MIL-HDBK-1021/2
30 SEPTEMBER 1988
SUPERSEDING
NAVFAC DM-21
CHAPTER 3
JUNE 1973

MILITARY HANDBOOK

GENERAL CONCEPTS FOR AIRFIELD

PAVEMENT DESIGN

AMSC N/A

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ABSTRACT

This handbook presents basic concepts regarding airfield pavement design and is intended for use by experienced engineers. The contents include criteria on selection of pavement type, traffic areas and design loadings, pavement rehabilitation and economic analysis.

FOREWORD

This handbook has been developed from an evaluation of facilities in the shore establishment, from surveys of the availability of new materials and construction methods, and from selection of the best design practices of the Naval Facilities Engineering Command (NAVFACENGCOM), other Government agencies, and the private sector. This handbook was prepared using, to the maximum extent feasible, national professional society, association, and institute standards. Deviations from these criteria in the planning, engineering, design, and construction of Naval shore facilities, cannot be made without prior approval of NAVFACENGCOM HQ (Code 04).

Design cannot remain static any more than can the functions it serves or the technologies it uses. Accordingly, recommendations for improvement are encouraged and should be furnished to Commander, Western Division, Naval Facilities Engineering Command (Code 406.2), P.O. Box 727, San Bruno, CA 94066.

THIS HANDBOOK SHALL NOT BE USED AS A REFERENCE DOCUMENT FOR PROCUREMENT OF FACILITIES CONSTRUCTION. IT IS TO BE USED IN THE PURCHASE OF FACILITIES ENGINEERING STUDIES AND DESIGN (FINAL PLANS, SPECIFICATIONS, AND COST ESTIMATES). DO NOT REFERENCE IT IN MILITARY OR FEDERAL SPECIFICATIONS OR OTHER PROCUREMENT DOCUMENTS.

AIRFIELD PAVEMENT DESIGN CRITERIA MANUALS

Criteria Manual	Title	Preparing Activity
DM-21.1	Airfield Geometric Design	LANTDIV
MIL-HDBK-1021/2	General Concepts for Pavement Design	WESTDIV
DM-21.3/ TM 5-825.2/ AFM 88-6, Chap 2	Flexible Pavement Design for Airfields (TRI SERVICE)	LANTDIV
MIL-HDBK-1021/4	Rigid Airfield Pavement Design for Airfields	WESTDIV
MIL-HDBK-1021/5	Soil Stabilization for Pavement (PROPOSED)	SOUTHDIV
DM-21.06	Airfield Subsurface Drainage and Pavement Design For Frost Conditions	SOUTHDIV
MIL-HDBK-1021/7	Airfield Pavement Evaluation (UNDER PREPARATION)	HDQTRS
DM-21.9	Skid Resistant Runway Surface	HDQTRS

NOTE: Design manuals, when revised, will be converted to military handbooks.

This handbook is issued to provide immediate guidance to the user. However, it may or may not conform to format requirements of MIL-HDBK-1006/3 and will be corrected on the next update.

GENERAL CONCEPTS FOR AIRFIELD PAVEMENT DESIGN

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Section 1: INTRODUCTION

1.1 Scope. This handbook includes information and criteria on general pavement design concepts for rigid and flexible pavements for all Navy and Marine Corps airfield facilities. These criteria include selection of pavement type, definition of traffic areas, aircraft characteristics, pavement rehabilitation guidelines, and life-cycle cost analysis.

1.2 Cancellation. This handbook cancels and supersedes Chapter 3 of NAVFAC DM-21, Airfield Pavements, June 1973.

Section 2: SELECTION OF PAVEMENT TYPE

2.1 Pavement Types. Surfaces of new airfield pavement are constructed with either Asphalt Concrete (AC) or Portland Cement Concrete (PCC). AC and PCC are used as overlays for the rehabilitation of existing deteriorated pavements.

2.1.1 Flexible Pavements. Flexible pavements are designed to distribute the high stresses from the applied wheel loads through the various pavement layers, thereby reducing the stress transmitted to the subgrade. Flexible pavements are also designed to limit deflections under load, to prevent permanent deformation in any of the pavement layers, and to resist fatigue cracking of the asphalt concrete surface.

The typical cross-section of a flexible pavement has an asphalt concrete surface layer or wearing course placed on top of a base layer, one or more subbase layers, and the subgrade (see Figure 1). The base and subbase courses can be constructed with a variety of stabilized (asphalt-modified or cement-modified) and unstabilized aggregate materials. The layer thicknesses and materials vary. (Refer to NAVFAC DM-21.3, Flexible Pavement Design For Airfields.)

Flexible pavements are typically used for runway interiors, taxiway interiors, and shoulders. Refer to Section 3 for guidance on traffic areas. Flexible pavements are not used where there is a danger of aviation fuel, brake fluid, or hydraulic fluid spillage, or excessive heat from the blast of jet engines. Hydrocarbon products and excessive heat will soften asphalt concrete and cause premature pavement distress.

Flexible pavements have several advantages when they are used. They can adjust to some movement in the subgrade without cracking. There is also an extremely short waiting period between the end of construction of the pavement and the beginning of use by traffic.

2.1.2 Rigid Pavements. Rigid pavements are designed to distribute surface loads over a wide area of the subgrade through slab action. This is accomplished by the higher modulus of elasticity and rigidity of the PCC surface layer. Most of the load-carrying capacity of the rigid pavement is provided by the surface layer. Rigid pavements must be designed for small corner and edge deflections to reduce pumping and erosion of the base. (Refer to MIL-HDBK-1021/4, Rigid Pavement Design for Airfields.) PCC pavements are resistant to fuel spillage and jet blast and are used in apron areas, power check pads, and runway ends. Concrete pavements are designed to withstand the heavier static loads applied to the critical areas of the runways, taxiways, and aprons.

2.1.2.1 Non-Reinforced Portland Cement Concrete. This type of rigid pavement does not contain reinforcement. The dimensions of the slabs are reduced to prevent cracks from forming in the interior due to thermal curling and shrinkage stresses. Dowels are sometimes used at joints to provide improved load transfer between slabs. The increased load transfer will greatly reduce slab stresses and deflections and aid in preventing pavement distresses; however, misaligned dowels can lead to spalling.

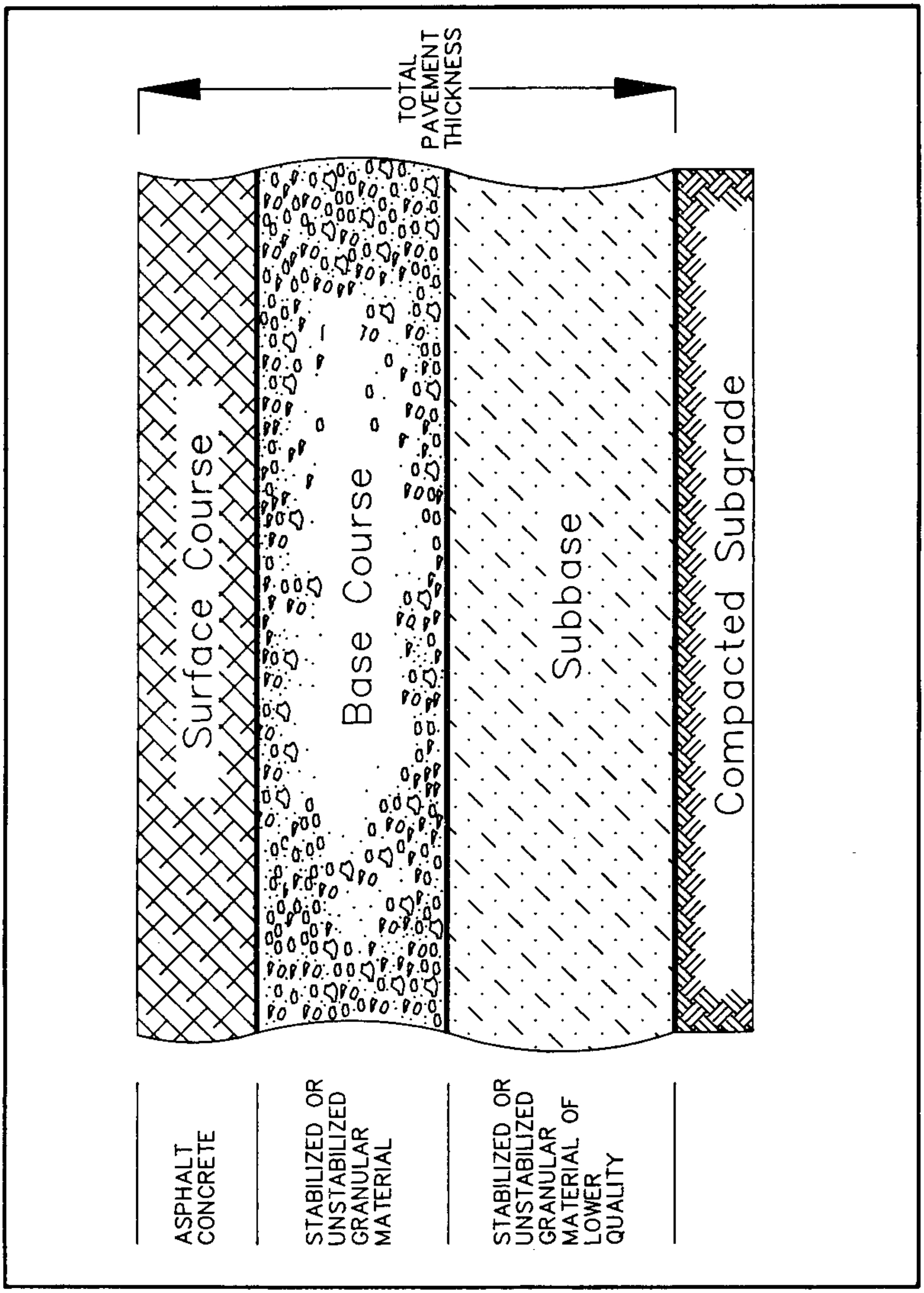


Figure 1
Cross Section of a Flexible Pavement

The typical cross-section of rigid pavement has a PCC surface, a base layer of either stabilized or unstabilized aggregate and has one or more subbase layers. The subgrade may also be treated with admixtures and compacted in place to serve as a subbase (see Figure 2). The surface layer of the rigid pavement is designed so that it is thick enough to control fatigue cracking in the form of corner breaks and transverse and longitudinal cracking for the given design traffic. Properly designed and maintained, jointed, non-reinforced concrete pavement will not exhibit pumping or faulting. Also, the short transverse joint spacing reduces transverse cracking that can occur in longer slabs from non-load causes.

2.1.2.2 Reinforced Portland Cement Concrete. Rigid pavements for airfields are constructed with reinforcing steel. The reinforcement is normally placed in the upper half of the concrete layer. Pavement thickness is not reduced from that obtained in non-reinforced concrete pavement design. Reinforced pavements use a longer joint spacing than non-reinforced jointed pavements. The reinforcing steel holds together cracks that develop from shrinkage, warping, curling, and load stresses. A typical reinforced concrete pavement cross section does not differ significantly from the non-reinforced concrete pavement cross section shown in Figure 2. Dowels are used at transverse joints for load transfer purposes since the slabs are typically longer than non-reinforced pavements and the joint movements are greater. Reinforced concrete pavements are not normally used for Navy and Marine Corps projects, but may be considered for special or unusual design conditions, on a case-by-case basis, when approved by the Naval Facilities Engineering Command.

2.1.3 Overlays. Overlays are constructed for either structural or functional reasons. Functional overlays are constructed to improve surface characteristics, such as friction or roughness or surface condition. Structural overlays are constructed to restore or to increase the structural capacity of the pavement due to deterioration or to increase the structural capacity of an otherwise sound pavement to accommodate increased traffic or a change in mission. PCC and asphalt concrete are the most common types of overlays.

2.1.3.1 Flexible Overlays. Flexible overlays are constructed from bituminous materials. They may be specified for either structural or functional purposes. The intended purpose of the overlay determines its design. The design is also affected by the type and condition of the existing pavement. Functional overlays that correct a surficial problem, such as skid resistance or hydroplaning, are constructed with a minimum thickness. Functional overlays are described in NAVFAC DM-21.3.

Design considerations for a structural overlay are different from those for a functional overlay. For a structural flexible overlay, the existing pavement is evaluated to determine its load-carrying capacity. The overlay thickness is a function of several factors, including existing distress, layer thicknesses, and material properties. For the design of flexible overlays on existing flexible pavements, refer to NAVFAC DM-21.3, and to MIL-HDBK-1021/4 for flexible design criteria of overlays on existing rigid pavements.

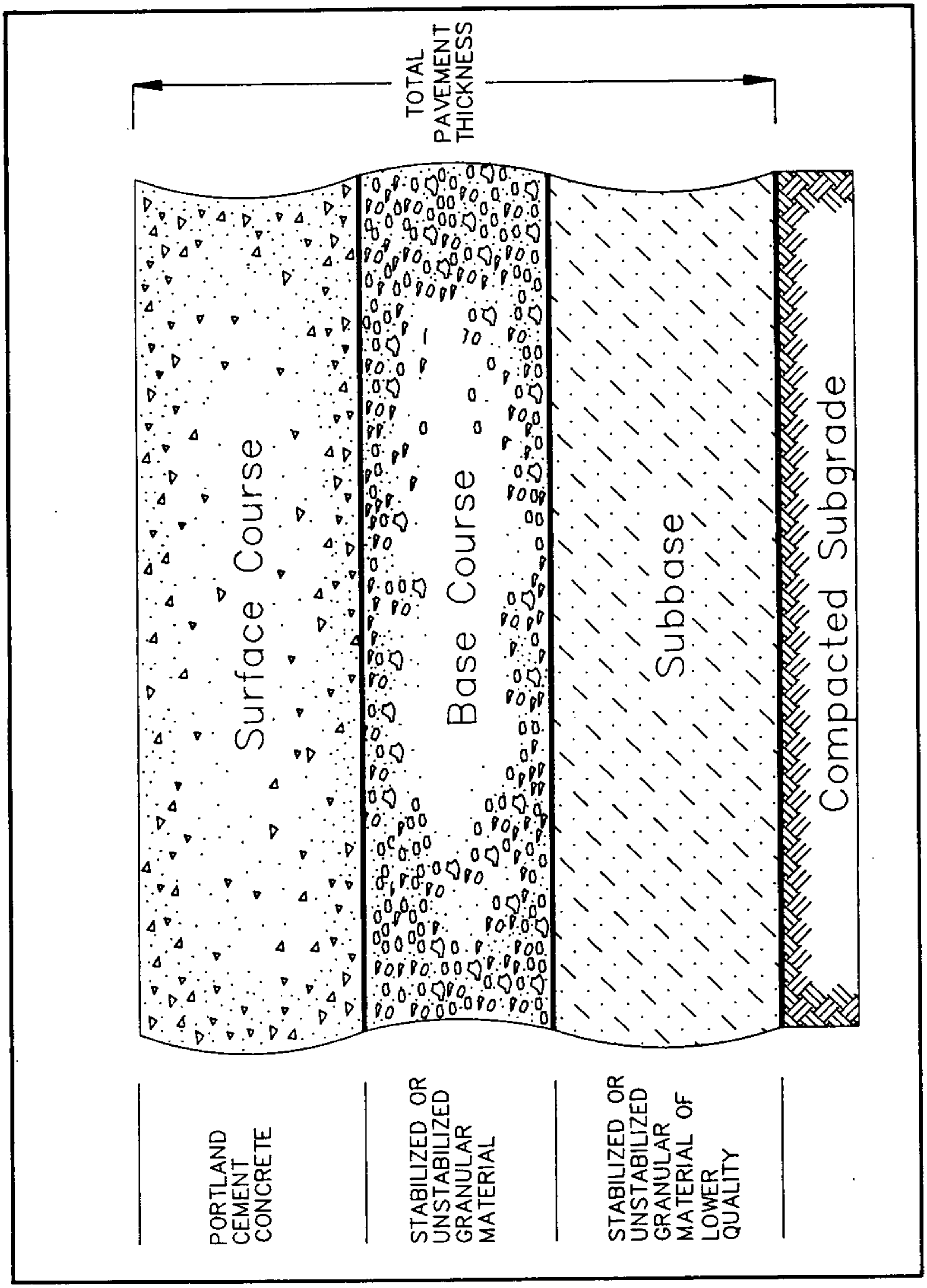


Figure 2
Cross Section of a Rigid Pavement

Flexible overlays are generally constructed as an asphaltic concrete layer with a dense-graded aggregate. Variations to these requirements are common for certain overlays such as porous friction courses.

There are several reasons to use an asphalt concrete overlay rather than a PCC overlay. If a functional overlay is needed, an asphalt concrete overlay is generally the most economical method of construction. AC overlays are also preferred for their ease of construction and the short airfield closure time. Flexible overlays must be properly designed to prevent the occurrence of rutting and fatigue cracking.

A major problem with asphalt concrete overlays is reflection cracking. Steps should be taken to minimize the development of reflection cracking, as discussed in Section 4. Pre-overlay repair is another major factor in the performance of asphalt concrete overlays. Any significant deterioration of the existing pavement surface should be repaired prior to construction of the overlay.

2.1.3.2 Portland Cement Concrete Overlays. PCC overlays are built to increase structural capacity and to improve the operational characteristics of the surface. PCC overlays can be constructed over either existing rigid or flexible pavements. The overlay can be completely unbonded, partially bonded, or fully bonded with the underlying pavement. There are many factors which affect their design. Refer to MIL-HDBK-1021/4 for criteria on the use and design of Portland cement conrete overlays. A cross-section of a typical PCC overlay is shown in Figure 3.

The performance of PCC overlays is dependent on the design and construction of the overlay. Critical factors affecting the performance of the overlay include the surface preparation, extent of existing surface distress, drainage, and existing load-carrying capacity. Unbonded overlays use a bituminous separation layer to prevent reflection cracking. To ensure good performance of an unbonded overlay in areas where extensive fuel spillage is expected, consider a coal tar concrete separation layer.

2.2 Pavement Materials. A typical pavement cross-section consists of a surface course, base course, subbase course, and subgrade. Typical cross-sections for flexible and rigid pavements are shown in Figure 1 and Figure 2. The components of each of the pavement and foundation layers in those cross-sections is discussed in paragraphs 2.2.1 through 2.2.8.

2.2.1 Subgrade. The subgrade is the foundation upon which the pavement is built, usually on existing soil. Subgrade also refers to imported soil in cases where undesirable soil must be replaced or where fill is needed.

The typical constituent elements of the subgrade which are of interest in the design of pavements are the fines (silts and clays), sands, and aggregates. Subgrade soils are classified according to ASTM D2487, Unified Soil Classification System. The variability of the subgrade material may be unlimited; subgrade soil classification can vary throughout a project.

