A)): _    To Printer Or Screen
(P/S) _"
   LOCATE 15, 7
   PRINT "Wheel Coordinates (CM): Wheel Num: __  X: ____  Y: ____"
   Frame 16, 38, 24, 63, 2
   LOCATE 25, 5
   PRINT SPACE$(15); "[SF4]-Quit   [F10]-Calculate    [Esc]-Reset";

END SUB

'
'************************************************************************
'*                                                                      *
'*  This procedure does the actual input of data for all the fields.    *
'*  The type of field will decide what characters will be acceptable.   *
'*                                                                      *
'************************************************************************
'
SUB EditFld (CurrFld$, ValidChars$, StRow%, StCol%, FldType%, FldLen%,
ExitKey$)

   SELECT CASE FldType%     ' Set up valid characters for field type
      CASE 1                ' String
         ValidChars$ = "
```

```
ABCDEFGHIJKLMNOPQRTSUVWXYZ1234567890-=‘~!@#$%^%^&*()_+<>?,./;’[]\|}{":
      CASE 2                ’ Integer
         ValidChars$ = "1234567890-+"
      CASE 3                ’ Float
         ValidChars$ = "1234567890.EeDd+-"
      CASE ELSE             ’ Any other values, accept the values passed in
ValidChars$
   END SELECT
   Count% = 0
   LenFld% = LEN(CurrFld$)
   IF LenFld% < FldLen% THEN    ’ Fill field with _ to max length
      CurrFld$ = CurrFld$ + STRING$(FldLen% - LenFld%, "_")
   END IF
   LOCATE StRow%, StCol%
   PRINT CurrFld$
   ExitKey$ = ""
   DO
      LOCATE StRow%, StCol% + Count%, 1, 5, 7
      InChar$ = ""
      WHILE InChar$ = ""
         InChar$ = INKEY$       ’ wait for and read keystroke
      WEND
      IF INSTR(ValidChars$, UCASE$(InChar$)) > 0 THEN
         IF Count% < FldLen% THEN   ’ if valid character insert in field
            MID$(CurrFld$, Count% + 1, 1) = InChar$
            PRINT InChar$;
         END IF
         IF Count% < FldLen% THEN
            Count% = Count% + 1     ’ check to ensure not at end
         ELSE
            BEEP
         END IF
      ELSE                          ’ this is an extended key
         SELECT CASE InChar$
            CASE CrsrLeft           ’ left arrow key
               IF Count% > 0 THEN
                  Count% = Count% - 1
               ELSE
                  BEEP
               END IF
            CASE CrsrRight           ’ right arrow key
               IF Count% < FldLen% THEN
                  Count% = Count% + 1
               ELSE
                  BEEP
               END IF
’
            CASE BS                  ’ back space
               IF Count% > 0 THEN
                  IF Count% = FldLen% THEN
                     MID$(CurrFld$, Count%, 1) = " "
                  ELSE
                     MID$(CurrFld$, Count%, FldLen% - Count% + 1) =
MID$(CurrFld$, Count% + 1, FldLen% - Count%)
                  END IF
                  CurrFld$ = CurrFld$ + " "
                  LOCATE StRow%, StCol%
                  PRINT LEFT$(CurrFld$, FldLen%)
                  Count% = Count% - 1
               ELSE
                  BEEP
```

```
              END IF
           CASE Esc, ABORT, CrsrUp, CrsrDown, Retrn, PF10
              ExitKey$ = InChar$  ' Escape, up arrow, down arrow, Return,
Shift F4, F10
           CASE ELSE
              BEEP
        END SELECT
     END IF
   LOOP UNTIL ExitKey$ <> ""
   Count% = FldLen%
   WHILE MID$(CurrFld$, Count%, 1) = "_" AND Count% > 1
      Count% = Count% - 1
   WEND
   IF Count% = 1 AND LEFT$(CurrFld$, 1) = "_" THEN
      CurrFld$ = ""
   ELSE
      CurrFld$ = LEFT$(CurrFld$, Count%)
   END IF

END SUB

'
'*************************************************************************
'*                                                                       *
'*  This procedure draws a line frame on the screen starting at ULRow%, *
'*  ULCol% down and across to LRRow%, LRCol%.  If LineType% = 1 then a  *
'*  single line is drawn if it is 2 a double line frame is drawn.        *
'*                                                                       *
'*************************************************************************

'
SUB Frame (ULRow%, ULCol%, LRRow%, LRCol%, LineType%)

   OldY% = POS(1)
   OldX% = CSRLIN
   FrameWidth% = LRCol% - ULCol% - 1
   FrameHeight% = LRRow% - ULRow% - 1
   Offset% = ULCol% - 1
   SELECT CASE LineType%
      CASE 1
         URCorner$ = "┐"
         LLCorner$ = "└"
         HorizLine$ = "─"
         ULCorner$ = "┌"
         VertLine$ = "│"
         LRCorner$ = "┘"
      CASE 2
         URCorner$ = "╗"
         VertLine$ = "║"
         LLCorner$ = "╚"
         ULCorner$ = "╔"
         LRCorner$ = "╝"
         HorizLine$ = "═"
   END SELECT
   LOCATE ULRow%, ULCol%
   PRINT ULCorner$; STRING$(FrameWidth%, HorizLine$); URCorner$;
   FOR Count% = 1 TO FrameHeight%
      LOCATE ULRow% + Count%, ULCol%
      PRINT VertLine$; SPACE$(FrameWidth%); VertLine$;
   NEXT Count%
   LOCATE LRRow%, ULCol%
```

```
   PRINT LLCorner$; STRING$(FrameWidth%, HorizLine$); LRCorner$;
   LOCATE OldY%, OldX%

END SUB

'
'************************************************************************
'*                                                                      *
'*  This procedure controls the input of data.  The Ident field is      *
'*  entered.  A value must be entered before moving to the next field.  *
'*  Once values have been entered the user may move to any field to     *
'*  the previously entered value.  EditFld is called to accept data for *
'*  all fields.  The user must press SPF4 or PF10 to exit this routine. *
'*                                                                      *
'************************************************************************
'
SUB InputData (Ident$, GRWght&, PcntLoad#, NumWhls%, TirePress#, VehType$,
ExitKey$)

   CurrFld% = 1
   DO
      DO
         IF ExitKey$ = Esc THEN     ' Re-initialize variables
            Ident$ = ""
            GRWght& = 0
            PcntLoad# = 0#
            NumWhls% = 0
            TirePress# = 0#
            VehType$ = ""
            WhlCnt% = 1
            CurrFld% = 1
            DrawScreen
         END IF
         SELECT CASE CurrFld%         ' set up parameters to pass to EditFld
            CASE 1                    ' Ident field
               CurrField$ = Ident$
               StRow% = IDRow
               StCol% = IDCol
               FldLen% = IDLen
               FldType% = 1
            CASE 2                    ' Gross Weight
               IF GRWght& <> 0& THEN
                  CurrField$ = LTRIM$(STR$(GRWght&))
               ELSE
                  CurrField$ = "0"
               END IF
               StRow% = GWRow
               StCol% = GWCol
               FldLen% = GWLen
               FldType% = 2
            CASE 3                    ' Percent load on wheels
               IF PcntLoad# <> 0# THEN
                  CurrField$ = LTRIM$(STR$(PcntLoad#))
               ELSE
                  CurrField$ = "0"
               END IF
               StRow% = LGRow
               StCol% = LGCol
               FldLen% = LGLen
               FldType% = 3
'
```