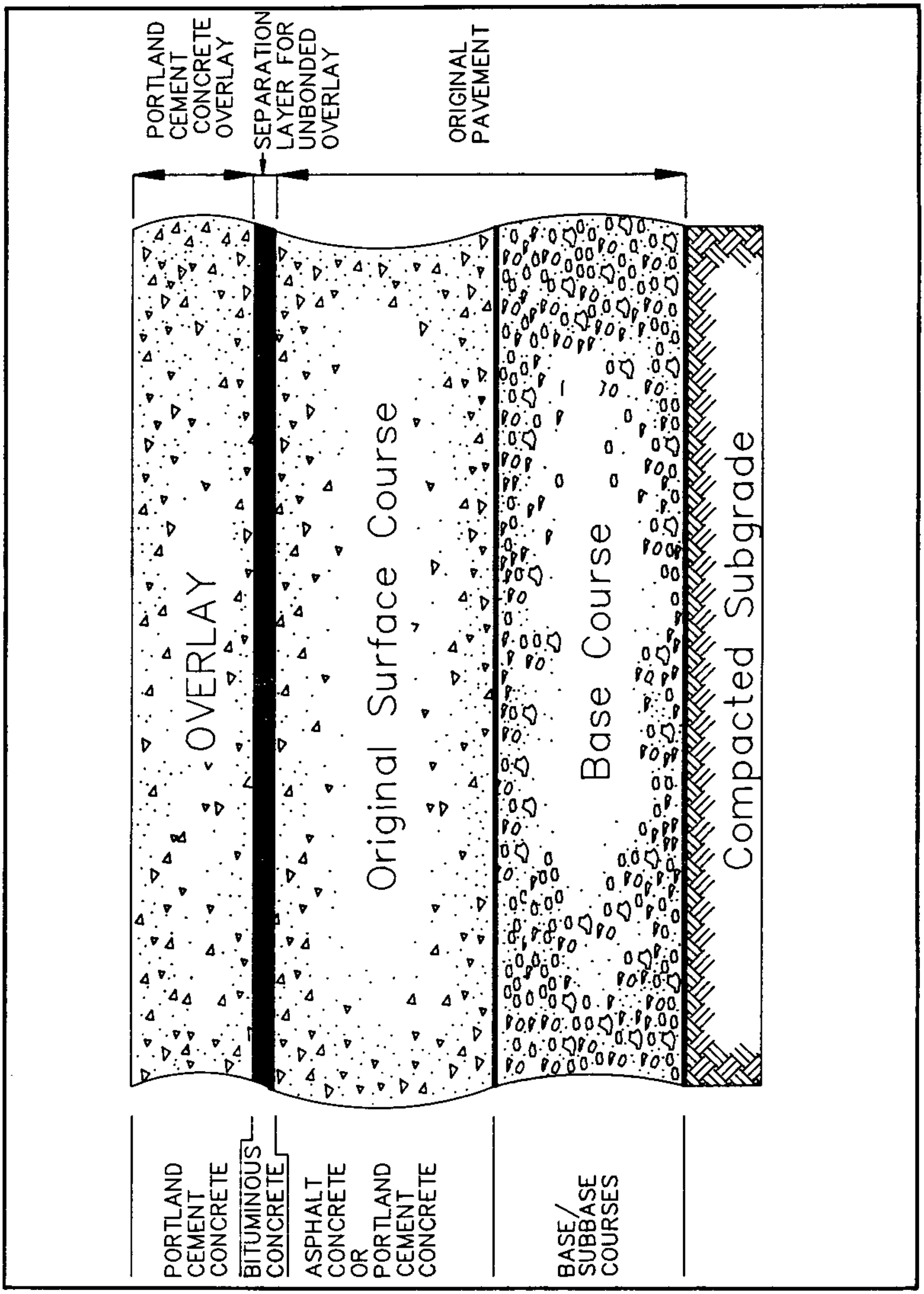


Figure 3
Cross Section of a Pavement with a Portland Cement Concrete Overlay

Subgrade soils can be stabilized to improve their properties, to expedite construction, and to improve subgrade strength and stability. A stabilized subgrade can also prevent subgrade fines from infiltrating into a granular base course as well as improving drainage characteristics of the stabilized subgrade layer and reducing the softening effect which moisture in the subgrade will have on the pavement structure. A granular layer (unstabilized) that is sandwiched between a lower stabilized layer and the concrete pavement slab is designed to drain so that moisture will not be trapped in the layer. When required, a subsurface drainage installation should be designed to remove moisture from this layer. For a detailed discussion of soil stabilization, refer to MIL-HDBK-1021/5, Soil Stabilization for Pavements, and refer to MIL-HDBK-1021/4 and NAVFAC DM-21.3 for criteria on airfield subgrade evaluation and preparation.

2.2.2 Base and Subbase Course Materials. The layers between the subgrade and the surface layer are referred to as the subbase and base courses. In the flexible pavement system, the main purpose of these layers is to limit deflections and to distribute the load applied to the surface throughout the pavement layers. The result is a reduction of the stress transmitted to the subgrade and the deflections of each layer. The main purpose of the base course in the rigid pavement system is to provide uniform support, and to assist in pavement drainage. For both pavement types, these layers protect frost-susceptible layers, help control pumping, and expedite construction.

Different materials can be specified for a base or subbase course, depending on the purpose of the layer. In addition to naturally occurring aggregates, which are used in the majority of applications, some man-made aggregates, such as slag, may be used where available. Refer to DM-21.06, Airfield Subsurface Drainage and Pavement Design for Frost Conditions, and for information on subbase and base course design for frost conditions and drainage. Refer to NFGS-02232, Select Material Base Course for Rigid Pavement, for specifications on base course material for rigid pavement. Refer to NFGS-02233, Graded Crushed Aggregate Base Course for Flexible Pavement, MIL-HDBK-1021/4, and DM-21.03, for guidance on material selection and specifications on subbase and base materials for flexible pavements.

2.2.2.1 Granular Layers. For rigid pavements, high quality granular bases are constructed with aggregates meeting the requirements of NFGS-02232. Limits are placed on gradation, the Atterberg limits, and the California Bearing Ratio (CBR). In addition, consideration should be given to the abrasion resistance and freeze-thaw durability of the aggregate. Similar limitations are placed on granular material base and subbase layers for flexible pavements. Refer to DM-21.3 and MIL-HDBK-1021/4 for more information on acceptable materials for granular layers. To achieve a drainable base, fines must be reduced considerably from that normally used for a dense gradation.

2.2.2.2 Stabilized Layers. A stabilizing agent may be mixed with granular material to form a stabilized base. Typical products used to form a stabilized layer include asphalt cement and emulsions, Portland cement, lime, fly ash, and a combination of lime and fly ash. A stabilized base is a stronger layer and is used to provide increased support to the pavement and to improve load transfer. For a detailed discussion on stabilization, refer to TM 5-822-4, Soil Stabilization for Pavements. Additional guidance on the use of stabilized layers is provided in NAVFAC DM-21.3 and MIL-HDBK-1021/4. Portland cement stabilized layers must meet the requirements in NFGS-02247, Portland Cement Stabilized Course for Airfields, Roads and Streets.

2.2.2.3 Lean Concrete Layers. Lean concrete bases are constructed of a mixture of locally available granular materials (not select) and Portland cement. Lean concrete bases are typically used in the construction of PCC pavements and may be an economical method of increasing pavement support and reducing pumping. Adequate strength must be achieved to prevent erosion or freeze-thaw damage problems. Lean concrete bases are not typically used with bituminous surface courses because of the occurrence of reflective cracking. Refer to MIL-HDBK-1021/4 for criteria on the use of lean concrete base courses.

2.2.2.4 Recycled Concrete Layers. Old PCC slabs may be broken up and recycled for use as coarse aggregate for a variety of purposes, including granular layers. Where the old pavement is available, recycling should be considered as an alternative to importing virgin material, based on an economic analysis and the availability of equipment. If recycled material is used, the resulting aggregate shall still meet the requirements for a granular base material, as outlined in NFGS-02232.

2.2.3 Portland Cement Concrete. PCC is a mixture of granular material, portland cement, and water, which cures to form a hard, continuous matrix. Admixtures may be included for several purposes, as described in NFGS-02559, Portland Cement Concrete Pavement for Roads and Airfields, and MIL-HDBK-1021/4. Different requirements exist for the aggregates and the Portland cement which depend on the desired characteristics of the product. Specifications for PCC are found in NFGS-02559 and MIL-HDBK-1021/4.

2.2.4 Asphalt Concrete. AC is a mix composed of asphalt cement and aggregate. The asphalt cement and the aggregate are heated so that they can be easily mixed and placed. The mix cools and sets to form a durable, impervious wearing course. Specifications control all elements of an asphalt cement mix and are found in DM-21.3, and NFGS-02573, Bituminous Hot Mix Pavement.

2.2.5 Polymer Concretes. After curing, PCC is impregnated with a polymer to form polymer concrete. The polymer replaces water in the pore structure and improves the durability and strength of the mix. It also creates an impervious layer. Polymer concretes are typically used for partial depth spall repair where rapid opening to traffic is required. Polymerization is an expensive process and its use should be restricted to cases where the desired performance cannot be obtained with conventional materials.

2.2.6 Latex-Modified Asphalts. AC can be made more flexible and more resistant to thermal cracking and improve its resistance to moisture by the inclusion of synthetic rubber or latex particles in the mix. The use of latex-modified asphalts will be considered on a case-by-case basis by Headquarters Naval Facilities Engineering Command (NAVFACENGCOMHQ).

2.2.7 Fabrics. Synthetic fabrics, referred to generically as geotextiles, have been used in the construction of airfield pavements. They serve to improve stabilization, provide positive separation of layers, or to aid in pavement drainage. Synthetic fibers are spun or woven in sheets which are placed directly on the ground or as interlayers. Geotextiles have also been used in asphalt concrete overlays to retard reflective cracking. Geotextiles for use in both drainage and separation applications are described in NAVFAC DM-21.06 and DM-5.4, Pavements.

2.2.8 Rubberized (Latex) Coal Tars. In pavement areas where a fuel-resistant asphalt surface is desired, a rubberized coal tar layer may be considered. Rubberized coal tars are resistant to jet fuel and are considered more heat resistant than coal tar concrete. The addition of synthetic rubber improves the temperature susceptibility of the tar. Coal tar is a potent cancer causing agent and is hazardous when being applied or removed. It should be used only when other materials are unsatisfactory. Stringent personal protective measures must be taken during application or removal. To ensure adequate performance, the surface to which the overlay is applied must be clean. All loose material, dirt, clay, oil, grease, hydraulic fluid or other material which might prevent a suitable bond from developing between the surface and the applied coal tar layer must be removed. Pavement surfaces that have been softened by petroleum derivatives or have failed for other reasons should be removed entirely and replaced. For surface preparation required prior to application of a tar overlay, refer to NAVFAC MO-102, Maintenance and Repair of Surface Areas. Refer to TM 5-822-8 for specifications for rubberized tars.

2.3 Resistance to Fuel Spillage. Where fuel spillage is likely to occur, the pavement surface must be designed so that it is resistant to the harmful effects of the fuel.

2.3.1 Acceptable Pavement Types. A PCC pavement is not susceptible to damage from the hydrocarbons found in aviation fuels and is therefore an acceptable fuel resistant pavement. AC pavements are susceptible to damage from fuel spills. In pavement areas where fuel or hydraulic brake fluid spillage is a frequent occurrence, only PCC pavements may be constructed. Where existing asphalt pavements must be given short-term protection against fuel spills, apply a rubberized coal tar seal coat.

2.3.2 Areas Requiring Fuel Resistant Pavement. Areas of an airfield which are subject to fuel spillage are to be constructed using PCC pavements. These areas include:

a) runway ends,
b) aprons,
c) refueling lanes,
d) holding areas,
e) power check pads,
f) compass calibration pads,
g) arming and dearming pad, and
h) washracks.

2.3.3 Fuel Resistant Joint Sealants. In the areas where fuel resistant pavements are required, joint sealant shall also be resistant to damage from fuel spillage. The joint sealants that are acceptable include hot-poured rubberized coal tar sealants meeting Federal Specification SS-S-1614, Sealing Compound, Jet Fuel Resistant, Hot Applied, One Component, For Portland Cement and Tar Concrete Pavements, and cold-applied polymer type sealants meeting Federal Specification SS-S-200, Sealing Compound, Two Component, Elastometric, Polymer Type, Jet Fuel Resistant, Cold Applied. Fuel resistant joint sealants shall meet the requirements found in NFGS-02561, Joints, Reinforcement, and Mooring Eyes in Concrete Pavements. Preformed compression seals may be used when approved by NAVFACENGCOM.

2.4 Resistance to Jet Blast. The exhaust temperature from jet engines under certain operating conditions can reach temperatures which will damage the pavement surface. Hot-mix asphaltic concrete will begin to deform under static loads at temperatures between 120 °F (49 °C) and 140 °F (60 °C). However, asphaltic concrete pavements will generally resist temperatures up to 300 °F (149 °C) before surface damage such as aggregate stripping occurs. In areas where a pavement will sustain temperatures in or above this range for a prolonged period, PCC pavement will be used.

2.4.1 Acceptable Pavement Types. Following the procedures outlined in MIL-HDBK-1021/4, airfield pavement areas subject to severe jet blast shall be designed as rigid pavement. Where the danger exists that a concrete pavement will experience damage, such as surface scaling, from extreme temperatures, an aggregate with a low coefficient of thermal expansion such as basalt shall be used. A shorter joint spacing than normal may be used to reduce thermal curling stresses from the jet blast. This will reduce transverse and longitudinal cracking.

2.4.2 Areas Requiring Jet Blast Resistant Pavement. Pavement areas that are subject to severe jet blast include jet engine power check facilities, runway ends, taxiway ends, and warm-up pads. Other areas where aircraft are standing and are operated for a long time or with the afterburners operating should be designed as critical areas.

2.4.3 Jet Blast Resistant Joint Sealants. Jet blast resistant joint sealants shall be used in pavement areas subject to jet blast. Jet blast resistant joint sealants shall meet Federal Specification SS-S-200, Type M (machine applied) fast cure or Type H (hand mixed) retarded cure liquid sealant or compression seals.

2.5 Foreign Object Damage (FOD) Protection. Any loose object on an airfield pavement can be sucked up or blown into a jet engine, causing severe damage to the engine. Damage caused by foreign objects on the pavement is commonly called Foreign Object Damage (FOD). Appropriate maintenance measures must be taken to ensure that objects capable of causing FOD do not develop on the airfield pavement surface.

2.5.1 Policy on Slurry Seals. On airfield pavements asphalt slurry seals may generally be used for overruns, shoulders, auxiliary and outlying airfields, and locations having primarily propeller driven aircraft. For air stations having a high volume of tactical jet traffic where potentially long pavement closure for curing and sweeping is unacceptable, the asphalt slurry seal should not be used.

2.5.2 Policy on Chip Seals and Surface Treatments. Neither seal coats with cover aggregate (chip seals) nor bituminous surface treatments will be used on bituminous primary, secondary, or supporting pavements where jet aircraft operate. For basic training outlying fields bituminous surface treatments may be considered for the stabilized area of the type 1 clear zone (refer to DM-21.1, Airfield Geometric Design).

2.6 Critical Areas. Certain critical pavement areas shall be constructed as rigid pavement. Critical areas include the following:

a) maintenance and parking aprons,
b) access ramps to hangars and docks,
c) stub parking (hardstands),
d) all corrosion control facilities (such as washracks and rinse facilities),
e) compass calibration pads,
f) power check facilities,
g) aircraft refueling lanes,
h) runway ends [1,000 ft (305 m)],
i) warm-up pads, and
j) taxiway ends adjacent to runway (holding areas, runup areas).

The engineer may designate additional areas which are subject to excessive heat or fuel spillage as critical areas.

2.7 Non-Critical Areas. Those portions of the airfield that are subject to neither jet blast nor fuel spillage are designated as non-critical areas. These include:

a) the interior portion of runways and taxiways,
b) intermediate taxiway turnoffs,
c) towways,
d) paved shoulders, and
e) runway overruns.

The pavement surface in these areas shall be constructed as either a flexible or rigid pavement. The pavement type shall be determined on the basis of a life-cycle cost analysis which includes both construction and maintenance costs. Refer to the following paragraphs and the discussion of the life cycle cost procedure in Section 5 for further information.

2.8 Life Cycle Cost. This section defines life cycle cost analysis and discusses the current life cycle cost policy from NAVFAC P-442, Economic Analysis Handbook, for new pavement design. The life cycle cost analysis procedure is presented in Section 5.

2.8.1 Definition of Life Cycle Cost. Life cycle costs are those costs incurred over the analysis period for a pavement. Life cycle costs for an airfield pavement include not only the initial construction cost, but also annual maintenance expenses, periodic rehabilitation costs, and any other direct and indirect expenditures necessary to acquire and maintain the pavement. The salvage value is the costs that can be recovered from the pavement at the end of the analysis period and is also a part of the lifecycle cost of the pavement. Salvage value shall be considered in a life cycle cost analysis.

Since the expenses and the return (salvage value) occur at different times throughout the life of the facility, for the sum of the costs to be meaningful, all costs must be considered in a common time frame. This adjustment is made through the use of a discount rate to provide a comparison of present value or equivalent annual cost. Life-cycle costs do not include any sunk costs, or costs incurred prior to the decision to proceed with an alternative.

2.8.2 Life Cycle Cost Policy. For an airfield pavement, a life cycle cost analysis of the available alternatives shall be performed in order to select the preferred alternative for any new facility or rehabilitation project under consideration. The life cycle cost analysis procedure is presented in Section 5 of this handbook.

Section 3: TRAFFIC AREAS AND DESIGN LOADINGS

3.1 General. Traffic is an important input for pavement thickness design. An airfield pavement shall be designed to support a forecast number of loadings by one or more types of aircraft expected to use the facility over the design period. This requires information related to:

a) aircraft types (gear configurations),
b) maximum gross weight of each aircraft type,
c) lateral wander associated with each aircraft type, and
d) predicted number of operations of each aircraft type over the design life of the pavement.

3.2 Traffic Areas. Airfield pavements are categorized by traffic area as a function of either lateral traffic distribution or aircraft weight or both. The three principal traffic areas recognized on Navy and Marine Corps air stations are primary, secondary, and supporting. For purposes of standardization and for preparation of the Tri-Service design criteria, a primary area corresponds to an Air Force B traffic area and a secondary traffic area corresponds to an Air Force C traffic area. These designated traffic areas for a typical airfield layout plan are shown in Figure 4.

3.2.1 Primary Traffic Areas. Primary traffic areas require high pavement strength due to the combination of high operating weights and channelized traffic. Primary traffic areas include:

a) first 1000 ft (305 m) of runways,
b) primary taxiways,
c) holding areas, and
d) aprons.

3.2.2 Secondary Traffic Areas. Secondary traffic areas are normally subjected to unchannelized traffic and aircraft operating at lower weights than primary traffic areas. Secondary traffic areas include:

a) runway interiors, and
b) intermediate taxiway turnoffs.

3.2.3 Supporting Areas. Supporting areas are not intended for normal aircraft operations. They are designed to withstand occasional passes of aircraft on an emergency basis. Supporting traffic areas include:

a) inner 10 ft (3.05 m) of runway shoulders,
b) stabilized portions of runway overruns, and
c) blast protective pavement.

3.3 Aircraft Loadings. Factors which must be considered in pavement thickness design are the landing gear configuration, weight distribution, gear loads, number of wheels, wheel spacing, tire width, and tire inflation pressure. These characteristics are different for each aircraft and will result in a different pavement response. All aircraft expected to use the facility over the design period shall be considered in the pavement thickness design.