```
CASE 4                   ' Number of wheels
   IF NumWhls% <> 0 THEN
      CurrField$ = LTRIM$(STR$(NumWhls%))
   ELSE
      CurrField$ = "0"
   END IF
   StRow% = NWRow
   StCol% = NWCol
   FldLen% = NWLen
   FldType% = 2
   WhlCnt% = 1
CASE 5                   ' Tire pressure
   IF TirePress# <> 0# THEN
      CurrField$ = LTRIM$(STR$(TirePress#))
   ELSE
      CurrField$ = "0"
   END IF
   StRow% = TPRow
   StCol% = TPCol
   FldLen% = TPLen
   FldType% = 3
CASE 6                   ' Vehicle type
   CurrField$ = VehType$
   StRow% = VTRow
   StCol% = VTCol
   FldLen% = VTLen
   FldType% = 4
   ValidChars$ = "GA"    ' only characters that will be accepted
CASE 7
   CurrField$ = PrtScrn
   StRow% = PSRow
   StCol% = PSCol
   FldLen% = PSLen
   FldType% = 4
   ValidChars$ = "PS"
CASE 8                   ' Wheel X coord
   IF NumWhls% = 0 THEN
      BEEP               ' Must enter number of wheel before
      CurrFld% = 4       ' entering coordinates
      CurrField$ = "0"
      StRow% = NWRow
      StCol% = NWCol
      FldLen% = NWLen
      FldType% = 2
      WhlCnt% = 1
   ELSE
      IF WheelX%(WhlCnt%) <> 0 THEN
         CurrField$ = LTRIM$(STR$(WheelX%(WhlCnt%)))
      ELSE
         CurrField$ = "0"
      END IF
      LOCATE 15, 41
      PRINT WhlCnt%; "  X: ";
      PRINT USING "####"; WheelX%(WhlCnt%);
      PRINT "  Y: ";
      PRINT USING "####"; WheelY%(WhlCnt%);
      StRow% = WXRow
      StCol% = WXCol
      FldLen% = WXLen
      FldType% = 2
   END IF
```

```
'
            CASE 9                    ' Wheel Y coord
               IF WheelY%(WhlCnt%) <> 0 THEN
                  CurrField$ = LTRIM$(STR$(WheelY%(WhlCnt%)))
               ELSE
                  CurrField$ = "0"
               END IF
               LOCATE 15, 41
               PRINT WhlCnt%; "  X: ";
               PRINT USING "####"; WheelX%(WhlCnt%);
               PRINT "  Y: ";
               PRINT USING "####"; WheelY%(WhlCnt%);
               StRow% = WYRow
               StCol% = WYCol
               FldLen% = WYLen
               FldType% = 2
         END SELECT
         CurrField$ = LEFT$(CurrField$, FldLen%)
         EditFld CurrField$, ValidChars$, StRow%, StCol%, FldType%, FldLen%,
ExitKey$
      LOOP UNTIL CurrField$ <> "" OR ExitKey$ = ABORT
      IF ExitKey$ <> Esc AND ExitKey$ <> ABORT THEN
         SELECT CASE CurrFld%        ' Reassign CurrField to appropriate
variable
            CASE 1
               Ident$ = CurrField$
            CASE 2
               GRWght& = VAL(CurrField$)
               LOCATE GWRow, GWCol
               PRINT USING "####.#"; GRWght&
            CASE 3
               PcntLoad# = VAL(CurrField$)
               LOCATE LGRow, LGCol
               PRINT USING "###.#"; PcntLoad#
            CASE 4
               NumWhls% = VAL(CurrField$)
               LOCATE NWRow, NWCol
               PRINT USING "##"; NumWhls%
            CASE 5
               TirePress# = VAL(CurrField$)
               LOCATE TPRow, TPCol
               PRINT USING "###.##"; TirePress#
            CASE 6
               VehType$ = UCASE$(CurrField$)
            CASE 7
               PrtScrn = UCASE$(CurrField$)
            CASE 8
               WheelX%(WhlCnt%) = VAL(CurrField$)
            CASE 9
               WheelY%(WhlCnt%) = VAL(CurrField$)
               IF WhlCnt% > 7 THEN
                  Start% = WhlCnt% - 6
               ELSE
                  Start% = 1
               END IF
               DispStart% = 1         '  display wheel coords in window
               FOR Count% = Start% TO WhlCnt%
                  LOCATE 16 + DispStart%, 40
                  PRINT USING "###"; Count%;
                  PRINT ":      ";
                  PRINT USING "###"; WheelX%(Count%);
```

```
                  PRINT "      ";
                  PRINT USING "###"; WheelY%(Count%);
                  DispStart% = DispStart% + 1
               NEXT Count%
         END SELECT
'
         SELECT CASE ExitKey$   '  take appropriate action according to last
            CASE CrsrUp         '  last key pressed while in EditFld
               IF CurrFld% > 1 THEN
                  IF CurrFld% = 8 THEN
                     IF WhlCnt% >= 1 THEN
                        IF WhlCnt% > 1 THEN
                           WhlCnt% = WhlCnt% - 1
                           CurrFld% = 9
                        ELSE
                           CurrFld% = CurrFld% - 1
                        END IF
                     END IF
                  ELSE
                     CurrFld% = CurrFld% - 1
                  END IF
               ELSE
                  BEEP
               END IF
            CASE CrsrDown, Retrn, PF10
               IF CurrFld% = 9 THEN
                  IF WhlCnt% <= NumWhls% THEN
                     IF WhlCnt% < NumWhls% THEN
                        WhlCnt% = WhlCnt% + 1
                        CurrFld% = 8
                     ELSE
                        CurrFld% = 1
                        WhlCnt% = 1
                     END IF
                  END IF
               ELSE
                  CurrFld% = CurrFld% + 1
               END IF
         END SELECT
      END IF
   LOOP UNTIL ExitKey$ = ABORT OR ExitKey$ = PF10

END SUB         '

SUB Page

   IF PrtScrn = "S" THEN
      CLS
   END IF
   PRINT #FileNum, SPACE$(25); "FLEXIBLE PAVEMENT DESIGN"
   PRINT #FileNum, "     "; STRING$(70, "*")
   PRINT #FileNum, "      RUN IDENTIFICATION : "; Ident$
   PRINT #FileNum, "      Gross Weight (KN)  : ";
   PRINT #FileNum, USING "#####.#"; GRWght&
   PRINT #FileNum, "      % Load on Gear     : ";
   PRINT #FileNum, USING "#####.#"; PcntLoad#
   PRINT #FileNum, "      Tire Load (KN)     : ";
   PRINT #FileNum, USING "#####.#"; TireLoad#
   PRINT #FileNum, "      Tire Pressure (MPA): ";
   PRINT #FileNum, USING "  ###.##"; TirePress#
   PRINT #FileNum,
```

```
   PRINT #FileNum,
   PRINT #FileNum, "      Wheel Coords (CM) :   Wheel #      X     Y"
   PRINT #FileNum,
   FOR Count% = 1 TO NumWhls%
      PRINT #FileNum, SPACE$(29); Count%; "        "; WheelX%(Count%); "
"; WheelY%(Count%)
   NEXT Count%
   PRINT #FileNum,
   IF UCASE$(VehType$) = "G" THEN
      PRINT #FileNum, "      Pavement"; SPACE$(15); " Subgrade Bearing
Strength (KN)"
      PRINT #FileNum, "      Thickness"; SPACE$(14); " Required For Over
Load Ratio Of"
      PRINT #FileNum, "        (CM)                0.625   1.00    1.25
1.50    2.00"
      PRINT #FileNum, "
================================================"
   ELSE
      PRINT #FileNum, "      Pavement"; SPACE$(18); " Subgrade Bearing
Strength (KN)"
      PRINT #FileNum, "      Thickness"; SPACE$(17); " Required For Over
Load Ratio Of"
      PRINT #FileNum, "        (CM)                     1.00     1.25
1.50     2.00"
      PRINT #FileNum, "
======================================="
   END IF

END SUB
```

APPENDIX E

RIGID PAVEMENT DESIGN

COMPUTER PROGRAM

"RIGID" is a BASIC program written using Microsoft QuickBasic 4.5 and can be used on any IBM-PC computer. The program may be modified for use with other machines or input/output modes. Refer to the following pages for an example program run and output which is briefly described below.

Once the program has been loaded into the system, it will then prompt the user to enter the necessary data.

INPUT 1: Allows the user to identify the aircraft or ground vehicle with a maximum of 30 characters.

INPUT 2: Aircraft gross weight in kN.

INPUT 3: The percent of the gross weight on the gear in question.

INPUT 4: The number of wheels in the gear.

INPUT 5: The tire pressure in MPa.

INPUT 6: The program will then prompt the user to determine whether a hardcopy printout of the results is required.

INPUT 7: The gear wheel co-ordinates. The (X,Y) co-ordinates in cm of the wheel centres inputed one pair at a time. The first wheel should normally be centred at (0,0) and other wheels identified so that the gear is oriented to roll in the X-axis direction as shown in figure D-1.

If the gear load is known, it may be used in place of gross weight and 100% used as percent of load on the main gear.

By pressing F10 the program should now execute on the assumption that the maximum moment is at the origin. If other locations are to be tested, then the values for X_o and Y_o specified in the program listing may be changes accordingly.

The program will produce the output shown the following pages. A zero in the table of slab thickness (h) versus bearing modulus (k) indicates either that the value for k is outside the range of $10\ N/cm^3 < k < 200\ N/cm^3$ or that the value would result from an extrapolation of the radius of relative stiffness versus moment curve.

The data may be used to plot graphs similar to Figure 3.10. By re-running at various weights, data may be obtained to plot nomographs of the type contained in AK-68-16 "Pavement Design - Evaluation Charts for Selected Aircraft".

"RIGID" PROGRAM RUN AND OUTPUT

• At the dos prompt type A:\RIGID

REQUEST Aircraft Name
INPUT 1 B720

REQUEST Gross Weight (KN)
INPUT 2 1045

REQUEST % Load on Gear
INPUT 3 47.5

REQUEST Number of Wheels
INPUT 4 4

REQUEST Tire Pressure (MPA)
INPUT 5 1.00

REQUEST To Printer or Screen (P/S)
INPUT 6 S

REQUEST Wheel Coordinates (CM)
INPUT 7 0,0
0,81
124,81
124,0

INPUT 8 Press F10 to Calculate.

REQUEST Another Weight? (Y/N)
INPUT 9 N

The input screen and program output are shown on the following pages.

```
                        RIGID PAVEMENT DESIGN

    Aircraft Name    : B720
    Gross Weight (KN): 1045          % Load on Gear: 47.5
     Number of Wheels: 4       Tire Pressure (MPA) : 1.00
     Printer (P) or Screen (S): S

      Wheel Coordinate (CM): Wheel Num: ___  X: 124  Y: 0

                                         1:       0        0
                                         2:       0        81
                                         3:       124      81
                                         4:       124      0

               [SF4]-Quit     [F10]-Calculate    [Esc]-Reset
```

INPUT SCREEN

"RIGID" PROGRAM OUTPUT

```
                         RIGID PAVEMENT DESIGN
************************************************************************
Aircraft Name    :       B720
Gross Weight (KN):       1045.0                  % Load on Gear :47.5
Wheel Load (KN)  :       124.1                   Tire Pressure (MPA): 1.00

Wheel Coords (CM):     Wheel#      X      Y
                       1         0.0    0.0
                       2         0.0   81.0
                       3       124.0   81.0
                       4       124.0    0.0

                  Origin:        0.0    0.0

Stiffness              Moment             Angle
  (CM)                  (NM)              (Deg)
   40                  138.14             43.40
   80                  285.29             59.53
  120                  421.33             61.20
  160                  532.55             61.72
  200                  624.25             61.96
  240                  701.59             62.09
```

Slab Thickness(CM)	Bearing Modulus-K(N/CM3) For Slab Stress (Mpa) 2.75	3.50	4.10	5.50
12.5	0.00	0.00	0.00	155.27
13.0	0.00	0.00	0.00	128.25
13.5	0.00	0.00	0.00	107.21
14.0	0.00	0.00	0.00	90.53
14.5	0.00	0.00	0.00	77.10
15.0	0.00	0.00	0.00	66.12
15.5	0.00	0.00	173.56	57.04
16.0	0.00	0.00	149.61	49.43
16.5	0.00	0.00	129.85	42.99
17.0	0.00	0.00	113.34	37.48
17.5	0.00	180.70	99.42	32.74
18.0	0.00	158.79	87.57	28.63
18.5	0.00	140.20	77.39	25.04
19.0	0.00	124.29	68.58	21.90
19.5	0.00	110.56	60.90	19.14
20.0	0.00	98.63	54.16	16.70
20.5	0.00	88.19	48.21	14.55
21.0	195.76	79.00	42.95	12.66
21.5	176.04	70.87	38.26	10.98
22.0	158.72	63.64	34.08	0.00
22.5	143.42	57.18	30.33	0.00
23.0	129.84	51.39	26.98	0.00
23.5	117.73	46.18	23.96	0.00
24.0	106.87	41.49	21.26	0.00
24.5	97.11	37.25	18.83	0.00
25.0	88.29	33.42	16.65	0.00
23.5	117.73	46.18	23.96	0.00
24.0	106.87	41.49	21.26	0.00
24.5	97.11	37.25	18.83	0.00

"RIGID" PROGRAM OUTPUT (CONT'D)

25.0	88.29	33.42	16.65	0.00
25.5	80.31	29.95	14.70	0.00
26.0	73.05	26.81	12.95	0.00
26.5	66.45	23.97	11.38	0.00
27.0	60.43	21.39	0.00	0.00
27.5	54.93	19.07	0.00	0.00
28.0	49.91	16.97	0.00	0.00
28.5	45.30	15.07	0.00	0.00
29.0	41.09	13.36	0.00	0.00
29.5	37.23	11.82	0.00	0.00
30.0	33.70	10.44	0.00	0.00
30.5	30.47	0.00	0.00	0.00
31.0	27.51	0.00	0.00	0.00
31.5	24.81	0.00	0.00	0.00
32.0	22.35	0.00	0.00	0.00
32.5	20.10	0.00	0.00	0.00
33.0	18.05	0.00	0.00	0.00
33.5	16.18	0.00	0.00	0.00
34.0	14.49	0.00	0.00	0.00
34.5	12.95	0.00	0.00	0.00
35.0	11.56	0.00	0.00	0.00
35.5	10.30	0.00	0.00	0.00

"RIGID" PROGRAM LISTING