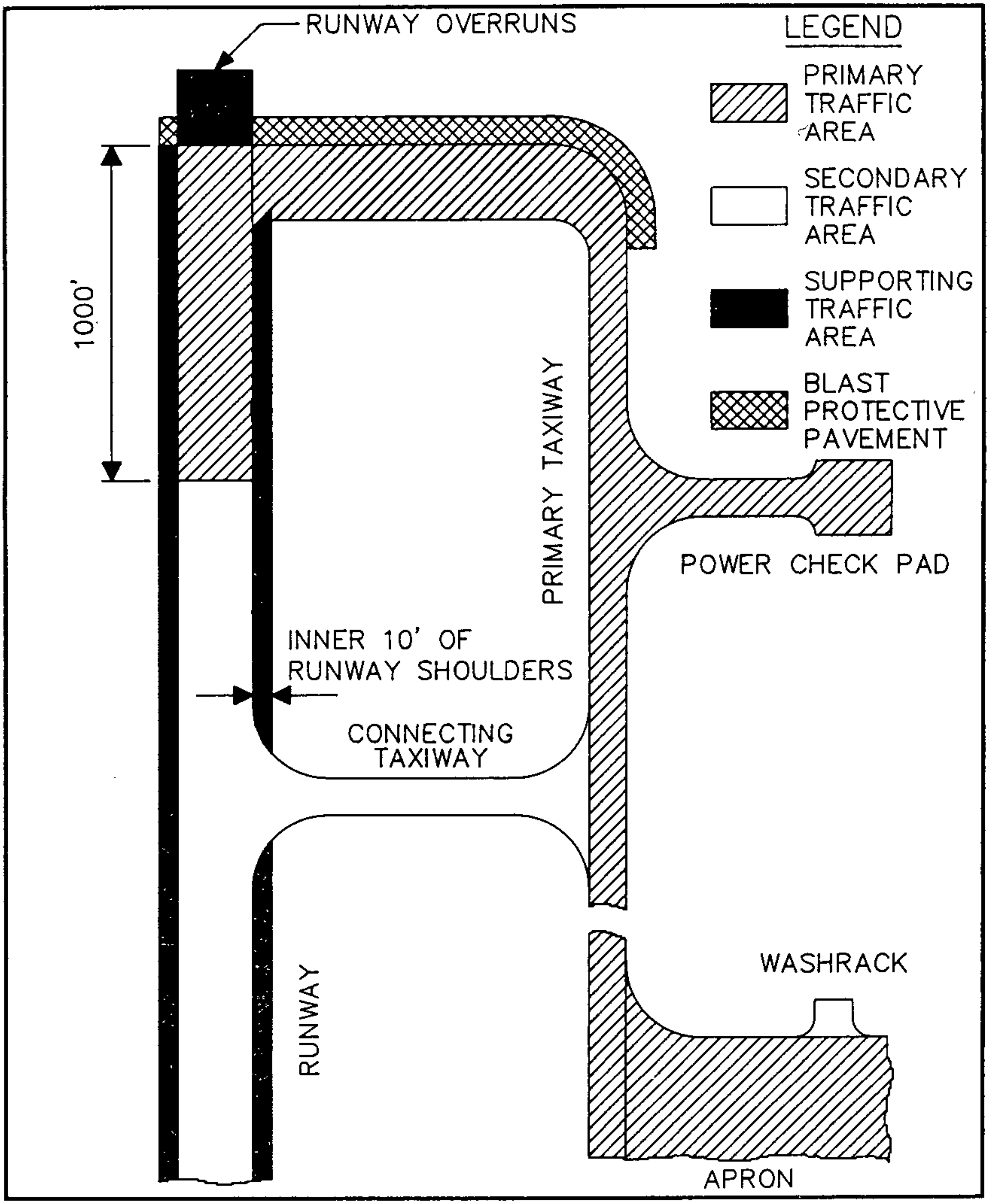


Figure 4
Primary, Secondary, and Supporting Traffic Areas
for Navy and Marine Corps Airfield Pavements

3.3.1 Aircraft Types. A landing gear assembly shall consist of a single wheel for smaller aircraft, or dual and dual tandem wheels for larger aircraft. Figure 5 illustrates the various multiwheel landing gear assemblies and lists typical aircraft for each.

3.3.2 Design Weight. The maximum static gear loads are used for pavement thickness design. Table 1 presents the design gear loads and other characteristics for Navy and Marine Corps aircraft. The design gear load is calculated from the design gross aircraft weight (typically, the maximum gross take-off weight) by assuming that 95 percent of the gross aircraft weight is carried by the main gears. The design gear loads given in Table 1 represent the maximum static gear loads expected to be applied to a pavement.

3.3.3 Use of Other Gear Loads in Design. Gear loads other than those listed in Table 1 may be used for design when required. Since certain areas of an airfield (e.g., runway shoulders, runway overruns) do not normally carry fully loaded aircraft, they do not need to be designed for the maximum gross weight.

3.3.4 Hangar Floors. Aircraft in hangars are not normally loaded with cargo, fuel or armaments. Hangar floors shall be designed for the empty weight of the aircraft. When exact data are not available, 60 percent of the maximum gross weight of the aircraft shall be used.

3.3.5 Standard Design Aircraft. One aircraft in each gear assembly group has been designated the representative aircraft for that group. Table 2 identifies these five standard aircraft types which are to be used as default values in the design of rigid and flexible pavements only when site-specific aircraft loadings are not available.

3.4 Aircraft Pass and Coverage Levels. In order to accurately quantify the damage that aircraft loadings will do to a pavement over the pavement design life, consider the lateral distribution of the aircraft as well as its wheel/gear configuration. The forecast number of aircraft passes over a pavement are converted to coverages. A coverage occurs at a specific point on the pavement surface when any portion of the tire print passes over that point. The critical point of greatest interest is that point which will be loaded the greatest number of times. For a given aircraft, the critical point is beneath one of the tires of a main gear when the aircraft is positioned at the center of the runway, taxiway, or other pavement feature.

Coverages resulting from operations of a particular aircraft type are a function of the number of passes, the number and spacing of wheels on the main landing gear, the width of the tire contact area, and the lateral distribution of the aircraft wheel paths relative to the pavement centerline. The collective influence of these factors is expressed in terms of pass-to-coverage ratios derived for each aircraft. Table 1 gives the pass-to-coverage ratios (for the critical point on the pavement surface) to be used for aircraft for primary (channelized) and secondary (unchannelized) traffic areas.

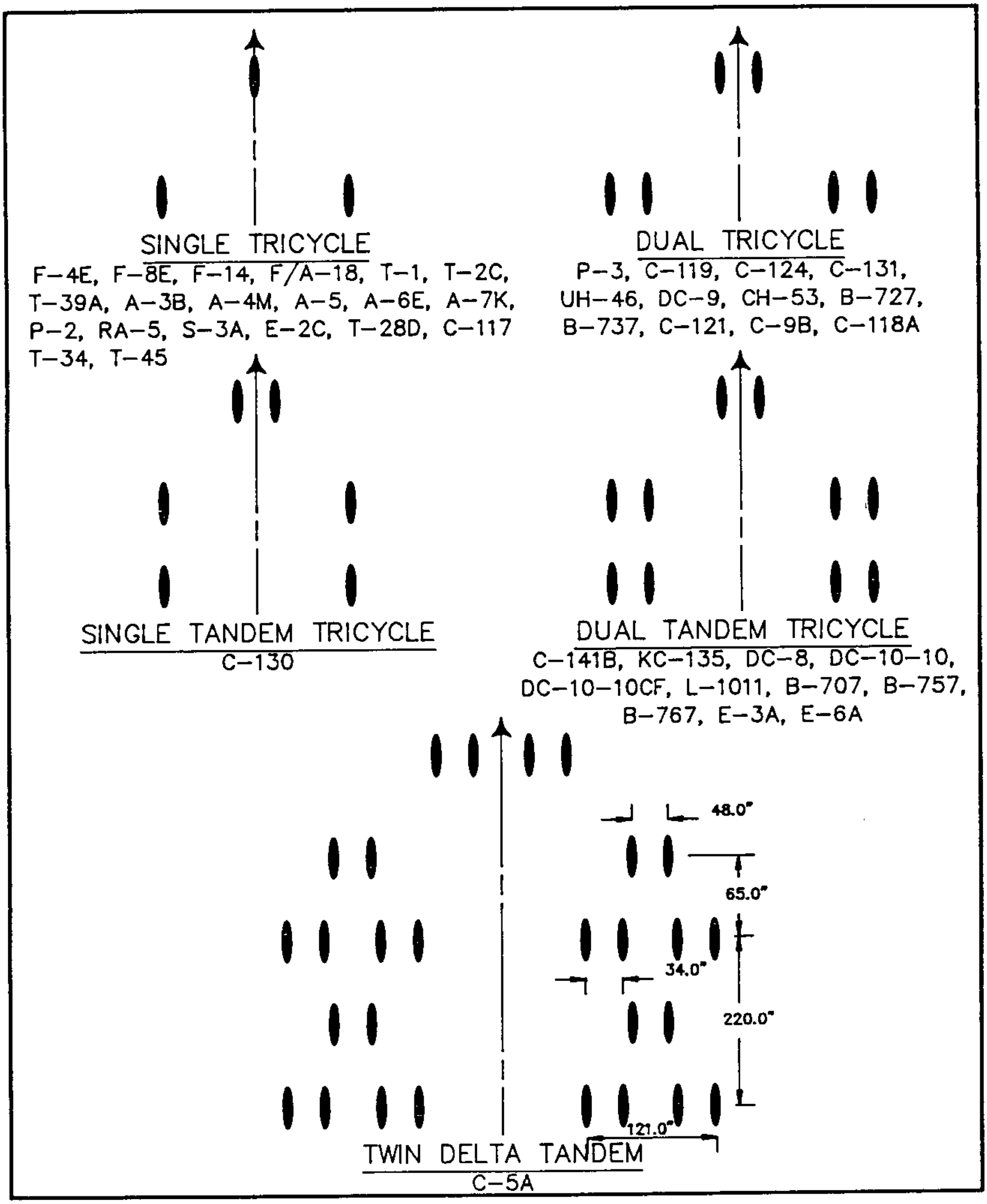


Figure 5
Multiwheel Landing Gear Assemblies for Navy and Marine Corps Aircraft.

Table 1
Aircraft Characteristics and Design Loadings for Navy and Marine Corps Air Stations

Type	DOD Designation	Type of Loading Gear	Design Gear Load	Design Tire Pressure	Pass/Coverage[3] Chan.	Pass/Coverage[3] Unchan.	Empty Weight (LBS)	Maximum Take-off Weight (LBS)	Wing Span (FT)	Length (FT)	Wheel Base (in.)	Tread (in.)	Main Gear Tire Spacing A(in.)[4]	Main Gear Tire Spacing B(in.)[5]
Attack	A-3B	ST	37,000 lb,	245 psi	3.48	14.96		78,000	72.5	76.4			–	–
	A-4M	ST	12,500 lb,	200 psi	11.63	23.26	10,500	24,500	27.5	41.25	160.5	93.5	–	–
	A-5	ST	29,500 lb,	300 psi	9.27	18.54	38,000	80,000	53.3	76.5	264.0	150.5	–	–
	RA-5C	ST	38,000 lb,	350 psi	8.82	17.64	38,800	81,700	53.3	76.5	264.0	150.5	–	–
	A-6E	ST	28,700 lb,	200 psi	7.67	15.35	26,600	60,400	53.0	55.75	206.0	132.0	–	–
	A-7K	ST	21,000 lb,	200 psi	8.97	13.91	21,800	42,000	38.7	46.1	188.1	113.9	–	–
	AV-8B	SPECIAL	15,000 lb,	125 psi	3.89	7.47	12,000	24,000	25.3	45.7	135.0			
Fighter	F-4E	ST	22,500 lb,	300 psi	13.70	27.39	31,800	58,000	38.4	58.3	279.0	215.0	–	–
	F-8E	ST	18,000 lb,	265 psi	13.69	27.39	19,700	34,300	85.7	54.5			–	–
	F-14	ST	30,000 lb,	240 psi	8.58	17.00	36,700	72,600	64.1	61.98	276.5	192.0	–	–
	F/A-18	ST	21,000 lb,	200 psi	8.22	16.44	30,000	51,900	40.4	56.0	213.7		–	–
Trainer	T-1	ST	9,000 lb,	200 psi	13.69	27.39							–	–
	T-2C	ST	7,000 lb,	165 psi	14.10	28.20	8,000	14,000	37.9	38.8	155.0	221.0	–	–
	T-39A	ST	9,000 lb,	165 psi	12.45	24.89	10,000	18,700	44.4	43.8	174.0	86.0	–	–
	T-28D	ST	4,300 lb,	60 psi	10.85	21.02	6,700	9,000	41.0	33.0	144.0	162.0	–	–
	T-34C	ST	1,500 lb,	60 psi			2,200	3,000	33.3	28.8			–	–
	T-44A	ST	4,500 lb,	90 psi	12.99	24.75	6,300	9,600	50.3	35.5	147.5	153.0	–	–
Patrol	P-3C	DT	68,000 lb,	190 psi	3.45	6.49	66,200	143,000	99.7	116.8	357.0	374.0	26.0	–
	S-3A	ST	19,000 lb,	245 psi	10.43	20.87	26,864	46,000	68.7	53.3	225.0	165.0	–	–
Transport and Tanker	C-5A	TDT	190,000 lb,	115 psi	1.62	2.20	318,000	837,000	222.7	247.8	765.1	449.5		
	C-121	DT	81,000 lb,	170 psi	3.45	6.18			123.0	113.6	599.0	336.0	28.0	–
	C-130	STT	84,000 lb,	95 psi	4.36	8.56	72,000	175,000	132.6	97.8	388.0	171.0	–	60.0
	KC-135	DTT	142,000 lb,	155 psi	3.37	5.97	104,300	301,600	130.8	152.9	708.0	265.0	35.8	59.8
	C-141B	DTT	155,000 lb,	180 psi	3.49	6.25	140,000	344,900	160.0	145.0	678.7	251.0	32.5	48.0
	C-9B	DT	51,300 lb,	152 psi	3.85	7.18	62,000	108,000	93.3	119.3	638.5	196.0	25.0	–
	C-117	ST	15,300 lb,	56 psi	5.56	11.11		36,800	95.0	64.4	440.0	222.0	–	–
	C-118A	DT	54,300 lb,	124 psi	3.48	6.39	59,000	112,000	117.5	106.8	432.0	296.5	29.0	–
Rotary Wing	UH-46E	DT	9,800 lb,	150 psi			12,550	22,800	51.0	84.4	298.0			
	CH-53E	DT	26,558 lb,	165 psi			33,226	69,750	79.0	90.0	327.0			
Commercial	B-707	DTT	157,000 lb,	180 psi	3.30	5.87	146,400	333,600	145.8	152.9	708.0	265.0	34.5	56.0
	B-727	DT	98,000 lb,	150 psi	3.30	5.88	101,500	209,500	108.0	153.6	760.0	225.0	34.0	–
	B-737	DT	54,000 lb,	150 psi	3.20	5.80	60,500	125,000	93.0	100.0	447.0	206.0	30.5	–
	B-747	DTT	190,000 lb,	195 psi	3.84	5.43	363,000	778,000	195.7	231.3	1008.0	434.0	43.25	54.0
	B-757-200	DTT	105,000 lb,	170 psi	3.30	5.88	129,900	220,000	124.5	155.3				
	B-767-200	DTT	143,000 lb,	183 psi	3.71	6.05	180,540	300,000	156.3	159.1				
	DC-8	DTT	172,000 lb,	196 psi	3.19	5.82		350,000	148.5	187.4	930.0	250.0	30.0	55.0
	DC-9 SERIES 10	DT	57,000 lb,	170 psi	3.61	6.73	50,840	90,500	89.4	104.4	524.4	196.8	24.0	–
	DC-10 SERIES 30	DTT	210,500 lb,	165 psi	3.77	5.61	267,197	572,000	165.3	181.6	868.6	429.0	54.0	64.0
	(Center Dual)		91,100 lb,	140 psi	2.63	3.96	248,485	466,000						
	L-1011-200	DTT	219,000 lb,	165 psi	3.66	5.57	249,100	450,000	155.3	177.8	840.0	432.0	52.0	70.0
Early Warning	E-2C	ST	24,500 lb,	260 psi	8.58	17.00	38,100	51,900	80.6	57.6	278.0	233.8	–	–
	E-3A	DTT	155,000 lb,	180 psi	3.30	5.87	88,000	325,000	145.8	152.9	708.0	265.0	34.5	56.0

ST = Single Tricycle
DT = Dual Tricycle
TDT = Twin Delta Tandem
STT = Single Tandem Tricycle
DTT = Dual Tandem Tricycle

NOTES:
1. Blank spaces indicate data not readily available.
2. This data represents the best available figures at the time of publication. The user should update this information for later models of the design aircraft.
3. Values given are for rigid and flexible pavements. Pass To Coverage Ratios for flexible pavements for aircraft with Dual Tandem Tricycle Gear are equal to one-half the value shown. All Tandem Wheel Aircraft produce only one maximum stress for each pass of the gear for rigid pavements.
4. A represents the transverse tire spacing on one main gear.
5. B represents the longitudinal tire spacing on one main gear.

Table 2
Standard Design Aircraft Types

LANDING GEAR ASSEMBLY	REPRESENTATIVE AIRCRAFT	WHEEL SPACING INCHES	(mm)	TIRE PRESSURE PSI	(MPa)	DESIGN GEAR LOAD POUNDS	(kg)
Single	F-14	-	-	240	(1.65)	30,000	(13 600)
Dual	P-3	26	(660)	190	(1.31)	68,000	(30 800)
Single Tandem	C-130	60	(1524)	95	(0.65)	84,000	(38 100)
Dual Tandem	C-141	32.5x48	(826x1219)	180	(1.24)	155,000	(70 300)
Twin Delta Tandem	C-5A	FIGURE 5		115	(0.79)	190,000	(86 200)

3.5. Procedure To Determine Pass-To-Coverage Ratio. The lateral distribution of aircraft traffic on runways, runway exits, and taxiways can be represented by a normal distribution function. Refer to Report No. FAA-RD-74-36, Field Survey and Analysis of Aircraft Distribution on Airport Pavements, which compares field observed lateral distribution patterns with the normal distribution function.

3.5.1 Normal Distribution. Two normal distributions are used, the standard normal and the general normal. The standard normal distribution is shown in Figure 6. In the standard normal distribution, the standard deviation (σ) is one, the mean (μ) is zero, and the maximum ordinate, C_z, is equal to $0.399/\sigma$. The standard normal distribution curve is defined by the following function:

EQUATION: $$f(z) = [1/(\sqrt{2\pi})]e^{-0.5z^2} \quad (1)$$

where $f(z)$ = the probability density of a standardized random variable (y-axis),

z = a variable of the standard normal distribution curve (x-axis).

Tabulated values of this curve are found in statistical handbooks. This standard normal distribution is important because it can be used to determine the properties of the general normal distribution (the actual aircraft lateral distribution), which has the following form:

EQUATION: $$f(x) = [1/S_x(\sqrt{2\pi})]e^{-0.5[(x-M)/S_x]^2} \quad (2)$$

where f(x) = the probability density of a general aircraft normal distribution,
x = a variable of the general normal distribution (lateral distance),
M = mean value of the general normal distribution, and
S_x = standard deviation of the general normal distribution.

The area or proportion of occurrences within any interval under the general normal distribution can be determined if M and S_x are known. The maximum ordinate, C_x, of the general normal distribution is equal to $0.399/S_x$.

3.5.2 Standard Deviation of Aircraft. The lateral standard deviation of aircraft has been measured in two investigations. The Corps of Engineers (COE) measurements are reported as the wander width over which 75 percent of the aircraft passes occur. Wander widths of 70 in. (178 mm) and 140 in. (356 mm) are identified for channelized and unchannelized traffic areas. In the standard normal distribution, 75 percent of the area under the curve lies between $-1.15 < z < +1.15$. The general normal distribution of aircraft traffic can be related to the standard normal distribution curve using the substitution:

EQUATION: $$z = (x-M)/S_x \tag{3}$$

where z = a variable of the standard normal distribution
x = a variable of the general normal distribution
S_x = standard deviation of the general normal distribution
M = mean value of the general normal distribution.

The general normal distribution curve for each wander width is shown in Figure 7. The standard deviation for a wander width of 70 in. (1.78 m) is 30.43 in. (0.773 m), calculated as shown in Figure 7, and defines the shape of the general normal distribution curve for channelized traffic areas. The standard deviation for a wander width of 140 in. (3.56 m) is 60.87 in. (154.6 m), and defines the shape of the general normal distribution curve for unchannelized traffic areas.

3.5.3 Normal Distribution For A Single Wheel. Coverage is defined in Section 3.4 as the maximum number of tire prints or partial tire prints applied to the pavement surface at that point where maximum accumulation occurs. For a single wheel, maximum accumulation occurs at the wheel centerline of the normal distribution curve, as shown in Figure 8. For a tire-contact width of W_t, accumulations will occur at the midpoint for only those wheel passes for which the wheel centerline is within a distance of $W_t/2$ from the midpoint. Therefore, the proportionate number of wheel passes that will accumulate at the midpoint (maximum point) of the curve will be the area under the curve within the width W_t, centered about the midpoint.