```
'*************************************************************************
'*                                                                       *
'* Program Name: RIGID.BAS                                               *
'* Purpose.....: This program is for rigid pavement design according     *
'*               to Transport Canada practices.  Questions regarding     *
'*               this program should be directed to AKPB.                *
'* Author......: AKPB                                                    *
'* Date........: Feb 1987                                                *
'* Language....: Hewlett Packard Basic                                   *
'*                                                                       *
'*************************************************************************
'* Compile Instructions:                                                 *
'*                                                                       *
'* BC D:\QB40\SRC\RIGID.BAS /E/X/O;                                      *
'* Link /EX/NOE RIGID , D:\EXE\RIGID.EXE, , ALL.LIB;                     *
'*                                                                       *
'*************************************************************************
'*                                                                       *
'* Modification History                                                  *
'* Programmer: Capt R.H.J. Boisjoli                                      *
'* Date......: Jul 88                                                    *
'* Description of Change: Translated to Microsoft Quick Basic 4.0.       *
'*                        This will allow the program to run on MSDOS    *
'*                        computers.                                     *
'*                                                                       *
'*************************************************************************

CONST IDRow = 5, IDCol = 24, IDLen = 30  ' Scrn row and col and len for
Ident$
CONST GWRow = 7, GWCol = 24, GWLen = 7   ' Scrn row and col and len for
GRWght#
CONST LGRow = 7, LGCol = 55, LGLen = 5   ' Scrn row and col and len for
PcntLoad#
CONST NWRow = 9, NWCol = 24, NWLen = 2   ' Scrn row and col and len for
NumWhls%
CONST TPRow = 9, TPCol = 55, TPLen = 6   ' Scrn row and col and len for
TirePress#
CONST WXRow = 15, WXCol = 49, WXLen = 4  ' Scrn row and col and len for
WheelX%
CONST WYRow = 15, WYCol = 58, WYLen = 4  ' Scrn row and col and len for
WheelY%
CONST PSRow = 11, PSCol = 33, PSLen = 1  ' Scrn row and col and len for
PrntScrn
CONST ReportFileName = "REPORT.FIL"      ' Report File Name
CONST false = 0, true = NOT false

DECLARE SUB Credit ()
DECLARE SUB Calculate (Ident$, GRWght#, PcntLoad#, NumWhls%, TirePress#)
DECLARE SUB DrawScreen (Ident$, GRWght#, PcntLoad#, NumWhls%, TirePress#)
DECLARE SUB EditFld (CurrFld$, ValidChars$, StRow%, StCol%, FldType%,
FldLen%, ExitKey$)
DECLARE SUB Frame (ULRow%, ULCol%, LRRow%, LRCol%, LineType%)
DECLARE SUB InputData (Ident$, GRWght#, PcntLoad#, NumWhls%, TirePress#,
ExitKey$)
DECLARE SUB Page (Ident$, GRWght#, PcntLoad#, NumWhls%, TirePress#, Load#)

DIM SHARED Esc AS STRING * 1           ' The Escape key
DIM SHARED BS AS STRING * 1            ' The back space key
```

```
DIM SHARED ABORT AS STRING * 2          ' The shift F4 key
DIM SHARED Retrn AS STRING * 1          ' The Return of Enter key
DIM SHARED CrsrRight AS STRING * 2      ' The right arrow key
DIM SHARED CrsrLeft AS STRING * 2       ' The left arrow key
DIM SHARED CrsrDown AS STRING * 2       ' The down arrow key
DIM SHARED CrsrUp AS STRING * 2         ' The up arrow key
DIM SHARED PF10 AS STRING * 2           ' The F10 key
OPTION BASE 1
DIM SHARED Cs#(73), Sn#(73), X#(73), Y#(73), X1#(10, 73), Y1#(10, 73),
R1#(10, 73)
DIM SHARED Xx#(10), Yy#(10), Str#(5), Bm#(100, 4), Xm#(6), Sti%(6), Ang#(6)
DIM SHARED PrtScrn AS STRING
DIM SHARED FileNum AS INTEGER
DIM SHARED PageLen AS INTEGER
DIM SHARED ReportFile AS STRING
DIM SHARED NumLines AS INTEGER
DIM SHARED Load#

'
'*************************************************************************
'*                                                                       *
'*  Main line.                                                           *
'*                                                                       *
'*************************************************************************

ON ERROR GOTO ErrHandler
BS = CHR$(8)
Esc = CHR$(27)
ABORT = CHR$(0) + CHR$(87)
Retrn = CHR$(13)
CrsrRight = CHR$(0) + CHR$(77)
CrsrLeft = CHR$(0) + CHR$(75)
CrsrUp = CHR$(0) + CHR$(72)
CrsrDown = CHR$(0) + CHR$(80)
PF10 = CHR$(0) + CHR$(68)
ExitKey$ = Esc
PrtScrn = "S"
Credit
DO
   InputData Ident$, GRWght#, PcntLoad#, NumWhls%, TirePress#, ExitKey$
   IF ExitKey$ = PF10 THEN
      IF PrtScrn = "S" THEN
         ReportFile = "SCRN:" + ReportFileName
         CLS
         NumLines = 0
         PageLen = 23
      ELSE
         PageLen = 54
         ReportFile = "LPT1:"
      END IF
      Calculate Ident$, GRWght#, PcntLoad#, NumWhls%, TirePress#
      IF PrtScrn = "S" THEN
         DrawScreen Ident$, GRWght#, PcntLoad#, NumWhls%, TirePress#
      END IF
      LOCATE 23, 5
      PRINT "Another Weight ? (Y/N)";
      LOCATE 23, 27, 1
      Ans$ = ""
      WHILE Ans$ = ""
         Ans$ = INKEY$
         IF UCASE$(Ans$) <> "Y" AND UCASE$(Ans$) <> "N" THEN
```

```
            Ans$ = ""
         END IF
      WEND
      IF UCASE$(Ans$) = "Y" THEN
         ExitKey$ = ""
         GRWght# = 0
         LOCATE 23, 5
         PRINT "                      ";
      END IF
   END IF
LOOP UNTIL GRWght# > 0 OR ExitKey$ = ABORT
CLS
END