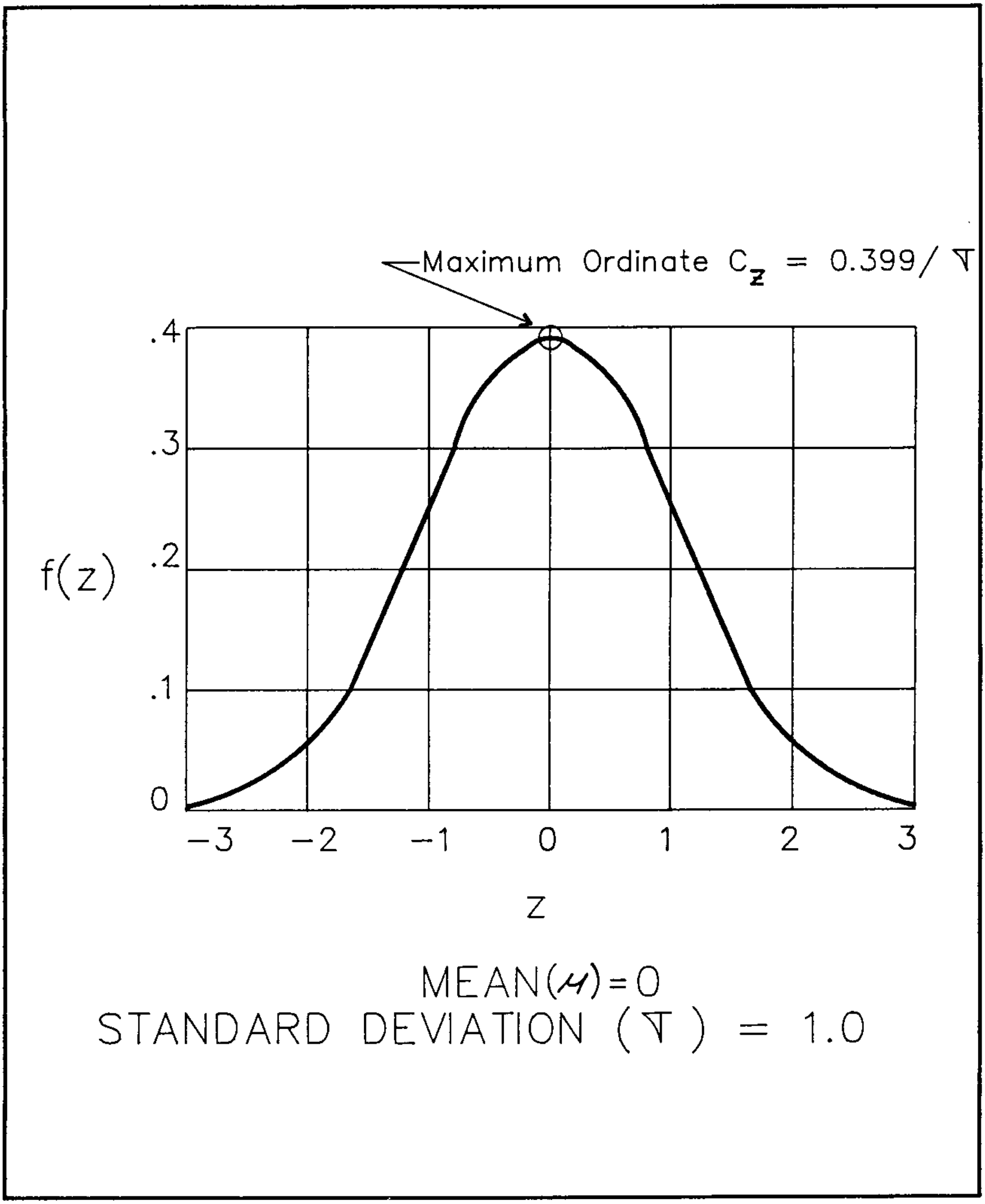


Figure 6
Standard Normal Distribution Curve

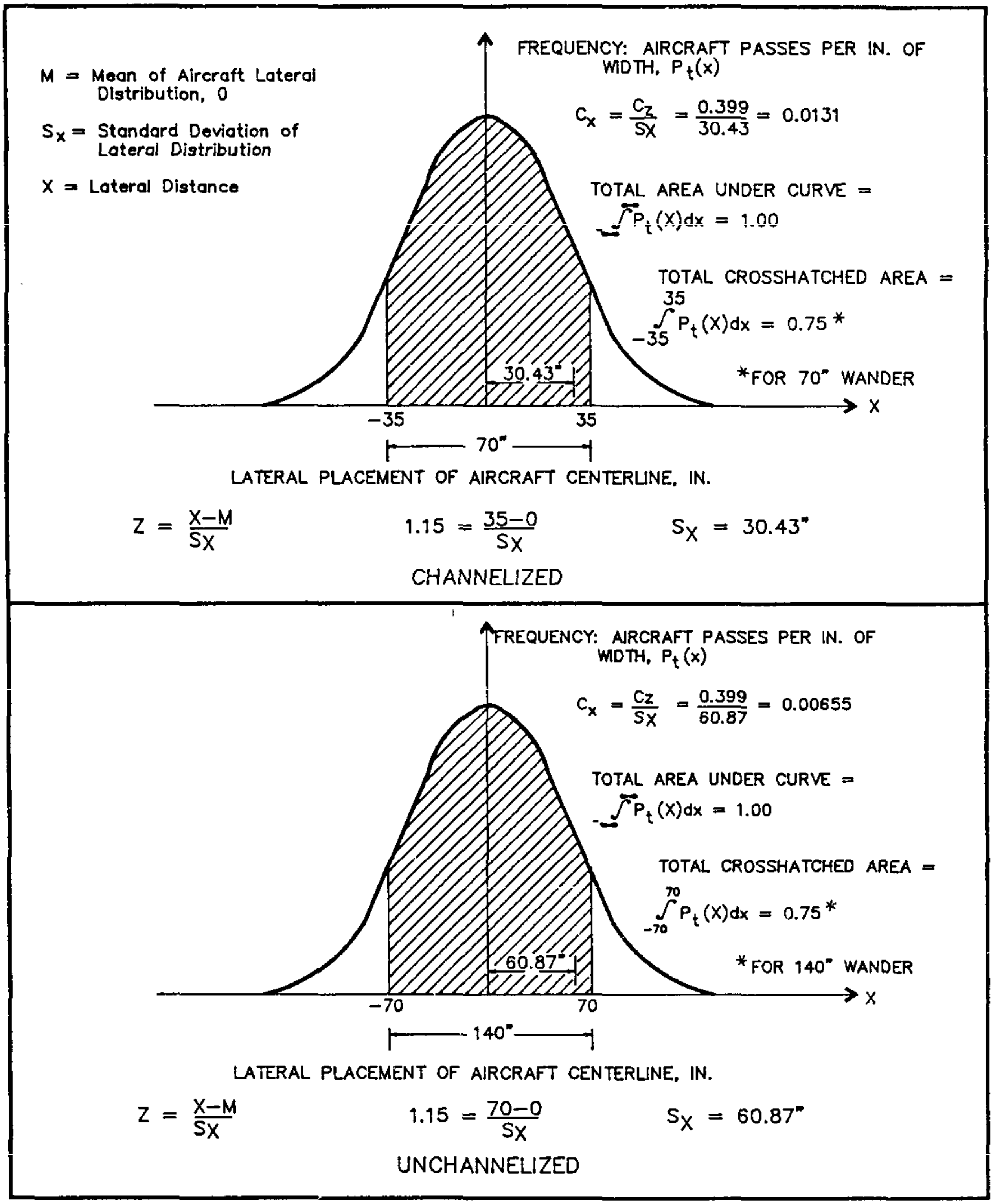


Figure 7
General Normal Distribution Curve For Airfield Traffic Wander Width of 70 inches (Channelized Traffic) and 140 inches (Unchannelized Traffic)

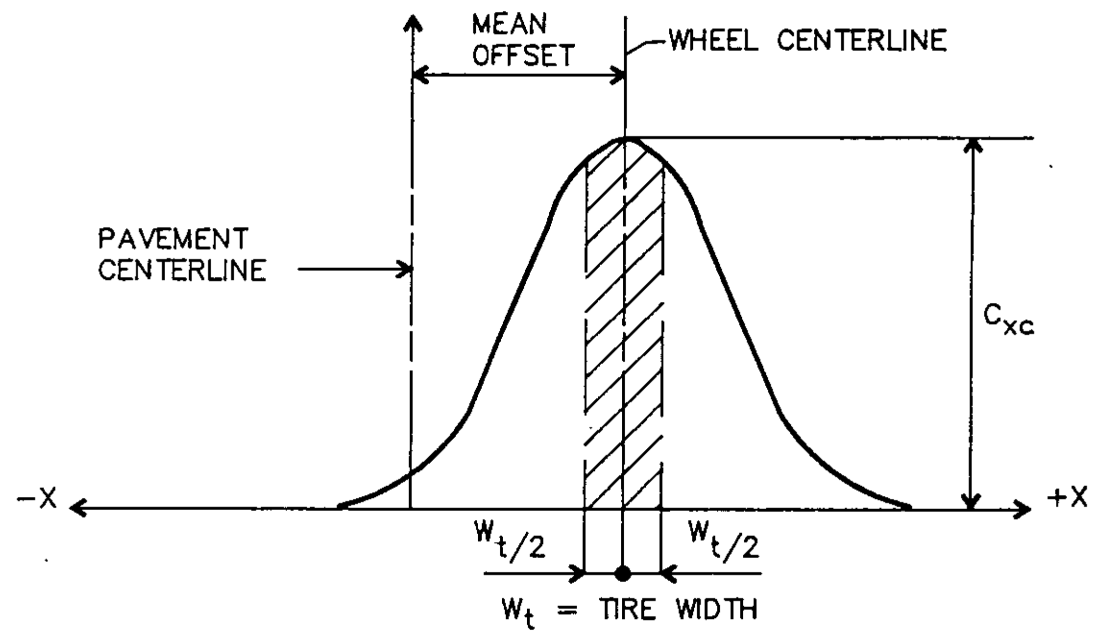


Figure 8
Theoretical Normal Distribution For a Single Wheel

That area can be approximated as $C_{xc} \times W_t$ where C_{xc} is the maximum ordinate of the cumulative distribution of all wheels. Therefore, for a tire contact width of W_t, the coverage per aircraft pass is approximated by $C_{xc} \times W_t$. The reciprocal of $C_{xc} \times W_t$ is referred to as the pass-to-coverage ratio. The pass-to-coverage ratio is calculated using the following equation:

EQUATION: $$P/C = 1/(C_{xc}\ W_t) \qquad (4)$$

where

P/C = the aircraft pass-to-coverage ratio,
W_t = aircraft tire-contact width, in inches, and
C_{xc} = maximum ordinate of the cumulative distribution of all wheels.

3.5.4 Cumulative Distribution For Multiwheel Gear. For an aircraft with many wheels, the maximum ordinate, C_{xc}, of the cumulative distribution of all the wheels is determined. This is shown for a Boeing 727 main gear in Figure 9, using, for an example, a standard deviation of 60.87 in. (1.546 m) for the aircraft centerline lateral distribution. The resultant cumulative distribution curve for all four wheels of the main gear has a C_{xc} value of 0.01217. The pass to coverage ratio for a tire width of 14.0 inches (356 mm) is equal to 1/(0.01217 x 14.0), or 5.87 aircraft passes per coverage.

In order to determine the pass-to-coverage ratio for any aircraft, the parameters C_{xc} and W_t are required. C_{xc} is dependent upon the aircraft main-gear configuration (number and spacing of wheels) and the standard deviation of the normal distribution function selected to represent the aircraft-centerline lateral distribution. W_t is normally calculated using the following equation (refer to U. S. Army Engineers Miscellaneous Paper No. 4-459, Ground Flotation Requirements for Aircraft Landing Gear, D.M. Ladd):

EQUATION: $$W_t = 0.878\ (A)^{0.5} \qquad (5)$$

where

W_t = aircraft tire contact width, in inches, and
A = aircraft tire contact area, in square inches.

3.5.5 P/C Ratios For Flexible And Rigid Pavements. The P/C ratio developed in this section is applicable to flexible pavements for all aircraft types. However, special consideration is necessary when applying this procedure to flexible pavements for aircraft with tandem-gear configuration. For flexible pavements, a coverage is a measure of the number of maximum stress applications that occur on the surface of the pavement due to applied traffic. A coverage occurs when a point on the pavement surface has been subjected to one application of maximum stress. Therefore, a dual tandem gear will produce two applications of stress on the surface of a flexible pavement. For rigid pavements, a coverage occurs when one maximum stress application occurs at the bottom of the slab. A moving dual tandem gear produces only one such maximum stress application. All dual tandem gear aircraft produce one maximum stress for each pass of the gear for rigid pavement and two stress applications for flexible pavements. The pass to coverage ratio calculated using the procedure presented in this section must be divided by two for flexible pavements.

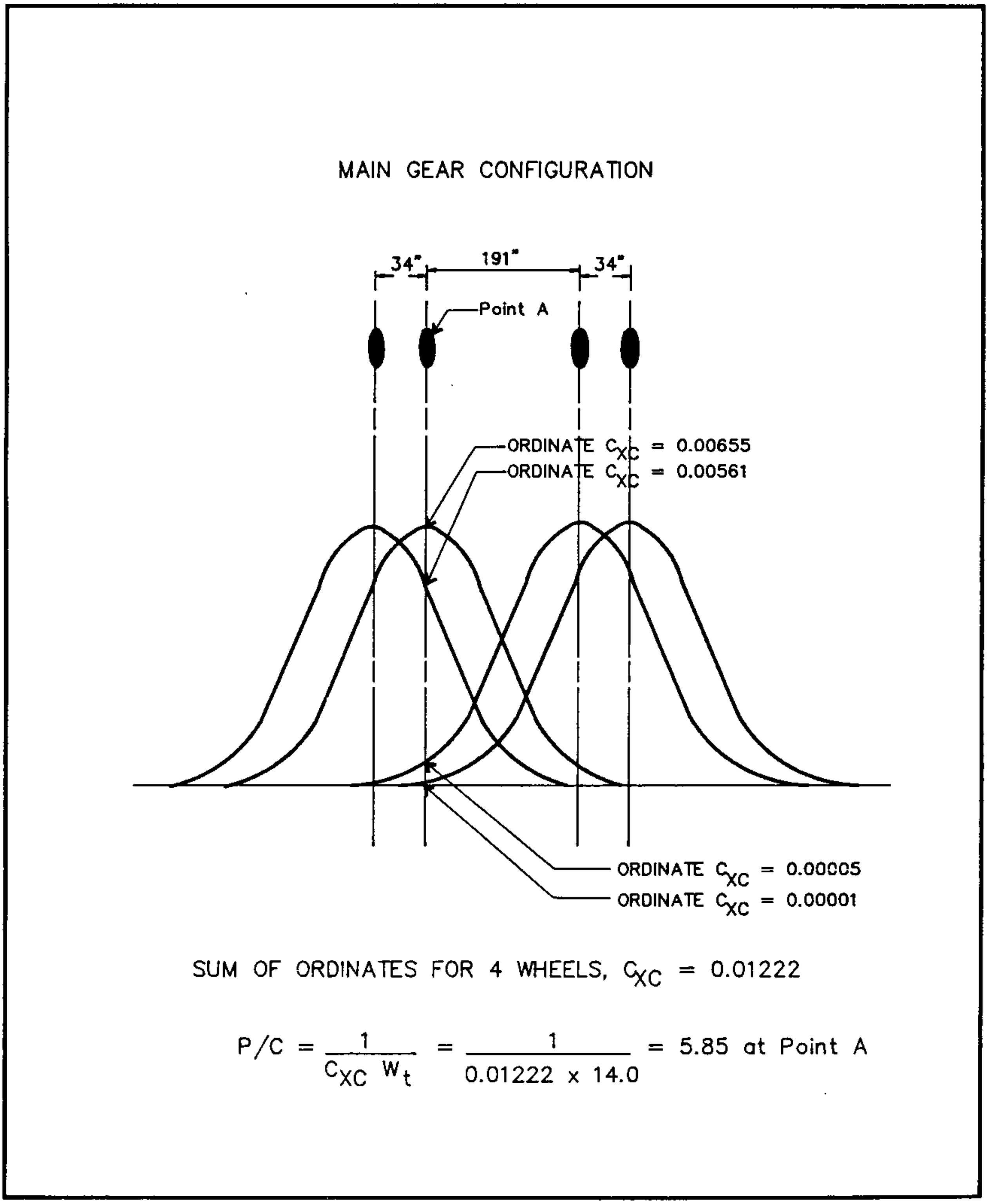


Figure 9
Normal Distribution for B-727 Main Gear For a Standard Deviation of 60.87 inches (Unchanneled Traffic Area)

3.6 Traffic Volume. The traffic type, volume, and pavement design life are essential inputs to the pavement design procedure. Determine the total number of passes of each aircraft type that the pavement will be expected to support over its design life. The minimum design life for Navy and Marine Corps facilities is 20 years. Only aircraft departures are normally included as passes in pavement thickness design. The exception to this is in touchdown areas on runways where the impact due to aircraft performing touch-and-go operations will cause pavement damage. On pavements that are to be used for touch-and-go operations, add the expected number of touch-and-go operations over the design life to the number of departures to arrive at the design traffic. Obtain data for the specific Navy and Marine Corps airfield facility under design to forecast aircraft traffic operations over the design life of the pavement.

When site-specific traffic projections are not available, the traffic pass levels listed in Table 3 are the minimum pass levels to be used in design.

Table 3
Minimum Pass Levels for Standard Aircraft
to be Used in Design When Traffic Projections are not Available

AIRCRAFT	TOTAL PASSES OVER 20 YEAR DESIGN LIFE*
F-14	300,000
P-3	100,000
C-130	50,000
C-141	25,000
C-5A	25,000

* Departures at Maximum Gross Load

SECTION 4. PAVEMENT REHABILITATION

4.1 General. This section presents pavement rehabilitation concepts for airfield pavements.

4.2 Pavement Evaluation. The complete evaluation of an airfield pavement shall include consideration of the overall pavement condition, structural capacity, and surface characteristics. The findings of the evaluation shall be summarized to facilitate the determination of feasible rehabilitation alternatives.

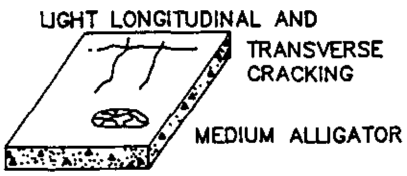
4.2.1 Visual Distress Evaluation. The Pavement Condition Index (PCI) rating procedure shall be used for performing the visual distress survey and condition rating of Navy and Marine Corps airfield pavements (refer to NAVFAC Interim Guide, Condition Survey Procedures, Navy and Marine Corps Airfield Pavements). The PCI is a rating from 0 to 100 which reflects the apparent structural integrity and functional surface condition of a pavement as it would be rated subjectively by a panel of experienced airfield pavement engineers. Its calculation, scale, and associated condition ratings are shown in Figure 10. The PCI is calculated from data collected during a visual distress survey in which pavement distresses are quantified by type, amount, and severity level for representative small sample units. The mean PCI, the average of the PCIs of sample units of the pavement, can be computed for any individual pavement by extrapolating the distresses from all measured sample units.