ErrHandler:
Errr% = ERR
LOCATE 22, 1
BEEP
SELECT CASE Errr%
   CASE 24, 25
      PRINT "Printer Not Ready. Please Check It.";
   CASE 27
      PRINT "Printer Out Of Paper.  Please Reload.";
   CASE ELSE
      PRINT "Unknown Error." + STR$(Errr%)
END SELECT
LOCATE 23, 1
PRINT "  Press any key to continue...";
WHILE INKEY$ = ""
WEND
LOCATE 22, 1
PRINT "                                   ";
LOCATE 23, 1
PRINT "                                ";
IF ((Errr% = 25) OR (Errr% = 27) OR (Errr% = 24)) THEN
   Errr% = 0
   RESUME
ELSE
   RESUME NEXT
END IF
END

'
'************************************************************************
'*                                                                      *
'*  This procedure calculates and prints the appropriate values.  Many  *
'*  of the variables do not have meningful names.  The names used in    *
'*  in the original Hewlett-Packard program were retained since there   *
'*  was no way of telling what they stood for.                          *
'*                                                                      *
'************************************************************************
'
SUB Calculate (Ident$, GRWght#, PcntLoad#, NumWhls%, TirePress#)

   Load# = GRWght# * PcntLoad# / (NumWhls% * 100) ' Load on one wheel
   Xo# = 0
   Yo# = 0
   Te# = Load# * (NumWhls% + 1)
   SELECT CASE INT(Te#)      ' From single wheel load, set stress value
      CASE IS > 1410         ' starting point and increment step size
         Js% = 50
```

```
      CASE IS > 560
         Js% = 40
      CASE IS > 260
         Js% = 30
      CASE ELSE
         Js% = 20
   END SELECT
   FileNum = FREEFILE
   OPEN ReportFile FOR OUTPUT AS FileNum
   Page Ident$, GRWght#, PcntLoad#, NumWhls%, TirePress#, Load#
   NumLines = 11 + NumWhls%
   Printed% = false

'
'*************************************************************************
'*                                                                       *
'*  This section does the actual calculations.                           *
'*                                                                       *
'*************************************************************************
'

   A# = .69158 * SQR(10 * Load# / TirePress#) ' Calculates tire imprint
length

' ***** Calculate Xn, Yn Coordinates for 72 segments of ellipse *****

   FOR Count% = 1 TO 73
      IF ((Count% MOD 6 = 0) AND (PrtScrn = "P")) THEN
         LOCATE 23, 1
         PRINT "Working...";
      END IF
      B# = Count% - 1
      C# = .0872664 * B#
      D# = SQR(1 + 1.25775 * SIN(C#) ^ 2)
      X#(Count%) = COS(C#) * (A# / D#)
      Y#(Count%) = SIN(C#) * (A# / D#)
      IF ((Count% MOD 5 = 0) AND (PrtScrn = "P")) THEN
         LOCATE 23, 1
         PRINT "          ";
      END IF
   NEXT Count%

' ***** Calculate Xn, Yn, coordinates for each wheel in gear *****
' ***** Configure about X, Y axis *****

   FOR Count1% = 1 TO NumWhls%
      FOR Count2% = 1 TO 73
         IF ((Count2% MOD 6 = 0) AND (PrtScrn = "P")) THEN
            LOCATE 23, 1
            PRINT "Working...";
         END IF
         X1#(Count1%, Count2%) = X#(Count2%) + Xx#(Count1%) - Xo#
         Y1#(Count1%, Count2%) = Y#(Count2%) + Yy#(Count1%) - Yo#
         R1#(Count1%, Count2%) = SQR(X1#(Count1%, Count2%) ^ 2 +
Y1#(Count1%, Count2%) ^ 2)
         IF ((Count2% MOD 5 = 0) AND (PrtScrn = "P")) THEN
            LOCATE 23, 1
            PRINT "          ";
         END IF
      NEXT Count2%
   NEXT Count1%        '
```

```
' ***** Calculate and output vlaues *****
' ***** For selected values the max moment and angle at which it occurs ****

   FOR Count1% = 1 TO 6
      IF ((NumLines = 0) OR (NOT Printed)) THEN
         PRINT #FileNum,
         PRINT #FileNum, "  Stiffness            Moment             Angle"
         PRINT #FileNum, "    (CM)                (NM)              (Deg)"
         NumLines = NumLines + 3
         Printed = true
      END IF
      Sti%(Count1%) = Js% * Count1%
      XL# = Sti%(Count1%)
      S1# = 0
      S2# = 0
      S3# = 0
      FOR Count2% = 1 TO NumWhls%
         FOR Count3% = 1 TO 72
            IF ((Count3% MOD 6 = 0) AND (PrtScrn = "P")) THEN
               LOCATE 23, 1
               PRINT "Working...";
            END IF
            Har# = (R1#(Count2%, Count3%) + R1#(Count2%, Count3% + 1)) / (4
* XL#)
            A# = Har# ^ 2
            B# = LOG(Har#)
            Temp1# = A# * ((1.606118 - B#) / 2261.947 + A# * (1 / 86400 - A#
* (1.944214 - B#) / 2850053))
            Temp# = (-((.077215 + B#) / .7853982) + A# * (.5 + A# *
(-((1.0894517# - B#) / 9.424778) + A# * (-(1 / 144) + Temp1#))))
            F1# = A# * Temp#
            Temp1# = A# * ((1.581118 - B#) / 5654.8669# + A# * (1 / 207360 -
A# * (1.932308 - B#) / 6650123))
            Temp# = (.125 + A# * (-((1.006118 - B#) / 28.274334#) + A# *
(-(1 / 384) + Temp1#)))
            F2# = A# * (-.3183102 + A# * (Temp#))
            A# = R1#(Count2%, Count3%) * R1#(Count2%, Count3% + 1)
            B# = (X1#(Count2%, Count3%) * Y1#(Count2%, Count3% + 1) -
X1#(Count2%, Count3% + 1) * Y1#(Count2%, Count3%)) / A#
            C# = (X1#(Count2%, Count3%) * X1#(Count2%, Count3% + 1) -
Y1#(Count2%, Count3%) * Y1#(Count2%, Count3% + 1)) / A#
            D# = (X1#(Count2%, Count3%) * Y1#(Count2%, Count3% + 1) +
X1#(Count2%, Count3% + 1) * Y1#(Count2%, Count3%)) / A#
            S1# = S1# + (2 * ATN(B# / (1 + SQR(1 - B# ^ 2)))) * F1#
            S2# = S2# + B# * C# * F2#
            S3# = S3# + B# * D# * F2#
            IF ((Count3% MOD 5 = 0) AND (PrtScrn = "P")) THEN
               LOCATE 23, 1
               PRINT "          ";
            END IF
         NEXT Count3%
      NEXT Count2%
      Xm#(Count1%) = TirePress# * XL# ^ 2 / 8 * (1.15 * S1# + 1.7 * SQR(S2#
^ 2 + S3# ^ 2))
      Ang#(Count1%) = ATN(-S3# / S2#) * 28.65
      IF S2# < 0 THEN
         Ang#(Count1%) = Ang#(Count1%) + 90#
      END IF
      PRINT #FileNum, "    "; USING "###"; Sti%(Count1%);
      PRINT #FileNum, SPACE$(6);
      PRINT #FileNum, TAB(19); USING "########.##"; Xm#(Count1%);
```