4.2.1.1 Mean PCI. The mean PCI of a pavement section describes its overall condition and thus is a general indicator of the level of rehabilitation work needed. The following are general guidelines which relate the pavement's mean PCI to the level of rehabilitation work that may be expected to be the most cost effective within the next two years (see Figure 11):

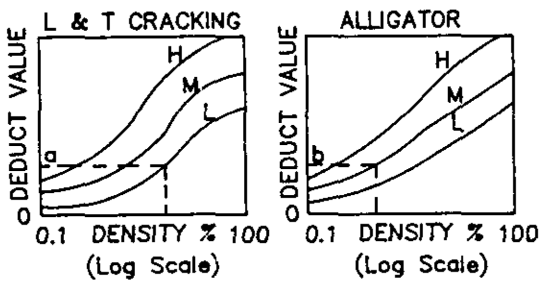
Current PCI	Most Cost Effective Rehabilitation (Within Next 2 Years)
71 to 100	Preventive maintenance and restoration (unless a structural deficiency is present), including joint/crack sealing; small amounts of: subsealing, slab replacement, full-depth repair, partial depth spall repair.
41 to 70	Rehabilitation may range from preventive maintenance to major rehabilitation. Decision requires an engineering evaluation and a life-cycle cost analysis.
26 to 40	Major or overall rehabilitation, including overlays with or without keel replacement. Decision requires an engineering evaluation and a life cycle cost analysis.
0 to 25	Overall rehabilitation or major reconstruction. Selection among alternatives requires an engineering evaluation and a life-cycle cost analysis.

STEP 1. DIVIDE PAVEMENT FEATURE INTO SAMPLE UNITS.

STEP 2. INSPECT SAMPLE UNITS: DETERMINE DISTRESS TYPES AND SEVERITY LEVELS AND MEASURE DENSITY.

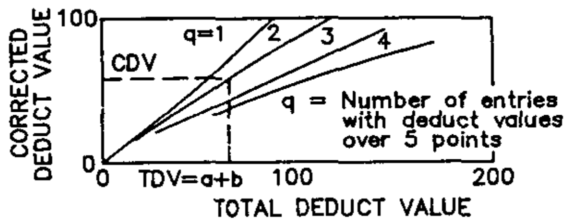


STEP 3. DETERMINE DEDUCT VALUES.

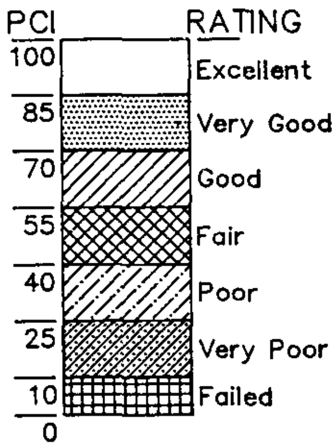


STEP 4. COMPUTE TOTAL DEDUCT VALUE (TDV) a+b

STEP 5. ADJUST TOTAL DEDUCT VALUE.



STEP 8. DETERMINE PAVEMENT CONDITION RATING OF FEATURE



STEP 6. COMPUTE PAVEMENT CONDITION INDEX (PCI) = 100 − CDV FOR EACH SAMPLE UNIT INSPECTED.

STEP 7. COMPUTE MEAN PCI OF ENTIRE SECTION FROM PCI'S OF SAMPLE UNITS).

NOTE: FOR DETAILED PROCEDURE SEE "CONDITION SURVEY PROCEDURES, NAVY AND MARINE CORPS AIRFIELD PAVEMENTS, "NAVFAC INTERIM GUIDE, OCTOBER, 1985.

Figure 10
Pavement Condition Index (PCI) Computation

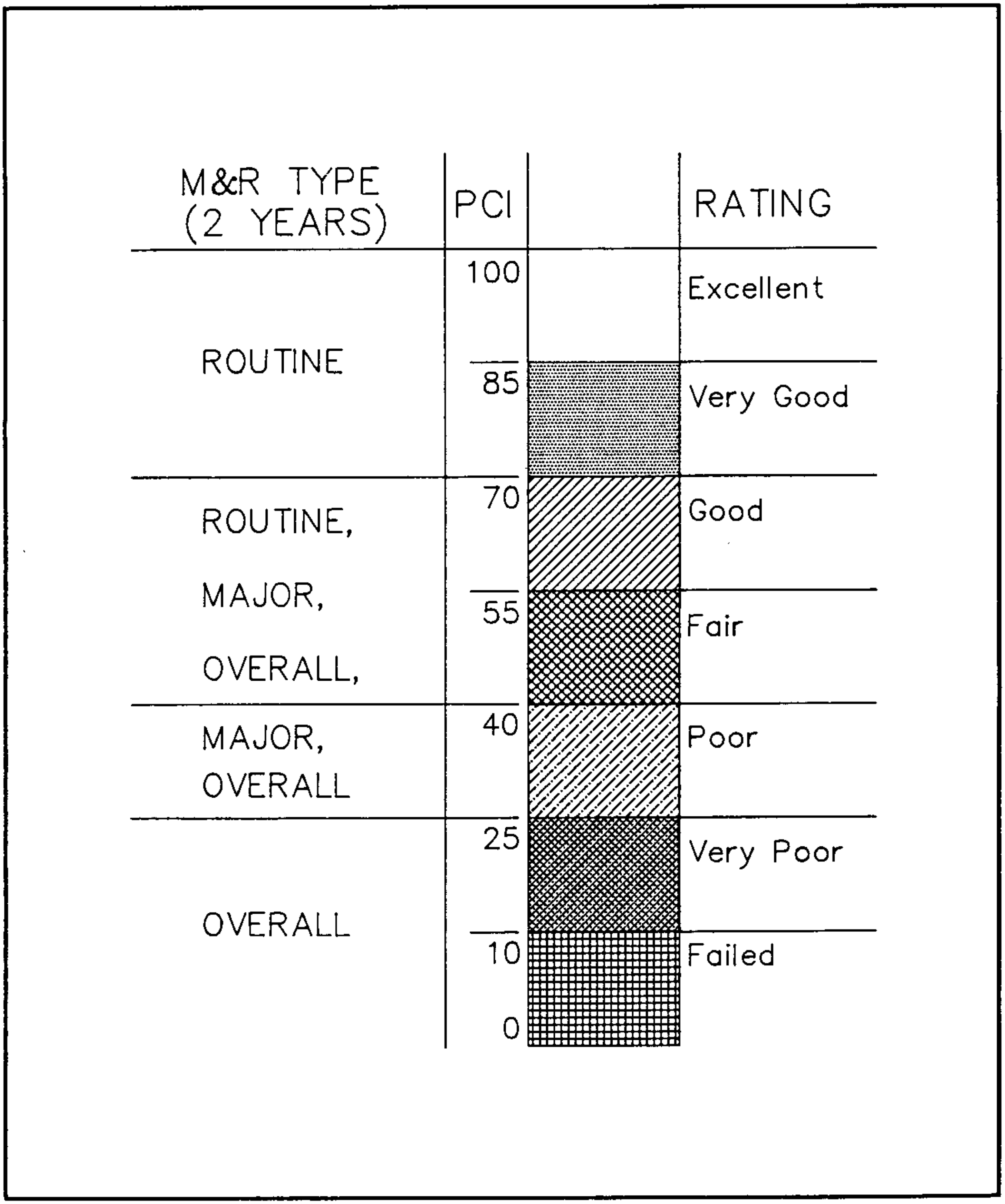


Figure 11
PCI Guidelines for Levels of Rehabilitation

4.2.1.2 Cause of Distress. The cause and extent of distress is very important for a complete evaluation of the pavement. The distress deduct values should be summarized by cause to provide assistance in selecting rehabilitation alternatives. Distress causes and effects are shown in Figure 12 for flexible airfield pavements, and in Figure 13 for rigid airfield pavements.

4.2.1.3 Variation in Condition. The variation of PCI within a pavement shall be graphed. This plot shows if there is a significant variation along the pavement's length, and if the variation is random or systematic. This will provide assistance in determining the need for localized repairs. The PCI should be plotted along the pavement's length and across its width at various locations. Isolated (random) locations of low PCI may be evident on the profile. These locations should receive localized repair. Systematic variation of the PCI may be evident along the length or across the width of the pavement. For example, the keel section of a runway may exhibit more distress than the outer sections. Systematic variation along the length of an airfield pavement cannot normally be corrected with localized repair and will require variation of the rehabilitation design. Example PCI profiles are shown in MIL-HDBK-1021/4.

4.2.1.4 Rate of Deterioration. Records of past PCI surveys shall be used to determine the rate of deterioration of the pavement. This is shown by graphing the pavement's PCI against its age, in years. The rate of long-term deterioration is classified as low, normal, or high with the use of Figure 14. These graphs are developed from airfields surveyed throughout the United States, as described in AFESC ESL-TR-79-18, Development of a Pavement Maintenance Management System Volume VI. High, short-term deterioration occurs when the PCI drops more than seven points in one year.

4.2.2 Drainage Evaluation. Some distresses are related to poor drainage. If the existence of poor drainage is not recognized and, where possible, corrected, any rehabilitation effort may not be effective. The amount, severity, and cause of moisture damage is important in the selection of the rehabilitation scheme.

4.2.2.1 Drainage Factors. The relevant moisture-related factors of pavement materials include drainability, permeability, physical geometry of the roadway, soil type, topography, water table, and existing drainage facilities. Each of these factors influence pavement performance and the development of moisture-related distresses.

4.2.2.2 Visual Drainage Survey. A survey shall be conducted to observe the external moisture conditions. Specific items to be noted include the presence of moisture in joints and cracks, pumping, pot holes, standing or ponded water, obstructed drainage such as grass and sod along the pavement edge that is higher than the pavement surface, and poor joint and crack sealant.

4.2.3 Structural Evaluation. The Navy procedure under development is for rigid, flexible, and composite pavements and is based on a layered elastic model that characterizes multi-layered pavement systems. The layer strength parameters are computed from field deflection measurements. The strength parameters are input into an evaluation program that is designed to handle multiwheel aircraft at varying traffic levels. The evaluation program computes the allowable load for a selected number of aircraft passes and the allowable passes of a specified design load. Strengthening requirements can then be determined for the design pass level and aircraft load. The procedure is being developed for application on personal computers. Draft copies of the documentation and the computer disks can be obtained from the Engineering Field Division of the Naval Facilities Engineering Command.

4.2.4 Survey of Pavement Functional Condition. The functional condition of an airfield pavement is determined by its surface characteristics, such as: friction, foreign object damage potential, profile, surface drainage, and roughness. During the visual PCI survey, the pavement shall be examined for loose materials from spalling or scaling which could damage jet aircraft engines. Pavement roughness and ride characteristics shall also be evaluated through observation and pilot feedback.

The friction characteristics of an airfield runway pavement decrease steadily over time, increasing the potential for hydroplaning. The existence of rubber buildup, flat cross slopes, depressions, and absence of texture are all indicators of potential for hydroplaning. Procedures for measuring skid resistance are described in NAVFAC DM-21.9, Skid-Resistant Runway Surface.

4.3 Rehabilitation Alternatives. Feasible maintenance and rehabilitation alternatives are selected based on the results of the pavement evaluation. The flow chart presented in Figure 15 is used for the preliminary selection of alternatives.

4.3.1 Preliminary Selection of Alternatives. Information from the pavement evaluation is used in Figure 15 for preliminary selection of rehabilitation alternatives. The pavement is considered to be structurally deficient if any of the following conditions exist:

a) load-associated distresses account for a majority of the distress deduct value,

b) the load-carrying capacity is deficient.

c) the rate of pavement deterioration is high, or

d) a change in mission requires a greater load-carrying capacity.

For a single feature, the flow chart may provide a variety of acceptable alternatives. These preliminary alternatives may be narrowed down by considering additional engineering and physical factors and constraints. Some additional factors include the availability of funds, feasibility of traffic interruption, and pavement use.

This reduced list of alternatives should then be evaluated using the life-cycle cost analysis presented in Section 5. The final selection of an alternative will require the judgment of the engineer in weighing economic and non-economic factors.

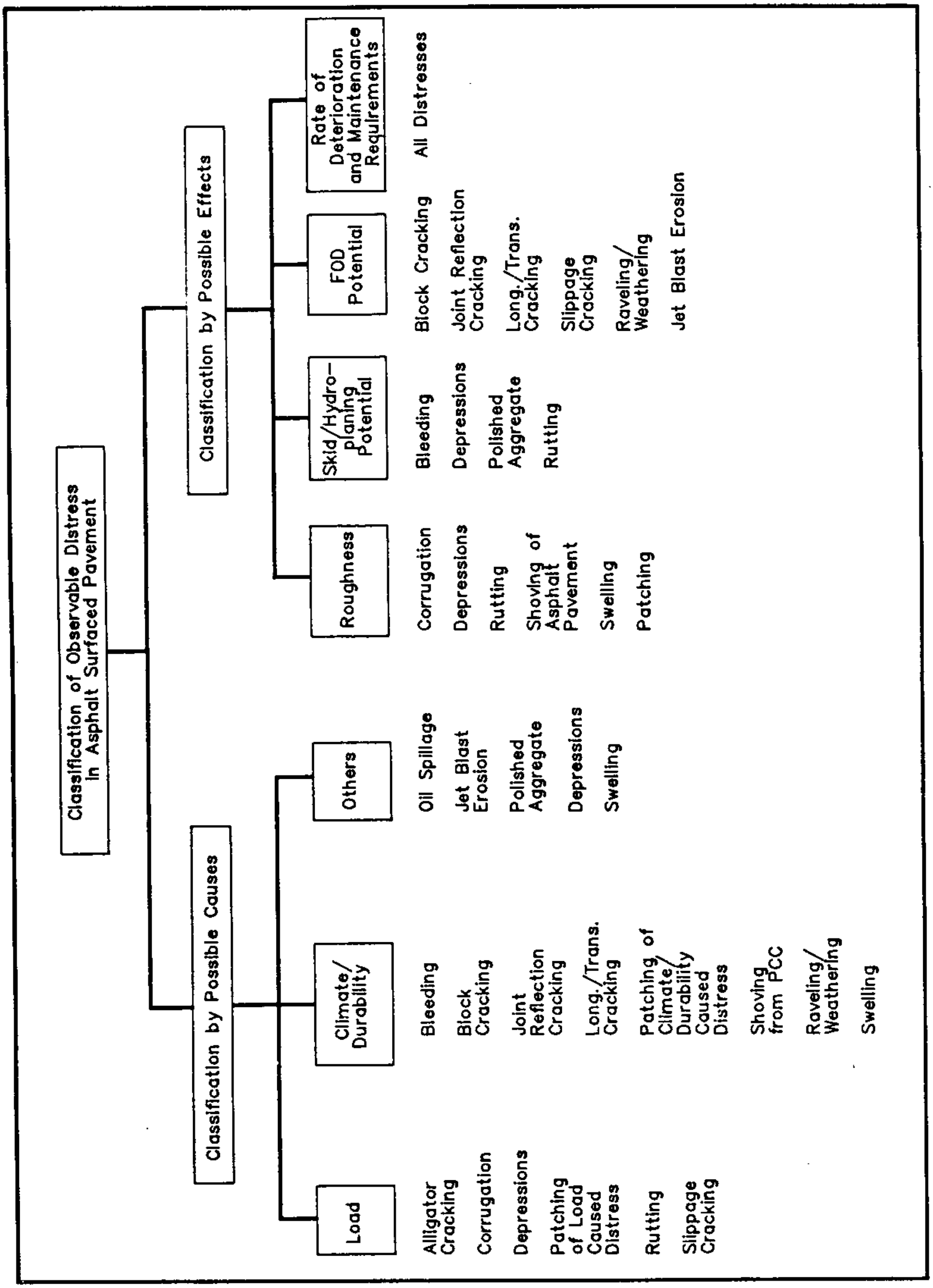


Figure 12
Classification of Observable Distress in Asphalt-Surfaced Pavements

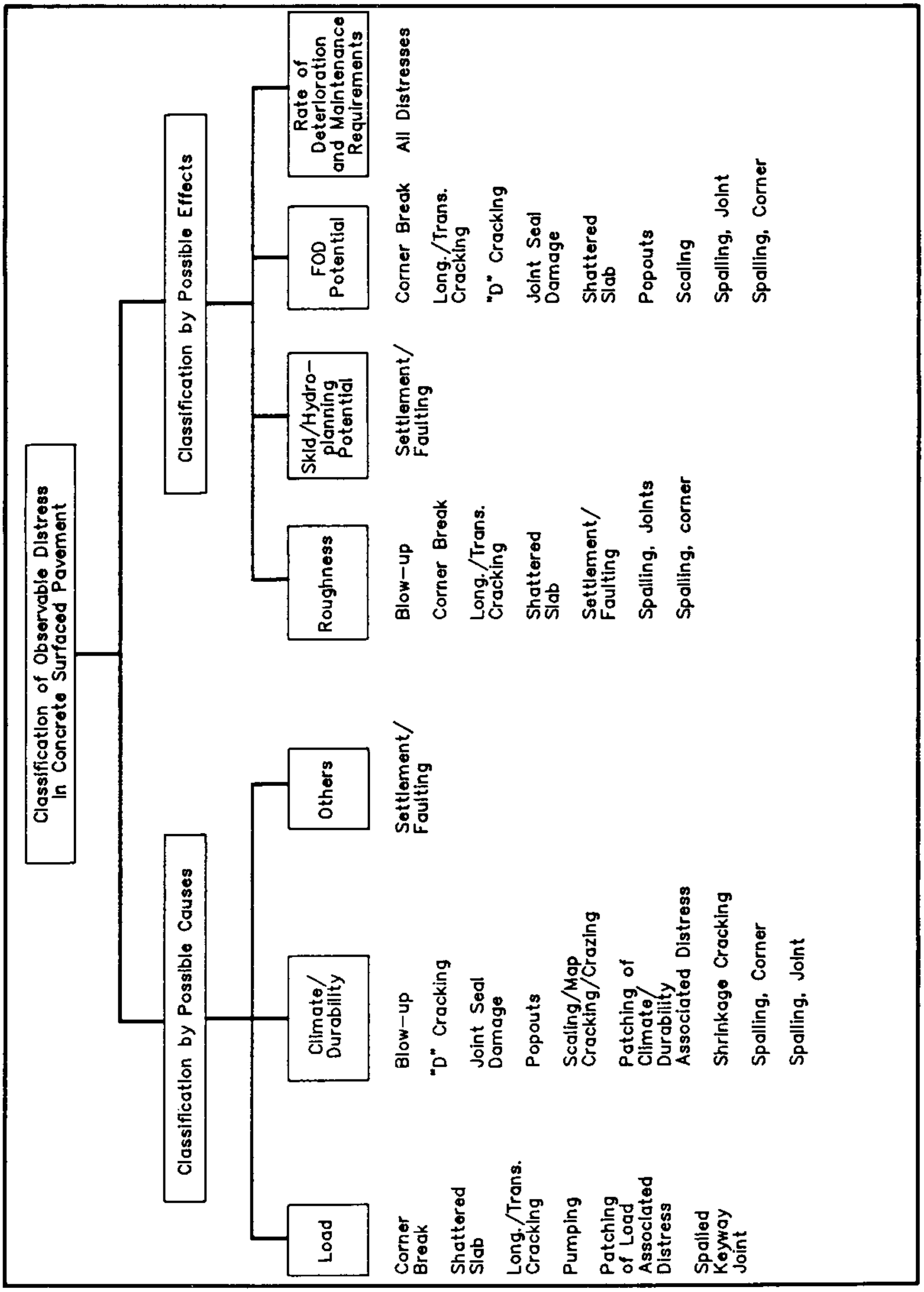


Figure 13
Classification of Observable Distress In Concrete-Surfaced Pavement

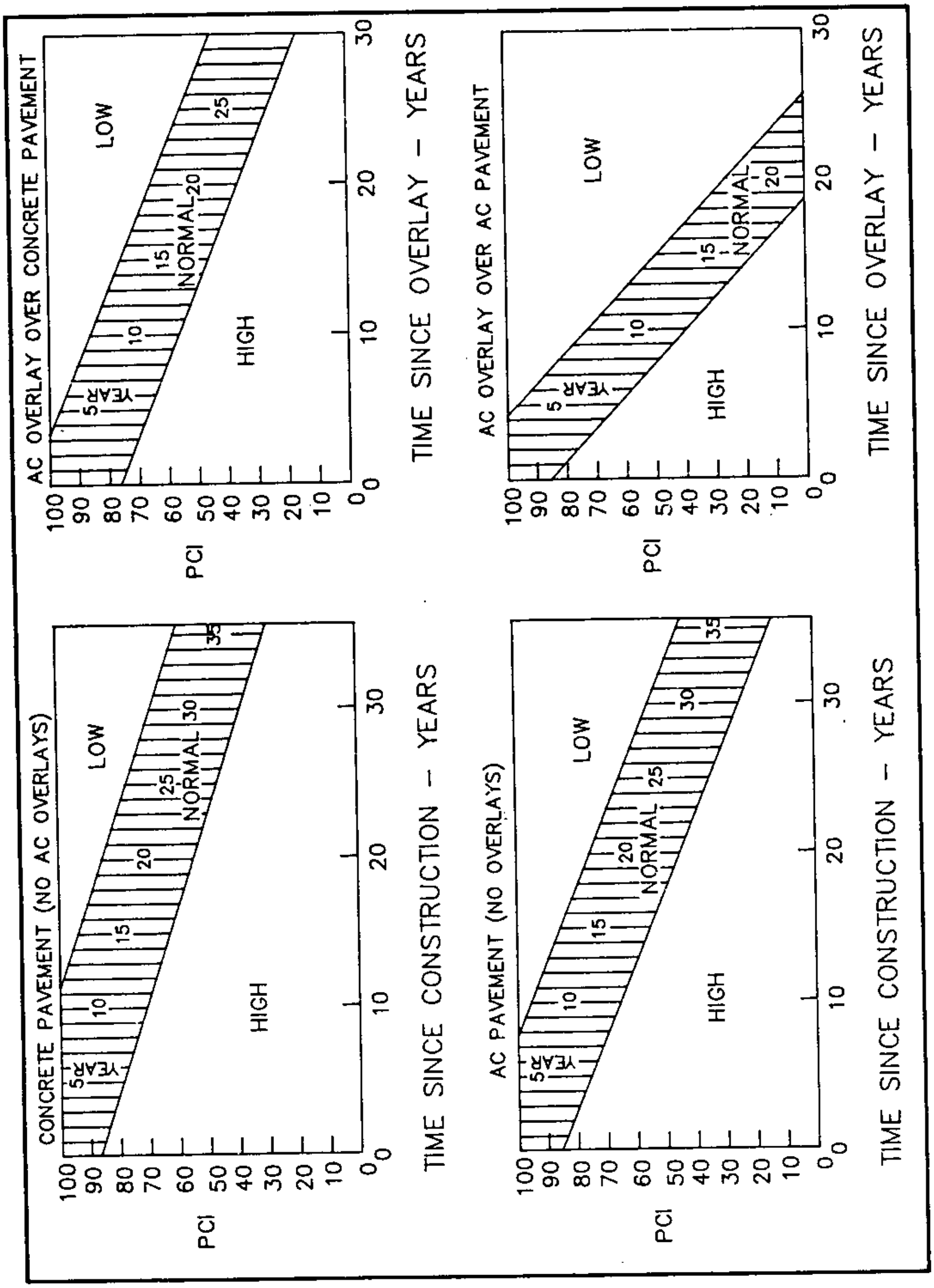


Figure 14
Classification of Rate of Deterioration

(from Development of a Pavement Maintenance Management System Volume VI)

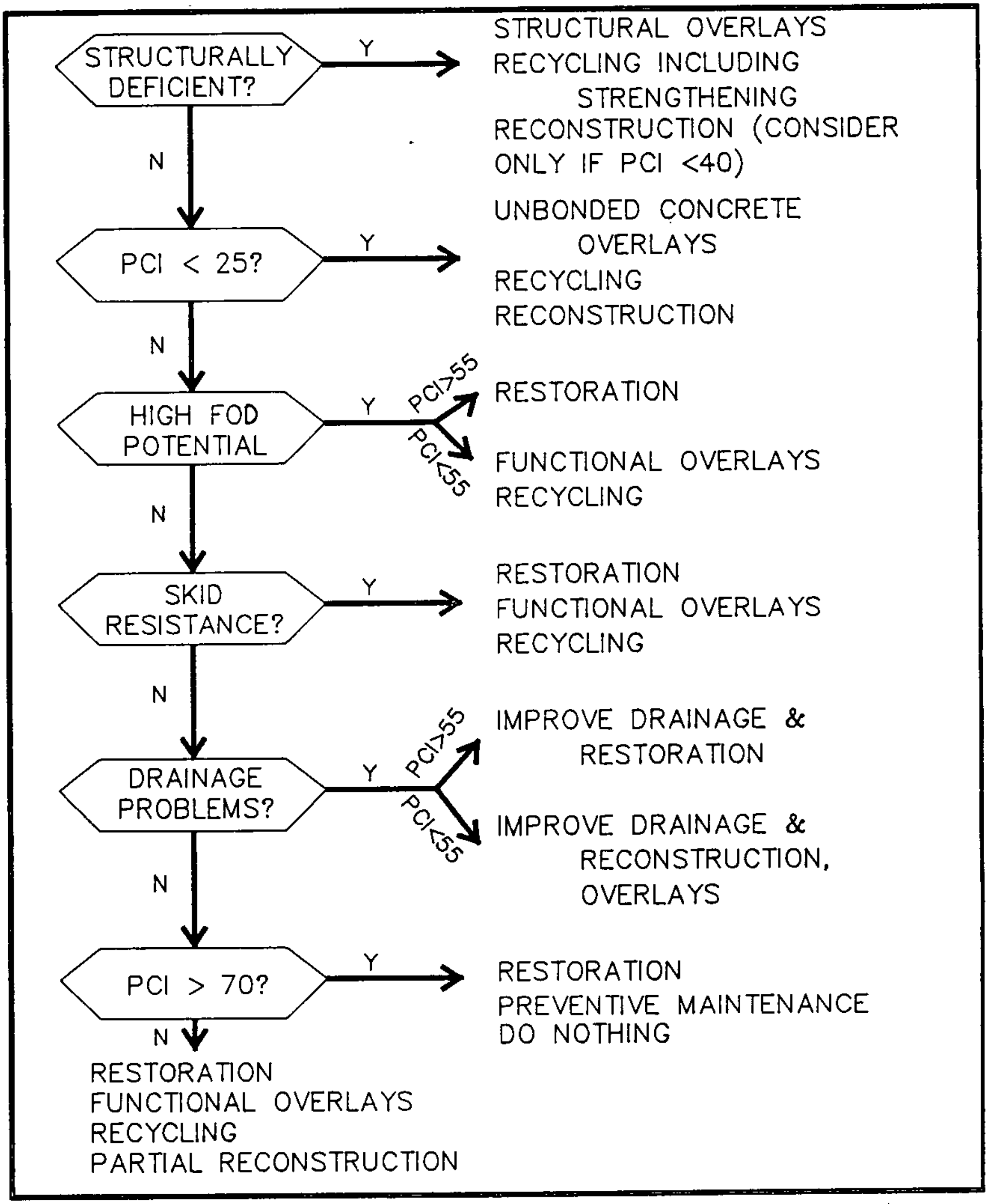


Figure 15
Guidance for Preliminary Selection of Rehabilitation Alternatives

4.3.2 Rehabilitation Categories. Three general categories of rehabilitation, other than reconstruction with new materials, are described as follows:

a) Overlays. Overlays are placed for both structural and functional improvements. Either AC overlays or unbonded concrete overlays can be used on asphalt concrete surfaced pavements. Both PCC and AC overlays may be used on Portland cement surfaced pavements. Recommendations for selection of overlay type for rigid pavements are shown in Table 4. Techniques are discussed in para. 4.4.

b) Restoration. Restoration includes partial depth repairs, full depth repairs, joint and crack sealing, bituminous patching, joint load transfer restoration, pressure relief joints, grooving, rubber removal and other techniques as shown in Tables 5 and 6. Recommendations for selection of specific restoration techniques are shown in Tables 5 and 6 for flexible and rigid pavements, respectively. Restoration techniques are covered in para. 4.5. Restoration may be needed both with or without an overlay.

c) Recycling. Recycling techniques may be used for functional improvements, or in conjunction with overlays and reconstruction for structural improvements. Recycling techniques are covered in paragraph 4.6.

4.4 AC - Portland Cement Concrete Overlays. AC or PCC overlays may be placed over rigid or flexible pavements. There are two distinct reasons for placing an overlay. Structural overlays are placed to improve the load-carrying capacity of the pavement. Functional overlays are placed to improve the surface characteristics of the pavement, such as friction, foreign object damage, profile, and surface drainage. Structural overlays are usually thicker than functional overlays. Functional overlays are feasible only when no structural deficiency is indicated.

4.4.1 Pre-Overlay Repair. The amount of pre-overlay repair and treatment will affect the future performance of the overlay. Pre-overlay repair is a function of the type of deterioration to be corrected. If the pavement is failing in fatigue due to a structural deficiency, then additional surface thickness will reduce critical tensile strains and stresses. This will correct the problem and give the desired life extension. However, if the cause of the deterioration lies beneath the surface layer, one of two general approaches must be followed.

The first approach is to repair localized deteriorated areas prior to overlaying. In PCC pavements, punchouts, shattered slabs, corner breaks, broken portions of slabs and joint spalling may be repaired. Subsurface drainage to remove free moisture should be considered if moisture accelerated distress is present. Slab support conditions should also be evaluated and corrected if deficient. An asphalt pavement with alligator cracking may require full-depth patching, through the base. If the subbase or base has deteriorated over a large portion of the project, a different rehabilitation alternative may be required, such as reconstruction, stabilization of the base or subbase, or recycling.

Table 4
Selection of Overlay Type for Rigid Pavements

PCI RATING	TYPE OF OVERLAY: * BONDED CONCRETE	* PARTIALLY BONDED CONCRETE	UNBONDED CONCRETE	ASPHALT CONCRETE
EXCELLENT (100–86)	YES	NO (costly)	NO (costly)	NO (not normally required)
VERY GOOD (85–71)	YES	YES	NO (costly)	NO (not normally required)
GOOD (70–56)	YES (w/repair)	YES	NO (costly)	YES
FAIR (55–41)	NO	YES (w/repair)	YES	YES (w/repair)
POOR (40–26)	NO	NO	YES	YES (w/repair)
VERY POOR (25–11)	NO	NO	YES	NO
FAILED (10–0)	NO	NO	YES (w/repair)	NO

* Placed over Portland Cement Concrete Surface only

Table 5
Restoration Methods for Flexible Pavements

Distress Type / M&R Method	DO NOTHING	CRACK SEAL	BITUMINOUS PARTIAL DEPTH PATCH	BITUMINOUS FULL DEPTH PATCH	APPLY SLURRY SEAL	APPLY REJUVENATOR	FUNCTIONAL OVERLAY	SURFACE RECYCLING	SEAL COATS	NOTES
1 Allig. Crack			M	M, H	L					
2 Bleeding	A							A		Modify Mixture
3 Block Crack	L	L,M,H					H*	H	A	*Include Reflective Crack Retardant Interlayer
4 Corrugation	L		M, H	M, H				L,M,H		
5 Depression	L		M, H	M, H			M, H			
6 Jet Blast	A		A		A					
7 Jt. Reflection Crack	L	L,M,H	H							
8 Long. & Trans. Crack	L	L,M,H	H							
9 Oil Spillage	A		A	A						
10 Patching	L	M	H*	H*						* Replace Patch
11 Polished Agg.	A									
12 Raveling/ Weathering	L		H		L, M, H	L	H	H	L,M,H	Modify Mixture
13 Rutting	L		M, H	M, H			H	L,M,H		*Mill Off Ruts
14 Shoving	L		M, H							
15 Slippage Crack	L		M, H							
16 Swell	L			M, H						

A = DISTRESS TYPES HAVING ONE SEVERITY LEVEL
L = DISTRESS AT LOW SEVERITY
M = DISTRESS AT MEDIUM SEVERITY
H = DISTRESS AT HIGH SEVERITY

Table 6
Restoration Methods for Rigid Pavements

Distress Type \ M&R Method	DO NOTHING	CRACK SEALING	JOINT SEALING	PARTIAL DEPTH PATCH (BONDED)	FULL DEPTH PATCH	SLAB REPLACEMENT	SLAB STABILIZATION	GRINDING SLAB	SLAB JACK-GROUT	PRESSURE RELIEF JOINTS	LOAD TRANSFER RESTORATION	NOTES
1 Blow-up					H* L, M	H*				H		* Must provide expansion joint
2 Corner Break	L	M			M, H							
3 Long/Trans/ Diag. Crack	L	M, H		H*	H	H						* Allow crack to continue through patch except when using ac
4 "D" Crack	L		L*	M, H	M, H	H						* If "D" crack exists, seal joints and cracks
5 Joint Seal Damage	L		M*, H									* Joint seal local areas
6 Small Patch < 5 ft.	L	M		M*, H*	H*							* Replace Patch
7 Large Patch > 5 ft.	L	M		M*, H*	H*	H						* Replace patch
8 Popouts	A											
9 Pumping		A	A				A					
10 Crazing/ Sealing	L			M, H		H*						* Only when surface is Unacceptable
11 Settlement/ Faulting	L		L			H		M, H	M, H			
12 Shattered Slab		L,M, H				M, H						
13 Shrinkage Crack	A											
14 Spalling Joint	L		L, M	L, M, H	M, H*	M, H*					H	* If caused by keyway failure, provide load transfer
15 Spalling Corner	L		L, M	M, H								

A = DISTRESS TYPES HAVING ONE SEVERITY LEVEL
L = DISTRESS AT LOW SEVERITY
M = DISTRESS AT MEDIUM SEVERITY
H = DISTRESS AT HIGH SEVERITY

The second approach is to place a thicker overlay to protect the weakened pavement layers. The reduced strength of a layer can be accounted for in the design of the overlay. The thickness of the overlay is increased to compensate for the decreased strength of that layer and to protect it from excessive stresses or deflections. The thickness required to adequately protect weak layers is normally so thick that this approach is not an economically feasible alternative. However, it may not be economical to repair all severity levels of distressed areas. Some combination of increased thickness and full-depth patching is usually the most cost effective approach.

4.4.2 Asphalt Concrete Overlays Over Rigid Pavements. The thickness of structural AC overlays for rigid pavements shall be determined in accordance with MIL-HDBK-1021/4. As shown in Table 4, AC overlays are an acceptable rehabilitation alternative for rigid pavements with poor to good condition ratings. AC overlays in excess of 2.5 in. (63.5 mm) are needed to provide any substantial structural improvement. This represents the approximate effect of a one inch increase of slab thickness, based on equivalent stress in the slab from traffic loads.

A major problem with asphalt overlays over jointed PCC pavement is reflection cracking. A number of methods have been developed to retard reflection cracking including:

a) Fabrics: Fabrics may be woven or non-woven synthetic fabrics. The purpose of the fabric is to provide physical restraint to the opening movement of the cracks in the overlay as the cracks and joints in the underlying pavement open. To accomplish this, the fabric is placed in the middle or the lower third of the overlay. Fabrics are not effective in northern climates where the air freezing index exceeds 500 and should therefore not be used. Refer to NAVFAC DM-5.4, Pavements, for information on fabrics.

b) Stress-relieving interlayers: The typical stress-relieving interlayer involves a spray application of rubber-asphalt directly on the original pavement surface, followed by placement and seating of aggregate chips. The stress- relieving interlayer functions as a soft interficial layer that dissipates the stresses developed by the joint movement entirely within the interlayer. These have not been shown to be effective on PCC and should therefore not be used.

c) Crack and seat: Cracking and seating the slabs is one method that reduces the joint opening deformation by reducing the slab length. The concrete slabs are cracked into small segments before overlaying. Seating of the broken slabs after cracking is necessary to re-establish firm support between the subbase and the slab. A disadvantage of this method is that the structural capacity of the concrete is substantially reduced. This must be accounted for in the design procedure.

4.4.3 Portland Cement Concrete Overlays on Rigid Pavements. There are three types of bonding conditions for concrete overlays over concrete pavements: fully bonded, partially bonded, and unbonded. There are also three different types of conventional concrete overlays: jointed reinforced, jointed non-reinforced, and continuously reinforced. The thickness of overlay required for all three types should be determined in accordance with MIL-HDBK-1021/4. Refer to NFGS-02559 for PCC pavement specifications.

The most effective type of concrete overlay and bonding condition to be used is a function of cost, the existing pavement condition, and construction quality control. Table 4 provides guidelines which should be used to determine feasible overlay types.

4.4.3.1 Fully Bonded Concrete Overlays. For fully bonded concrete overlays, a complete and permanent bond is necessary between the overlay and the existing pavement. Every effort must be made to achieve the fully-bonded condition. If the existing pavement is in fair to good condition a fully bonded concrete overlay may be cost-effective. The thickness required for a fully bonded overlay is much less than that required for other concrete overlay types.

4.4.3.2 Partially Bonded Concrete Overlays. Partially bonded concrete overlays may require either repair or replacement of damaged slabs, or both. The surface shall at least be cleaned by sweeping so that as much bonding as possible occurs. The PCC overlay slab must be capable of performing satisfactorily if substantial debonding occurs.

4.4.3.3 Unbonded Concrete Overlays. Unbonded concrete overlays are normally used to improve the structural capacity of an existing concrete pavement which is in relatively poor condition. A separation level-up layer is placed between the existing slab and the overlay to absorb movement of the base slab which would otherwise crack the PCC overlay. This separation layer shall be formed of AC or sand asphalt unless fuel spillage problems exist. Tar concrete should be used in areas subject to extensive jet fuel spillage in accordance with DM-21.3, Section 7. Unbonded overlays are thicker than the other concrete overlay types.

4.4.4 Overlays Over Flexible Pavements. Both AC and PCC overlays are used over flexible pavements. AC overlays are the predominant overlay type and are placed for either structural or functional improvements. The use of rigid overlays on flexible pavements is uncommon; however, they have been used successfully. This alternative may be most cost effective when severely distressed flexible pavements are encountered and there are no severe vertical elevation problems.

The required thickness of AC overlay is determined in accordance with DM-21.3. Refer to NFGS-02573 for specifications.

4.5 Restoration. Pavement restoration without overlays is an acceptable rehabilitation alternative for pavements in fair to excellent condition with no structural deficiency. Specific restoration techniques shall be chosen in accordance with Tables 5 and 6 for flexible and rigid pavements, respectively. Restoration techniques should correct any functional inadequacies such as roughness and skid resistance. Many restoration techniques must also be applied prior to overlaying.

4.5.1 Partial-Depth Spall Repair of Concrete Pavements. Partial-depth repairs can be used to correct certain types of distress that do not extend through the full depth of the slab, but instead affect only the top few inches. Partial-depth repairs may be used to repair crazing and scaling, joint spalling, corner spalling, longitudinal and transverse cracking, durability cracking, and deteriorated patches. Many of these distresses occur adjacent to joints. Effective sealing of these joints requires repair of the adjacent distress. Failure to repair these areas prior to placement of an overlay will often result in the appearance of reflective cracks.

If several spalls are present on one joint, it is usually more economical to repair the entire length of the joint than to repair individual spalls. Small spall areas along joints, spalls less than 6 in. (152.4 mm) long, may not require repair depending on how far back from the joint they go and whether this spall can be repaired with joint sealant.

4.5.2 Full-Depth Repair of Jointed Concrete Pavement. Full-depth concrete repairs are required to repair deteriorated joints and cracks. Localized failures at joints or cracks shall be repaired to prevent continued deterioration of the distressed area.