```
      PRINT #FileNum, TAB(36); USING "########.##"; Ang#(Count1%)
      NumLines = NumLines + 1
      IF NumLines > PageLen THEN
         IF PrtScrn = "S" THEN
            LOCATE 25, 1
            PRINT "Press Any Key To Continue...";
            WHILE INKEY$ = ""
            WEND
         END IF
         PRINT #FileNum, CHR$(12);
         NumLines = 0
      END IF
   NEXT Count1%
   IF PrtScrn = "S" THEN
      LOCATE 25, 1
      PRINT "Press Any Key To Continue...";
      WHILE INKEY$ = ""
      WEND
   END IF

' ***** Set slab stress level for which bearing modulus is to be calculated
*****
' ***** at selected slab thickness *****

   Str#(1) = 2.75
   Str#(2) = 3.5
   Str#(3) = 4.1
   Str#(4) = 5.5

'
   NumLines = 0
   T# = 10!               ' ***** Start at a slab thickness of 10 CM and
calculate modulus *****
   FOR Count1% = 1 TO 100 ' ***** slab thickness incremented by 0.5 CM per
loop *****
   IF NumLines = 0 THEN
      PRINT #FileNum, CHR$(12);
      PRINT #FileNum, "    Slab                   Bearing Modulus-K(N/CM3)
For"
      PRINT #FileNum, "Thickness(CM)                    Slab Stress (Mpa)"
      PRINT #FileNum, TAB(18); USING "#######.##"; Str#(1); Str#(2);
Str#(3); Str#(4)
      PRINT #FileNum, TAB(20); STRING$(40, "=")
      NumLines = NumLines + 4
   END IF
      IF ((Count1% MOD 6 = 0) AND (PrtScrn = "P")) THEN
         LOCATE 23, 1: PRINT "Working...";
      END IF
      Test# = 0
      FOR Count2% = 1 TO 4
         Tm# = Str#(Count2%) * T# ^ 2 / 6
         F# = 0
         FOR Count3% = 1 TO 6
            Ts# = Sti%(Count3%)
            FOR Count4% = 1 TO 6
               IF Count3% <> Count4% THEN
                  Ts# = Ts# * (Tm# - Xm#(Count4%)) / (Xm#(Count3%) -
Xm#(Count4%))
               END IF
            NEXT Count4%
            F# = F# + Ts#
```

```
         NEXT Count3%
         Bm#(Count1%, Count2%) = 235124 * (T# ^ 3 / F# ^ 4)
         IF F# < Sti%(1) THEN
            Bm#(Count1%, Count2%) = 100000
         END IF
         IF F# > Sti%(6) THEN
            Bm#(Count1%, Count2%) = 100000
         END IF
      NEXT Count2%
      FOR Count2% = 1 TO 4
         IF Bm#(Count1%, Count2%) < 10 THEN
            Bm#(Count1%, Count2%) = 100000
         END IF
         IF Bm#(Count1%, Count2%) > 200 THEN
            Bm#(Count1%, Count2%) = 100000
         END IF
         Test# = Test# + Bm#(Count1%, Count2%)
         IF Bm#(Count1%, Count2%) = 100000 THEN
            Bm#(Count1%, Count2%) = 0
         END IF
      NEXT Count2%
      IF Test# - 350000 >= 0 THEN
         Bm#(Count1%, 1) = -1
      ELSE
         PRINT #FileNum, USING "######.#"; T#;
         PRINT #FileNum, TAB(18); USING "#######.##"; Bm#(Count1%, 1);
Bm#(Count1%, 2); Bm#(Count1%, 3); Bm#(Count1%, 4)
         NumLines = NumLines + 1
         IF NumLines >= PageLen THEN
            IF PrtScrn = "S" THEN
               LOCATE 25, 1
               PRINT "Press Any Key To Continue...";
               WHILE INKEY$ = ""
               WEND
            END IF
            PRINT #FileNum, CHR$(12);
            NumLines = 0
         END IF
      END IF
      T# = T# + .5
      IF ((Count1% MOD 5 = 0) AND (PrtScrn = "P")) THEN
         LOCATE 23, 1
         PRINT "             ";
      END IF
   NEXT Count1%
   IF PrtScrn = "P" THEN
      PRINT #FileNum, CHR$(12);
   ELSE
      LOCATE 25, 1
      PRINT "Press Any Key To Continue...";
      WHILE INKEY$ = ""
      WEND
   END IF
END SUB

SUB Credit

   CLS
   LOCATE 5, 31
   PRINT "RIGID PAVEMENT DESIGN"
   LOCATE 7, 20
```

```
   PRINT "ACCORDING TO TRANSPORT CANADA PRACTICES"
   LOCATE 9, 32
   PRINT "TRANSLATED FROM "
   LOCATE 11, 30
   PRINT "HEWLETT PACKARD BASIC"
   LOCATE 13, 39
   PRINT "TO"
   LOCATE 15, 28
   PRINT "Microsoft Quick BASIC 4.0"
   LOCATE 17, 39
   PRINT "BY"
   LOCATE 19, 30
   PRINT "Capt R.H.J. Boisjoli"
   LOCATE 21, 23
   PRINT "Air Command Headquarters Winnipeg"
   LOCATE 23, 36
   PRINT "895-5869"
   DelayFinish& = TIMER + 3
   DO
   LOOP UNTIL TIMER > DelayFinish&

END SUB

'
'************************************************************************
'*                                                                      *
'*  This procedure displays the input screen.                           *
'*                                                                      *
'************************************************************************
'
SUB DrawScreen (Ident$, GRWght#, PcntLoad#, NumWhls%, TirePress#)

   CLS
   PRINT "K88041"; SPACE$(22); "RIGID PAVEMENT DESIGN";
   Frame 3, 1, 13, 80, 2
   LOCATE 5, 5
   PRINT "Aircraft Name    : ______________________________";
   LOCATE IDRow, IDCol
   PRINT Ident$
   LOCATE 7, 5
   PRINT "Gross Weight (KN): _______"; SPACE$(8); "% Load on Gear: _____";
   LOCATE GWRow, GWCol
   PRINT USING "#####.#"; GRWght#;
   LOCATE LGRow, LGCol
   PRINT USING "###.#"; Load#
   LOCATE 9, 6
   PRINT "Number of Wheels: __"; SPACE$(8); "Tire Pressure (MPA): ______";
   LOCATE NWRow, NWCol
   PRINT USING "##"; NumWhls%;
   LOCATE TPRow, TPCol
   PRINT USING "####.#"; TirePress#;
   LOCATE 11, 6
   PRINT "Printer (P) or Screen (S): _";
   LOCATE PSRow, PSCol
   PRINT PrtScrn;
   LOCATE 15, 7
   PRINT "Wheel Coordinates (CM): Wheel Num: __  X: ____  Y: ____";
   Frame 16, 38, 24, 63, 2
   IF WhlCnt% > 0 THEN
      DispStart% = 1
      FOR Count% = 1 TO WhlCnt%
```

```
         LOCATE 16 + DispStart%, 40
         PRINT USING "###"; Count%;
         PRINT ":      ";
         PRINT USING "###"; Xx#(Count%);
         PRINT "      ";
         PRINT USING "###"; Yy#(Count%);
         DispStart% = DispStart% + 1
      NEXT Count%
   END IF
   LOCATE 25, 5
   PRINT SPACE$(15); "[SF4]-Quit   [F10]-Calculate    [Esc]-Reset";

END SUB

'
'************************************************************************
'*                                                                      *
'*  This procedure does the actual input of data for all the fields.    *
'*  The type of field will decide what characters will be acceptable.   *
'*                                                                      *
'************************************************************************
'
SUB EditFld (CurrFld$, ValidChars$, StRow%, StCol%, FldType%, FldLen%,
ExitKey$)

   SELECT CASE FldType%    ' Set up valid characters for field type
      CASE 1               ' String
         ValidChars$ = "
ABCDEFGHIJKLMNOPQRTSUVWXYZ1234567890-='~!@#$%^%^&*()_+<>?,./;'[]\|}{":
      CASE 2               ' Integer
         ValidChars$ = "1234567890-+"
      CASE 3               ' Float
         ValidChars$ = "1234567890.EeDd+-"
      CASE ELSE            ' Any other values accept the values passed in
ValidChars$
   END SELECT
   Count% = 0
   LenFld% = LEN(CurrFld$)
   IF LenFld% < FldLen% THEN    ' Fill field with _ to max length
      CurrFld$ = CurrFld$ + STRING$(FldLen% - LenFld%, "_")
   END IF
   LOCATE StRow%, StCol%
   PRINT CurrFld$
   ExitKey$ = ""
   DO
      LOCATE StRow%, StCol% + Count%, 1, 5, 7
      InChar$ = ""
      WHILE InChar$ = ""
         InChar$ = INKEY$       ' wait for and read keystroke
      WEND
      IF INSTR(ValidChars$, UCASE$(InChar$)) > 0 THEN
         IF Count% < FldLen% THEN   ' if valid character insert in field
            MID$(CurrFld$, Count% + 1, 1) = InChar$
            PRINT InChar$;
         END IF
         IF Count% < FldLen% THEN
            Count% = Count% + 1     ' check to ensure not at end
         ELSE
            BEEP
         END IF
      ELSE                          ' this is an extended key
```

```
         SELECT CASE InChar$
            CASE CrsrLeft           ' left arrow key
               IF Count% > 0 THEN
                  Count% = Count% - 1
               ELSE
                  BEEP
               END IF
            CASE CrsrRight           ' right arrow key
               IF Count% < FldLen% THEN
                  Count% = Count% + 1
               ELSE
                  BEEP
               END IF                ' back space
            CASE BS
               IF Count% > 0 THEN
                  IF Count% = FldLen% THEN
                     MID$(CurrFld$, Count%, 1) = " "
                  ELSE
                     MID$(CurrFld$, Count%, FldLen% - Count% + 1) =
MID$(CurrFld$, Count% + 1, FldLen% - Count%)
                  END IF
                  CurrFld$ = CurrFld$ + " "
                  LOCATE StRow%, StCol%
                  PRINT LEFT$(CurrFld$, FldLen%)
                  Count% = Count% - 1
               ELSE
                  BEEP
               END IF
            CASE Esc, ABORT, CrsrUp, CrsrDown, Retrn, PF10
               ExitKey$ = InChar$  ' Escape, up arrow, down arrow, Return,
Shift F4, F10
            CASE ELSE
               BEEP
         END SELECT
      END IF
   LOOP UNTIL ExitKey$ <> ""
   Count% = FldLen%
   WHILE MID$(CurrFld$, Count%, 1) = "_" AND Count% > 1
      Count% = Count% - 1
   WEND
   IF Count% = 1 AND LEFT$(CurrFld$, 1) = "_" THEN
      CurrFld$ = ""
   ELSE
      CurrFld$ = LEFT$(CurrFld$, Count%)
   END IF
END SUB
'
'*************************************************************************
'*                                                                       *
'*  This procedure draws a line frame on the screen starting at ULRow%, *
'*  ULCol% down and across to LRRow%, LRCol%.  If LineType% = 1 then a  *
'*  single line is drawn if it is 2 a double line frame is drawn.       *
'*                                                                       *
'*************************************************************************
SUB Frame (ULRow%, ULCol%, LRRow%, LRCol%, LineType%)

   OldY% = POS(1)
   OldX% = CSRLIN
   FrameWidth% = LRCol% - ULCol% - 1
   FrameHeight% = LRRow% - ULRow% - 1
   Offset% = ULCol% - 1
```

```
   SELECT CASE LineType%
      CASE 1
         URCorner$ = "┐"
         LLCorner$ = "└"
         HorizLine$ = "─"
         ULCorner$ = "┌"
         VertLine$ = "│"
         LRCorner$ = "┘"
      CASE 2
         URCorner$ = "╗"
         VertLine$ = "║"
         LLCorner$ = "╚"
         ULCorner$ = "╔"
         LRCorner$ = "╝"
         HorizLine$ = "═"
   END SELECT
   LOCATE ULRow%, ULCol%
   PRINT ULCorner$; STRING$(FrameWidth%, HorizLine$); URCorner$;
   FOR Count% = 1 TO FrameHeight%
      LOCATE ULRow% + Count%, ULCol%
      PRINT VertLine$; SPACE$(FrameWidth%); VertLine$;
   NEXT Count%
   LOCATE LRRow%, ULCol%
   PRINT LLCorner$; STRING$(FrameWidth%, HorizLine$); LRCorner$;
   LOCATE OldX%, OldY%

END SUB

'
'*************************************************************************
'*                                                                       *
'*  This procedure controls the input of data.  The Ident field is      *
'*  entered.  A value must be entered before moving to the next field.  *
'*  Once values have been entered the user may move to any field to     *
'*  the previously entered value.  EditFld is called to accept data for *
'*  all fields.  The user must press SPF4 or PF10 to exit this routine. *
'*                                                                       *
'*************************************************************************
'
SUB InputData (Ident$, GRWght#, PcntLoad#, NumWhls%, TirePress#, ExitKey$)

   FOR CurrFld% = 1 TO NumWhls%
      Xx#(NumWhls%) = 0
      Yy#(NumWhls%) = 0
   NEXT CurrFld%
   CurrFld% = 1
   DO
      DO
         IF ExitKey$ = Esc THEN         ' Reinitialize variables
            FOR CurrFld% = 1 TO NumWhls%
               Xx#(NumWhls%) = 0
               Yy#(NumWhls%) = 0
            NEXT CurrFld%
            Ident$ = ""
            GRWght& = 0
            PcntLoad# = 0#
            NumWhls% = 0
            TirePress# = 0#
            WhlCnt% = 1
            CurrFld% = 1
            DrawScreen Ident$, GRWght#, PcntLoad#, NumWhls%, TirePress#
```