There are several types of distresses that occur at or near transverse joints that justify full-depth repair. Distresses that may require full-depth repair include blowups, corner breaks, "D" cracking, spalling, deterioration adjacent to existing repairs, and deterioration of existing repairs. Jointed concrete pavements typically require more repair at joints than between joints.

Some pavements develop intermediate cracks that deteriorate under repeated heavy-traffic loadings. Even if the pavement is not being considered for an overlay, working cracks should be sealed. Repair cracks that are working, (medium or high severity crack, spalling, or faulting) either with a full-depth repair or by slab replacement.

The boundaries of the repair shall be selected so that all of the underlying deterioration is removed, which prevents adjacent slab deterioration. Deterioration near joints and some cracks is generally greater at the bottom of the slab than at the top. Coring will provide valuable information on the extent of deterioration near joints and cracks in various conditions.

4.5.3 Slab Replacement. There are many situations in which the existing pavement distress is so extensive that full-depth repair of every deteriorated joint and crack would either be very expensive or impractical. In these cases, repair costs and FOD potential can be reduced by removing and replacing entire slabs.

4.5.4 Slab Stabilization and Slab Jacking. Loss of support beneath concrete pavement slabs accelerates pavement deterioration. If pumping has occurred and slab support is not re-established, the pavement will continue to show high deflections and rapid deterioration in the future, particularly in heavily-trafficked pavements. Even if an AC overlay is placed, high deflections at joints will lead to severe reflection cracks. Thus, where loss of support exists, it is necessary to stabilize the existing slab.

4.5.4.1 Definition of Slab Stabilization and Slab Jacking. Slab stabilization is defined as the insertion by pressure of a cement grout beneath the slab or subsequent courses. This grout serves to both fill voids and to provide a thin layer that should reduce deflections and resist pumping action. The purpose of slab stabilization is to restore support to the slab by filling the existing voids with material. Care shall be taken not to raise the slab during the stabilization process. Slab jacking is the lifting of a slab at a depression to its original smooth profile. The major purpose is to level out a depression.

4.5.4.2 Areas Requiring Slab Stabilization. Slab stabilization is needed at joints that are experiencing loss of support. These can be located through deflection testing at slab corners. Remeasuring deflections after stabilization gives an indication of the effectiveness of this rehabilitation method. Slab stabilization should only be performed at joints that exhibit a loss of support. Pumping grout under slabs that have full support should not be done; it may result in lifting and slab cracking.

4.5.4.3 Slab Stabilization Procedures. After the specific areas requiring slab stabilization have been located, holes are drilled through the concrete slab. The holes should be drilled through the base course when there is a stabilized base course beneath the slabs; then an expanding rubber packer connected to a discharge hose on a pressure grout pump is lowered into the hole and the grout is pumped. The pumping process must be carefully monitored to ensure that full support is restored without raising the slab. The cement grout usually consists of a cement-Pozzolan (fly-ash) slurry.

4.5.5 Joint and Crack Sealing. Sealing and resealing of joints and cracks in both concrete and asphalt pavements shall be considered during restoration. Inadequate sealing of joints and cracks increases distress caused by free water entering the pavement structure. It also allows the infiltration of incompressibles into the joint or crack.

Proper joint reservoir design will help to ensure adequate performance of the joint sealant. To accommodate the expected movement of the joint, the joint shape factor, the ratio of the opening's depth to width, shall be designed as given in NFGS-02561.

Several pavement areas require fuel-resistant or blast-resistant joint sealants. See paras. 2.3.3 and 2.4.3 for more information.

4.5.6 Repairs with Asphalt Concrete Mixtures. Hot-mix AC mixtures may be used for permanent repairs of AC pavements. They should not be used for full-depth patching of concrete pavements. Cold mix materials (a combination of aggregate and either a cutback or emulsion binder) can be used only for temporary patches.

4.5.7 Load-Transfer Restoration. The ability of a joint or crack to transfer load is a major factor in the structural performance of the joint or crack and the surrounding slab. Load transfer is determined from deflection measurements taken during the pavement evaluation. Joints that are doweled during original pavement construction normally have very good deflection load transfer (70 to 100 percent). However, repeated heavy loads can cause an elongation of the dowel sockets, resulting in looseness of the dowel and a reduction in load transfer efficiency. This leads to faulted and spalled joints, and increased potential for pumping and cracking. Many jointed non-reinforced concrete pavements have been constructed without dowels at transverse joints. Load transfer across joints in these pavements is accomplished through aggregate interlock. Transverse cracks also rely on aggregate interlock. Joints or cracks relying on aggregate interlock will lose their load transfer ability quicker than doweled joints.

Restoration of load transfer across a transverse joint or crack retards further deterioration of the concrete pavement. Reduction of deflection and stress greatly reduces the potential for pumping, faulting, and cracking and extends the life of the pavement. Load transfer restoration through retrofit dowel bars can be used for transverse joints or cracks that exhibit poor deflection load transfer (0 to 50 percent). Proprietary shear devices have also been used on airfield pavements. Projects for restoration of load transfer must be documented with a detailed analysis of the structural capacity, including existing and required load transfer, and must be reviewed and approved by the Engineering Field Division of the Naval Facilities Engineering Command.

4.5.8 Pressure Relief Joints. Large expansive pressures which can result in blowups may be caused by the intrusion of incompressibles into poorly sealed joints and cracks, expansion of reactive aggregates, and by extreme temperature and moisture conditions, especially in slabs longer than 25 ft (7.6 m).

If blowups have occurred in the pavement, pressure relief joints can be installed to prevent their reoccurrence. Pressure relief joints are full-width, full-depth cuts in the concrete slab. They are typically placed near the center of the slab, are 2 to 4 in. (51 to 102 mm) wide, and are filled with a compressible material such as sponge rubber or styrofoam. These joints are placed at fixed structures and approximately 1000 ft (305 m) apart in the pavement. They shall only be used in the presence of blow-ups and other pressure-related damage.

4.5.9 Bituminous Rejuvenation. Surface rejuvenators are liquid materials sprayed on an AC pavement surface. Rejuvenators will hold surface fines in place and reduce raveling. Rejuvenator materials affect the consistency of the asphalt, improving its cohesion properties.

Rejuvenators are used for the repair of low severity raveling and weathering. Their application also retards the development of these distresses. Bituminous surface rejuvenators should be compatible with the AC surface and tested before application to a large area. Refer to CEGS-02599, Bituminous Rejuvenation, for specifications. Repeated applications of rejuvenators will not be made in runways.

4.6 Recycling Alternatives. Recycling of existing pavement materials for reconstruction and rehabilitation of both asphaltic and PCC pavements must be considered. The economic benefits of recycling existing materials shall be evaluated. If removed materials cannot be used for surface courses meeting applicable standards, they should be considered for use in construction of the base or subbase. Guidelines for pavement recycling are provided in AFM 88-6, Chapter 6, Standard Practice Manual for Pavement Recycling.

4.6.1 Surface Recycling. Surface recycling is the process by which the surface of a bituminous pavement is reworked to a depth of less than 1 in. (25 mm). This operation is a single or multi-step process that may involve the use of new materials, including aggregates, asphalt, rejuvenating agents, or asphalt mixtures. Removal of the asphalt pavement surface by milling, including depths greater than one inch, is also classified as surface recycling.

4.6.1.1 Criteria for Use. Surface recycling is appropriate for correction of surface distresses that are not due to pavement structure or subgrade weakness. Surface distresses that can be corrected by surface recycling includes raveling and weathering, low severity corrugations, rutting, bleeding and cracking, loss of surface friction, and poor drainage profile. The distress, drainage, and structural evaluation data is used to determine that there is no structural, moisture, or material problem in the pavement before the option of surface recycling can be selected.

Surface recycling may create a more open, porous surface than new construction if no new materials such as asphalt, aggregates, or asphalt mixtures are used. Therefore, the surface may age or oxidize faster and create a higher FOD potential. This should be considered when determining its suitability and life.

4.6.1.2 Pavement Removal. Pavement removal is a technique applicable for the treatment of pavement distresses such as rutting, bleeding, or weathering. It is also appropriate in conjunction with other procedures, such as in preparaing for an overlay. The primary type of pavement removal is cold milling.

Cold milling is used to remove surface deterioration and to produce surface millings that can be recycled. Material is removed from the pavement surface by carbide-tipped cutters mounted on a revolving drum. Cold milling is appropriate for the treatment of bleeding, ravelling, rutting, and corrugations, to repair a rough riding surface, possibly to restore the transverse profile, and to prepare an existing pavement for overlay.

4.6.1.3 Hot Surface Recycling. In hot surface recycling, the top 0.75 in. (19 mm) to 1 in. (25 mm) of asphalt pavement is heated and scarified, mixed with a soft asphalt cement or a rejuvenator, either relaid or shaped with a screed, and compacted. Specifications for hot surface recycling are given in CEGS-02597, Heater-Planer and Heater-Scarifier Procedures for Bituminous Pavements.

Scarification is the process of breaking apart the heated mass of AC to allow thorough mixing of the required additives. A rejuvenator, or asphalt rejuvenating agent, is an organic material with chemical and physical characteristics selected to improve the performance of aged asphalt. The heater scarification process removes any surface distress present, softens the aged asphalt, retards reflection cracking, and promotes bonding with subsequent overlays. It softens the top inch, making it easier to rework. Because this mixture is hot, material can be added to it and mixed while on the pavement. This allows for the correction of gradation deficiencies, asphalt deficiencies or excesses, and asphalt properties. The corrected mixture should be immediately compacted if no overlay is added. If an overlay is added, it can be added by several methods:

a) overlay after compacting recycled mixture,

b) overlay after mixing new mix and recycled layer, prior to compaction, or

c) overlay prior to compaction of the recycled mixture, but without mixing the two materials.

Surface scarification without an added overlay is not approved for Navy airfield pavements. Surface milling has largely replaced heater scarification for pavement rehabilitation and its use will be preferred.

Surface scarification with overlay may be considered for short life rehabilitation objectives for pavements having light traffic and low tire pressures.

4.6.2 <u>In-Place Recycling</u>. In-place recycling is a process in which the pavement section is ripped or pulverized in place to a depth greater than one inch to provide a new base course, followed by reworking the material on site, reshaping, compacting, and placing a new surface. Admixtures such as asphalt, lime, cement, and fly ash, can be added during processing to provide a higher strength stabilized base.

4.6.2.1 <u>Criteria for Selection of In-Place Recycling</u>. In-place recycling is used primarily on distressed flexible pavements when it is feasible to use the recycled material as a stabilized base material. The recycled material provides a material with structural properties similar to a new stabilized material. The main uses for the in-place recycled material are to upgrade the structural capacity of the pavement without altering the horizontal and vertical geometry, to correct surface distresses and mixture problems in the asphalt concrete, and to correct base course deficiencies including gradation, moisture problems, and density. If the surface and underlying layers are inadequate to support a structural overlay, recycling should be considered.

4.6.2.2 <u>Types of In-Place Recycling</u>. Cold mix recycling refers to the in-place pulverization of the surface course and base course with the addition of a bituminous material to produce a bituminous stabilized base.

4.6.3 Hot-Mix Recycling. Hot-mix asphalt pavement recycling is a process in which some portion or all of the pavement structure is removed, reduced to the appropriate size and hot mixed with added asphalt cement at a central plant. The process normally includes the addition of new aggregate and sometimes a rejuvenating agent. The finished product should meet all standard material and mix specifications and construction requirements for a hot-mix asphalt base, binder, or surface course. Refer to NFGS-02573, and CEGS-02590, Recycled Asphalt Concrete Intermediate and Wearing Course for Airfields, Heliports, and Heavy-Duty Pavements (Central Plant Hot Mix).

Hot-mix recycling is used for pavement reconstruction or where a thick overlay is required. The hot-mix recycling option shall be evaluated using life-cycle cost analysis.

4.6.4 Rigid Pavement Recycling. Rigid pavement recycling consists of breaking up an existing concrete pavement slab to produce recycled concrete aggregate. The resulting aggregate is used in place of virgin aggregate in the reconstruction of the pavement.

4.6.4.1 Criteria for Selection of Portland Cement Concrete Recycling. If reconstruction of a PCC pavement is selected as a feasible alternative, rigid pavement recycling shall be considered. However, if the existing concrete exhibits reactive aggregate distress, the pavement shall not be recycled. A concrete pavement which has an asphalt overlay can be recycled, but the two layers should be recycled separately. AC shall not be recycled for aggregate to be used in a PCC mix because the asphalt cement will inhibit the ability of the concrete mix to entrain air.

4.6.4.2 Uses of Recycled Portland Cement Concrete. Recycled concrete aggregate can be used in any component of the pavement structure where virgin aggregate is used, including:

a) untreated, dense-graded aggregate base,

b) cement- and asphalt-stabilized bases,

c) lean concrete base,

d) PCC surfacing,

e) AC surfacing,

f) fill,

g) filter material, and

h) drainage layer or edge drains.

The PCC aggregate must be properly crushed and sized to meet gradation requirements given in NFGS-02232 and NFGS-02233 for base courses, or NFGS-02559 for PCC mixes.

4.6.5 Base Course Recycling. Both untreated and treated base courses may be formed from recycled materials. Stabilizing and reworking treatments may be done in-place or the materials may be removed and replaced. Recycled materials must meet the specifications for new base courses as stated in NFGS-02232 and NFGS-02233. Refer to MIL-HDBK-1021/4.

4.7 Example Problems. To demonstrate the rehabilitation alternative selection process, example problems are provided in paras. 4.7.1, 4.7.2 and 4.7.3. These examples also demonstrate life-cycle cost analyses in Section 5. These problems are provided as examples only. The numbers and conditions presented may not be representative of real designs at a typical Naval airfield. Results should not be extrapolated for use in other situations.

4.7.1 Example One: Portland Cement Concrete Taxiway. Background data about Taxiway Feature T24C and results of the PCI survey are provided in Figure 16. This taxiway is in very poor condition and has been determined to be structurally deficient. Due to the number of shattered slabs and otherwise poor condition, some traffic has been rerouted and the taxiway is currently in low use. However, because of an expected increase in overall airfield traffic within the next year, Taxiway E must be rehabilitated and structurally improved.

The pavement evaluation information is used with the flow chart in Figure 15 to develop the following list of preliminary alternatives, along with the constraints:

a) Replace Keel Section: Replacing a keel or other section can be eliminated as a feasible alternative because in general, the whole width of the taxiway is in poor condition.

b) PCC Overlay: According to the pavement design procedures in MIL-HDBK-1021/4, a 10 in. (254 mm) unbonded PCC overlay is required. This overlay thickness would produce unacceptable elevation differences for existing connecting taxiways.

c) AC Overlay: According to the pavement design procedures in MIL-HDBK-1021/4, a 13.5 in. (343 mm) AC overlay is required. This overlay thickness would produce unacceptable elevation differences for existing connecting taxiways.

d) PCC Reconstruction: The new design, or reconstruction, requires 12 in. (305 mm) of PCC (refer to MIL-HDBK-1021/4).

e) AC Reconstruction: According to the pavement design procedures in DM-21.3, a total cross-section thickness, including surface, base, and subbase, of 23 in. (584 mm) is required.

f) PCC Recycling: PCC recycling is a feasible alternative to reconstruction with all new materials for both asphalt and Portland cement concrete.

Background Data

Facility: Connecting Taxiway E Feature: T24C

Length: 750 ft (229 m) Width: 75 ft (23 m)

Subgrade: Silty Sand; CBR = 9;
$k = 110$ lb/in^3 (300 kg/m^3)

Base: 12 in (305 mm) Untreated; CBR = 100;
k (on top of base) = 200 lb/in^3 (550 kg/m^3)

Original Construction: 1958; 10-in. (250 mm) jointed non-reinforced concrete keyed longitudinal joints.

Previous Work: No previous major overall rehabilitation; some slab replacement; patching; not well maintained in recent years.

Future Design

Design Aircraft: C-5A
Total Passes Over 20 Year Design Life = 25,000
Total Passes Over 40 Year Design Life = 50,000

Evaluation Data

Distress Type		Deduct Value
Load Associated:		
Corner break		4.5
Long/Trans. Cracking		26.7
Large Patch		1.1
Shattered Slab		46.3
Joint Spalling (Keyway)		1.3
	Subtotal	79.9
Climate/Durability Associated:		
Joint Seal Damage		7.0
Small Patch		0.9
Large Patch		1.1
	Subtotal	9.0
	Total	88.9

PCI = 33
PCI_{STR} = 32

Figure 16
Example One: Background Data

Therefore, four feasible alternatives should be further considered:

a) Alternative One: PCC reconstruction with all new materials.

b) Alternative Two: PCC reconstruction using recycled PCC as the coarse aggregate.

c) Alternative Three: AC reconstruction with all new materials.

d) Alternative Four: AC reconstruction using recycled PCC as the coarse aggregate.

These alternatives are evaluated using life-cycle cost analysis in Section 5.

4.7.2 Example Two: Portland Cement Concrete Apron. Background information about Apron A18B and results of the PCI survey are presented in Figure 17. The apron is in good condition, with most of the existing distress due to structural damage. However, the structural evaluation does not show a structural deficiency. There are no major functional problems with the apron at the present time.

The evaluation information is used in the flow chart in Figure 15 to develop the following list of preliminary alternatives:

a) PCC Overlay: According to the pavement design procedures in MIL-HDBK-1021/4, a 6 in. (152 mm) partially bonded PCC overlay is required.

b) AC Overlay: AC is not acceptable on the apron due to its susceptibility to fuel spillage damage.

c) Replace a Localized Section: No systematic variation is noted. Therefore, this is not a feasible solution.

d) Reconstruction: According to MIL-HDBK-1021/4, a 12 in. (305 mm) new pavement is required. The funding is not currently available to reconstruct the apron. The apron is in overall good condition.

e) Restoration: Localized repair including fairly extensive slab replacement appears to be a feasible alternative.

Background Data

Facility: Apron

Feature: A18B

Area: 4000 yd^2 (3345 m^2)

Subgrade: Silty Sand

Base: 12 in (305 mm) Untreated
k (on top of base) = 200 lb/in^3 (550 kg/m^3)

Slab Size: 20 ft x 20 ft (6.1 m x 6.1 m)

Original Construction: 1964; 12-in. (305 mm) jointed non-reinforced concrete keyed longitudinal joints.

Previous Work: Patching; joint-sealed last year.

Future Design

Design Aircraft: C-5A
Total Passes Over 20 Year Design Life = 25,000

Evaluation Data

Distress Type		Deduct Value
Load Associated:		
Corner break		2.5
Long/Trans. Cracking		22.1
Large Patch		4.6
Joint Spalling (Keyway)		9.5
Shattered Slab		10.0
	Subtotal	48.7
Climate/Durability Associated:		
Large Patch		4.6
Small Patch		2.4
Corner Spall		3.9
	Subtotal	10.9
	Total	59.6

PCI = 56
PCI_{STR} = 54

Figure 17
Example Two: Background Data

Therefore, two feasible alternatives should be further considered:

a) Alternative One: Partially bonded PCC overlay.

b) Alternative Two: Restoration through localized repair, including slab replacement.

These alternatives are evaluated using life-cycle cost analysis in Section 5.

4.7.3 Example Three: Asphalt Concrete Overlaid Runway Interior. Background data about Runway Feature R7C and results of the PCI survey are provided in Figure 18. This runway interior section is in very good condition. Feature R7C is structurally adequate. The only problems at the present time are raveling/weathering and joint reflection cracking deterioration. However, the short-term rate of deterioration has been high. The FOD potential is increasing and the joint/reflection cracking is rapidly progressing. This is a high priority pavement. Therefore, a decision has been made to rehabilitate the pavement before the condition becomes significantly worse.

Background Data

Facility: Runway Interior | Feature: R7C

Length: 6000 ft (1829 m) | Width: 200 ft (61 m)

Subgrade: Silty Clay | Base: 10 in. (254 mm) Stabilized

Original Construction: 1958; 12 in. (305 mm) jointed non-reinforced concrete keyed longitudinal joint.