```
END IF
SELECT CASE CurrFld%          ' Set parameters to pass to EditFld
   CASE 1                     ' Ident field
      CurrField$ = Ident$
      StRow% = IDRow
      StCol% = IDCol
      FldLen% = IDLen
      FldType% = 1
   CASE 2                     ' Gross weight
      IF GRWght# <> 0# THEN
         CurrField$ = LTRIM$(STR$(GRWght#))
      ELSE
         CurrField$ = ""
      END IF
      StRow% = GWRow
      StCol% = GWCol
      FldLen% = GWLen
      FldType% = 2
   CASE 3                     ' Percent load
      IF PcntLoad# <> 0# THEN
         CurrField$ = LTRIM$(STR$(PcntLoad#))
      ELSE
         CurrField$ = ""
      END IF
      StRow% = LGRow
      StCol% = LGCol
      FldLen% = LGLen
      FldType% = 3            '
   CASE 4                     ' Number of wheels
      IF NumWhls% <> 0 THEN
         CurrField$ = LTRIM$(STR$(NumWhls%))
      ELSE
         CurrField$ = ""
      END IF
      StRow% = NWRow
      StCol% = NWCol
      FldLen% = NWLen
      FldType% = 2
      WhlCnt% = 1
   CASE 5                     ' Tire pressure
      IF TirePress# <> 0# THEN
         CurrField$ = LTRIM$(STR$(TirePress#))
      ELSE
         CurrField$ = ""
      END IF
      StRow% = TPRow
      StCol% = TPCol
      FldLen% = TPLen
      FldType% = 3
   CASE 6
      CurrField$ = PrtScrn
      StRow% = PSRow
      StCol% = PSCol
      FldLen% = PSLen
      FldType% = 4
      ValidChars$ = "PS"
   CASE 7                     ' Wheel X coord
      IF NumWhls% = 0 THEN
         BEEP                 ' Must enter number of wheel before
         CurrFld% = 4         ' entering coordinates
         CurrField$ = ""
```

```
                  StRow% = NWRow
                  StCol% = NWCol
                  FldLen% = NWLen
                  FldType% = 2
                  WhlCnt% = 1
               ELSE
                  CurrField$ = LTRIM$(STR$(Xx#(WhlCnt%)))
                  LOCATE 15, 41
                  PRINT WhlCnt%; "  X: ";
                  PRINT USING "####"; Xx#(WhlCnt%);
                  PRINT "  Y: ";
                  PRINT USING "####"; Yy#(WhlCnt%);
                  StRow% = WXRow
                  StCol% = WXCol
                  FldLen% = WXLen
                  FldType% = 2
               END IF
            CASE 8                     ' Wheel Y coord
               CurrField$ = LTRIM$(STR$(Yy#(WhlCnt%)))
               LOCATE 15, 41
               PRINT WhlCnt%; "  X: ";
               PRINT USING "####"; Xx#(WhlCnt%);
               PRINT "  Y: ";
               PRINT USING "####"; Yy#(WhlCnt%);
               StRow% = WYRow
               StCol% = WYCol
               FldLen% = WYLen
               FldType% = 2
         END SELECT            '
         CurrField$ = LEFT$(CurrField$, FldLen%)
         EditFld CurrField$, ValidChars$, StRow%, StCol%, FldType%, FldLen%,
ExitKey$
      LOOP UNTIL CurrField$ <> "" OR ExitKey$ = ABORT
      IF ExitKey$ <> Esc AND ExitKey$ <> ABORT THEN
         SELECT CASE CurrFld%      ' reassign CurrField to appropriate
variable
            CASE 1
               Ident$ = CurrField$
            CASE 2
               GRWght# = VAL(CurrField$)
               LOCATE GWRow, GWCol
               PRINT USING "#####.#"; GRWght#;
            CASE 3
               PcntLoad# = VAL(CurrField$)
               LOCATE LGRow, LGCol
               PRINT USING "###.#"; PcntLoad#;
            CASE 4
               NumWhls% = VAL(CurrField$)
               LOCATE NWRow, NWCol
               PRINT USING "##"; NumWhls%;
            CASE 5
               TirePress# = VAL(CurrField$)
               LOCATE TPRow, TPCol
               PRINT USING "####.#"; TirePress#;
            CASE 6
               PrtScrn = UCASE$(CurrField$)
            CASE 7
               Xx#(WhlCnt%) = VAL(CurrField$)
            CASE 8
               Yy#(WhlCnt%) = VAL(CurrField$)
               IF WhlCnt% > 7 THEN
```

```
                  Start% = WhlCnt% - 6
               ELSE
                  Start% = 1
               END IF
               DispStart% = 1      ' Display wheel coordinates
               FOR Count% = Start% TO WhlCnt%
                  LOCATE 16 + DispStart%, 40
                  PRINT USING "###"; Count%;
                  PRINT ":       ";
                  PRINT USING "###"; Xx#(Count%);
                  PRINT "       ";
                  PRINT USING "###"; Yy#(Count%);
                  DispStart% = DispStart% + 1
               NEXT Count%
         END SELECT                ' 
         SELECT CASE ExitKey$      ' Take appropriate action according to
last
            CASE CrsrUp            ' key pressed while in EditFld
               IF CurrFld% > 1 THEN
                  IF CurrFld% = 7 THEN
                     IF WhlCnt% >= 1 THEN
                        IF WhlCnt% > 1 THEN
                           WhlCnt% = WhlCnt% - 1
                           CurrFld% = 8
                        ELSE
                           CurrFld% = CurrFld% - 1
                        END IF
                     END IF
                  ELSE
                     CurrFld% = CurrFld% - 1
                  END IF
               ELSE
                  BEEP
               END IF
            CASE CrsrDown, Retrn, PF10
               IF CurrFld% = 8 THEN
                  IF WhlCnt% <= NumWhls% THEN
                     IF WhlCnt% < NumWhls% THEN
                        WhlCnt% = WhlCnt% + 1
                        CurrFld% = 7
                     ELSE
                        CurrFld% = 1
                        WhlCnt% = 1
                     END IF
                  END IF
               ELSE
                  CurrFld% = CurrFld% + 1
               END IF
         END SELECT
      END IF
   LOOP UNTIL ExitKey$ = ABORT OR ExitKey$ = PF10

END SUB

SUB Page (Ident$, GRWght#, PcntLoad#, NumWhls%, TirePress#, Load#)

   '***** Print input values *****

   PRINT #FileNum, SPACE$(25); "RIGID PAVEMENT DESIGN"
   PRINT #FileNum, STRING$(75, "*")
   PRINT #FileNum,
```

```
   PRINT #FileNum, "Aircraft Name    :   "; Ident$
   PRINT #FileNum, "Gross Weight (KN):   "; USING "####.#"; GRWght#;
   PRINT #FileNum, SPACE$(19); "% Load on Gear     : "; USING "####.#";
PcntLoad#
   PRINT #FileNum, "Wheel Load (KN)  :   "; USING "####.#"; Load#;
   PRINT #FileNum, SPACE$(19); "Tire Pressure (MPA): "; USING "####.##";
TirePress#
   PRINT #FileNum,
   PRINT #FileNum, "Wheel Coords (CM):  Wheel#     X        Y"
   FOR Count% = 1 TO NumWhls%
      PRINT #FileNum, TAB(22); USING "###"; Count%;
      PRINT #FileNum, USING "#######.#"; Xx#(Count%); Yy#(Count%)
   NEXT Count%
   PRINT #FileNum,
   PRINT #FileNum, "                  Origin: "; USING "#####.#"; Xo#; Yo#

END SUB
```