Previous Work: 6 in. (152 mm) AC overlay was placed in 1974. A 2 in. (51 mm) AC overlay was placed in 1982.

Evaluation Data

Distress Type		Deduct Value
Load Associated:		---
Climate/Durability Associated:		
Raveling/Weathering		13.0
Joint Reflection Cracking		31.0
	Subtotal	44.0
Other:		
Jet Blast Erosion		0.9
	Total	44.9

PCI = 71

Figure 18
Example Three: Background Data

The evaluation information is used in the flow chart in Figure 15 to develop a list of preliminary alternatives. Although the PCI is presently 71, due to the currently high rate of deterioration, the PCI is expected to be somewhat lower by the time of rehabilitation. Therefore, alternatives were examined for a PCI less than 70. Possible alternatives include:

a) Alternative One: Place another 2-in. (51 mm) overlay similar to that placed in 1982. This will immediately improve the pavement condition. However, the rate of deterioration probably will remain high due to continued reflection cracking.

b) Alternative Two: Mill off 2 in. (51 mm), heater scarify the top 1 in. (25 mm) of the remaining surface, and place a 2-in. (51 mm) hot mix overlay. This alternative is proposed to retard reflection cracking.

Life-cycle cost analysis is applied to these alternatives in Section 5.

SECTION 5. ECONOMIC ANALYSIS

5.1 General. This section presents guidelines for life-cycle cost analysis of pavement alternatives. Selecting the best alternative requires the performance of an economic analysis to compare the cost-effectiveness of all feasible alternatives.

Life-cycle cost analysis is a method of determining the total cost to all branches of the Government of the acquisition or maintenance of an alternative over its full useful life. Life-cycle costing pertains to all costs incurred from the viewpoint of the U. S. Government, not just the Navy. If a Navy investment results in another Government agency incurring additional costs, those costs must be included in the analysis even though the Navy does not pay them.

It is the responsibility of the engineer to identify all feasible alternatives. A feasible alternative is one that fits within the prescribed constraints, such as limited construction funds and facility closure time. Once feasible alternatives have been developed, they must be evaluated and the preferred alternative chosen. There is no absolute and indisputable method for selecting the most desirable alternative for a given project. A considerable amount of engineering judgment must be applied to each project.

The evaluation of all of the feasible alternatives includes the determination of life-cycle costs. Life-cycle costs can be expressed as a present worth (PW) or as an equivalent uniform annual cost (EUAC).

5.2 Present Worth. The present worth method converts all of the present and future costs to costs at the beginning of the life of the system. The present worth of some planned future expenditure is equivalent to the amount of money that would need to be invested at the present time at a given compound interest rate to equal the expected cost at the time it is needed. All costs are reduced to one single cost in the present. In this approach, the present worth costs for all feasible alternatives are compared and the alternative with the lowest present worth is identified.

5.2.1 Present Worth of a Single Future Sum. The following equation is for the present worth of a single future sum of money for a given number of years with a given discount rate.

EQUATION: $$PW = F\,(1/(1+i)^n) \qquad (6)$$

where
- PW = present worth,
- F = the future sum of money at the end of n years from now that is equal to the PW with a discount rate of i (based on current dollars),
- n = number of time periods,
- i = discount rate per time period.

The present worth of a single future value F can be determined by multiplying it by the single-payment present-worth factor. Values for the single-payment present-worth factor are provided in Table 7.

Table 7
Present Worth Factors for a Single Future Sum

$$PWF = \frac{1}{(1 + i)^n}$$

Period	4%	6%	8%	10%	12%
1	0.9615	0.9434	0.9259	0.9091	0.8929
2	0.9246	0.8900	0.8573	0.8264	0.7972
3	0.8890	0.8396	0.7938	0.7513	0.7118
4	0.8548	0.7921	0.7350	0.6830	0.6355
5	0.8219	0.7473	0.6806	0.6209	0.5674
6	0.7903	0.7050	0.6302	0.5645	0.5066
7	0.7599	0.6651	0.5835	0.5132	0.4523
8	0.7307	0.6274	0.5403	0.4665	0.4039
9	0.7026	0.5919	0.5002	0.4241	0.3606
10	0.6756	0.5584	0.4632	0.3855	0.3220
11	0.6496	0.5268	0.4289	0.3505	0.2875
12	0.6246	0.4970	0.3971	0.3186	0.2567
13	0.6006	0.4688	0.3677	0.2897	0.2292
14	0.5775	0.4423	0.3405	0.2633	0.2046
15	0.5553	0.4173	0.3152	0.2394	0.1872
16	0.5339	0.3936	0.2919	0.2176	0.1631
17	0.5134	0.3714	0.2703	0.1978	0.1456
18	0.4936	0.3503	0.2502	0.1799	0.1300
19	0.4746	0.3305	0.2317	0.1635	0.1161
20	0.4564	0.3118	0.2145	0.1486	0.1037
21	0.4388	0.2942	0.1987	0.1351	0.0926
22	0.4220	0.2775	0.1839	0.1228	0.0826
23	0.4057	0.2618	0.1703	0.1117	0.0738
24	0.3901	0.2470	0.1577	0.1015	0.0659
25	0.3751	0.2330	0.1460	0.0923	0.0588
26	0.3604	0.2198	0.1352	0.0839	0.0525
27	0.3468	0.2074	0.1252	0.0763	0.0469
28	0.3335	0.1956	0.1159	0.0693	0.0419
29	0.3207	0.1846	0.1073	0.0630	0.0374
30	0.3083	0.1741	0.0994	0.0573	0.0334
31	0.2965	0.1643	0.0920	0.0521	0.0298
32	0.2851	0.1550	0.0852	0.0474	0.0266
33	0.2741	0.1462	0.0789	0.0431	0.0238
34	0.2636	0.1379	0.0731	0.0391	0.0212
35	0.2534	0.1301	0.0676	0.0356	0.0189
36	0.2437	0.1227	0.0626	0.0324	0.0169
37	0.2343	0.1158	0.0580	0.0294	0.0151
38	0.2253	0.1092	0.0537	0.0267	0.0135
39	0.2166	0.1031	0.0497	0.0243	0.0120
40	0.2083	0.0972	0.0460	0.0221	0.0107

5.2.2 Present Worth of a Uniform Series. The following equation is used to determine the present worth of a series of uniform end-of-the-year payments for a given number of years with a given discount rate. This equation is for recurring costs:

EQUATION: $PW = A\,[(1 + i)^n - 1/i(1 + i)^n]$ (7)

where

A = End-of-year payments in a uniform series for n years that are equivalent to the PW at a discount rate i,
PW = Present worth,
i = Discount rate,
n = Number of years.

The present worth of a series of annual payments A can be determined by multiplying A by the uniform series present-worth factor for given values of n and i. Values for the uniform series present-worth factor are provided in Table 8.

Present worth concepts are illustrated by the example cash flow diagrams in Figure 19.

5.3 Equivalent Uniform Annual Cost. The annualized method converts all of the present and future expenditures to a uniform annual cost. This method converts the cost of each alternative to a common basis, a uniform annual cost.

A given future expenditure must first be converted to its present worth before calculating its annualized cost. The following equation converts a present value to an equivalent uniform annual cost over the analysis period.

EQUATION: $EUAC = PW\,[i(1 + i)^n/(1 + i)^n - 1]$ (8)

where

EUAC = Equivalent uniform annual cost,
PW = Present worth of the cash flows,
i = Discount rate,
n = Number of years.

The annual cost is calculated by dividing the initial cost or the present worth of costs by the uniform series present-worth factor from Table 8. The alternative that yields the lowest annual cost is identified. In special cases, EUAC can be used to directly compare alternatives of unequal life. If each alternative will be replaced indefinitely by an alternative having equal cost, equal analysis periods are not required. This option should be used with caution, and only with EUAC.

Table 8
Present Worth Factors for a Uniform Series

$$PWA = \frac{(1 + i)^n - 1}{i\ (1 + i)^n}$$

Period	4%	6%	8%	10%	12%
1	0.9615	0.9434	0.9259	0.9091	0.8929
2	1.8861	1.8334	1.7833	1.7355	1.6901
3	2.7751	2.6730	2.5771	2.4869	2.4018
4	3.6299	3.4651	3.3121	3.1699	3.0373
5	4.4518	4.2124	3.9927	3.7908	3.6048
6	5.2421	4.9173	4.6229	4.3553	4.1114
7	6.0021	5.5824	5.2064	4.8684	4.5638
8	6.7327	6.2098	5.7466	5.3349	4.9676
9	7.4353	6.8017	6.2469	5.7590	5.3282
10	8.1109	7.3601	6.7101	6.1446	5.6502
11	8.7605	7.8869	7.1390	6.4951	5.9377
12	9.3851	8.3838	7.5361	6.8137	6.1944
13	9.9856	8.8527	7.9038	7.1034	6.4235
14	10.5631	9.2950	8.2442	7.3667	6.6282
15	11.1184	9.7122	8.5595	7.6061	6.8109
16	11.6523	10.1059	8.8514	7.8237	6.9740
17	12.1657	10.4773	9.1216	8.0216	7.1196
18	12.6593	10.8276	9.3719	8.2014	7.2497
19	13.1339	11.1581	9.6036	8.3649	7.3658
20	13.5903	11.4699	9.8181	8.5136	7.4694
21	14.0292	11.7641	10.0168	8.6487	7.5620
22	14.4511	12.0416	10.2007	8.7715	7.6446
23	14.8568	12.3034	10.3711	8.8832	7.7184
24	15.2470	12.5504	10.5288	8.9847	7.7843
25	15.6221	12.7834	10.6748	9.0770	7.8431
26	15.9828	13.0032	10.8100	9.1609	7.8957
27	16.3296	13.2105	10.9352	9.2372	7.9426
28	16.6631	13.4062	11.0511	9.3066	7.9844
29	16.9837	13.5907	11.1584	9.3696	8.0218
30	17.2920	13.7648	11.2578	9.4269	8.0552
31	17.5885	13.9291	11.3498	9.4790	8.0850
32	17.8736	14.0840	11.4350	9.5264	8.1116
33	18.1477	14.2302	11.5139	9.5694	8.1354
34	18.4112	14.3681	11.5869	9.6086	8.1566
35	18.6646	14.4982	11.6546	9.6442	8.1755
36	18.9083	14.6210	11.7172	9.6765	8.1924
37	19.1426	14.7368	11.7752	9.7059	8.2075
38	19.3679	14.8460	11.8289	9.7327	8.2210
39	19.5845	14.9491	11.8786	9.7570	8.2330
40	19.7928	15.0463	11.9246	9.7791	8.2438

PRESENT WORTH OF A SINGLE FUTURE SUM

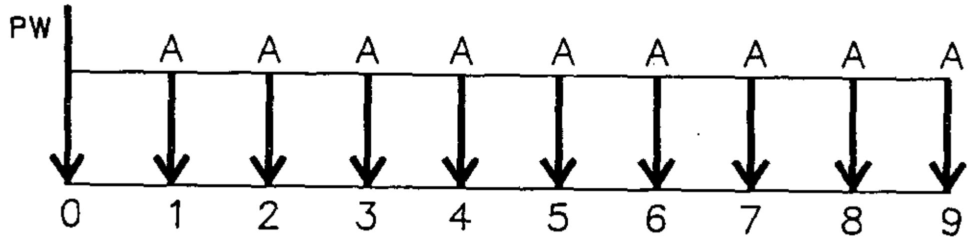
$i = 10\%$

$$PW = F(1/(1+i)^n)$$

$$PW = F[1/1.10^{20}]$$

$$PW = F(.1486)$$

PRESENT WORTH OF A UNIFORM SERIES



$i = 10\%$

$$PW = A\left[\frac{(1+i)^n - 1}{i(1+i)^n}\right]$$

$$PW = A\left[\frac{(1.10)^9 - 1}{.1(1.10)^9}\right]$$

$$PW = A\ (5.759)$$

Figure 19
Cash Flow Diagrams for Present Worth

5.4 Life-Cycle Cost Variables. Each of the variables which affect life-cycle cost must be evaluated. These variables include discount rate, analysis life, costs, and salvage value. The total life-cycle cost is the sum of the present values of all relevant costs. The cash flow diagram in Figure 20 illustrates the consideration of the life-cycle cost variables.

5.4.1 Discount Rate. The discount rate, or cost of capital, is a function of the time value of money. Therefore, future expenditures must be adjusted to a common point for an accurate comparison. As outlined in NAVFAC P-442, the Government recognizes the effect that the time value of money has on life-cycle cost analysis by specifying a 10% interest rate for discounting. This has been directed by OMB Circular A-94, Discount Rates to be Used in Evaluating Time-Distributed Costs and Benefits.

5.4.2 Analysis Period. In economic studies, projects under consideration are defined as having a service life, an economic life, and an analysis period. Service life estimates the actual time span from construction of a facility to retirement from service. The economic life is the life in which a project is economically profitable or until the service provided by the project can be provided by another facility at lower costs.

The analysis period may not be the same as the service life or the economic life of a project, but it represents a realistic estimate to be used in economic analysis. The analysis period utilized should be long enough to include the initial performance period and at least one rehabilitation period. However, the analysis period should not be excessive as the analysis becomes more uncertain due to changes in technology and events not occurring as predicted.

All alternatives being considered for a particular decision must be analyzed over the same analysis period.

5.4.2.1 Analysis Period for New Design. The analysis period for comparing new design alternatives shall be 25 to 40 years. This is considered a sufficient time period for predicting future costs for economic purposes in order to capture the most significant costs. Due to the effect of the discounting factor, the majority of the total equivalent cost of the system is generally consumed in the first 25 years.

5.4.2.2 Analysis Period for Rehabilitation. The analysis period for comparing rehabilitation alternatives on an existing pavement may be shorter than 25 years because the pavement system may be planned for replacement before 25 years. These other factors may dictate the analysis period that should be used. A minimum analysis period of 10 years shall be used for airfield pavements.

5.4.3 Costs. All costs to the United States Government should be considered. Those costs may include design costs, construction costs, maintenance costs, rehabilitation costs, and related costs. In the actual analysis, only those costs which differ between the alternatives being compared shall be considered.

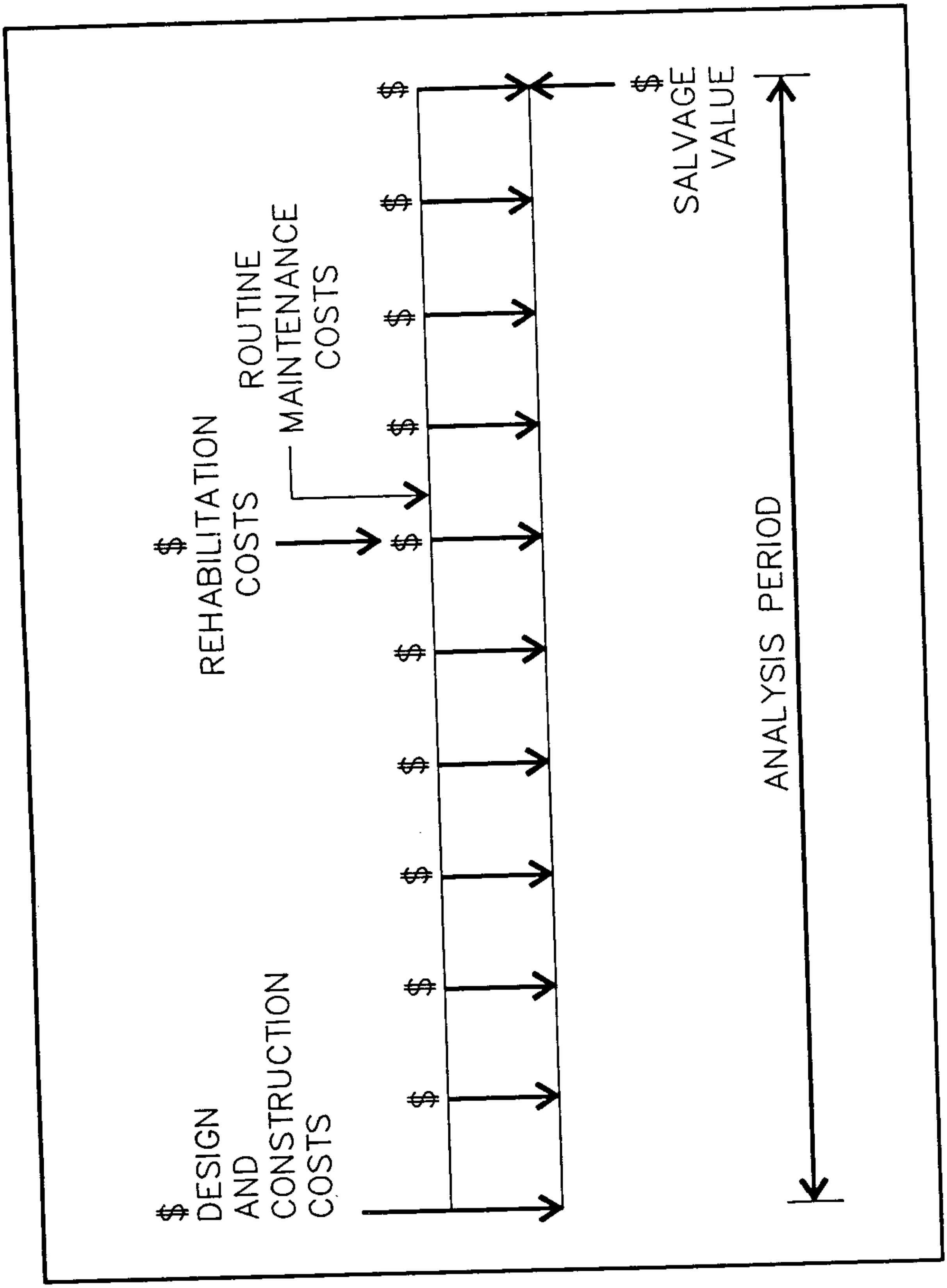


Figure 20
Life-Cycle Cost Analysis Variables

5.4.3.1 Design Costs. Design costs are the expected costs for designing a new or rehabilitated pavement, including materials, site investigations, traffic analysis, pavement design, and plans and specifications. Design costs need to be included only if the cost of designing one alternative is known to be different from the costs of designing another. If the design costs for all alternatives being considered are identical, then it shall be so noted and omitted from the analysis.

5.4.3.2 Construction Costs. Construction costs are the costs for building a section of pavement in accordance with the plans and specifications. Sources of information for construction costs include previous bids, previous projects, and historical cost data. These costs shall be obtained locally and updated frequently. The maximum time between updates should be a year. The construction costs used in the analysis shall be the most current and the most accurate data available.

5.4.3.3 Maintenance Costs. Maintenance costs are those costs associated with maintaining a pavement at or above a predetermined performance level. This includes both corrective and preventive maintenance, but does not include rehabilitation. Maintenance costs may be stated as cost per square yard per year for a given pavement type. Maintenance costs are one of the most difficult cost items to determine. Historical data is a good source for maintenance cost data. The cost of pavement maintenance is directly influenced by the type and extent of maintenance work performed at various time intervals in the future. Maintenance costs can be affected adversely when a maintenance activity is delayed; cost of maintenance increases as pavement condition deteriorates.

The differential in maintenance requirements between the various alternatives being considered must be included. If maintenance costs are identical for all alternatives, then maintenance is not included in the analysis.

5.4.3.4 Rehabilitation Costs. These costs cover the activities performed as part of pavement rehabilitation. These represent periodic costs at future dates used to restore the pavement to an acceptable performance level. The cost data normally used for rehabilitation are of the same general type as those used for new pavement construction.

For projects where the pavement has existed for years, rehabilitation will be at time zero and therefore constitutes the beginning of a life-cycle analysis. Future rehabilitation needs for a new pavement or for a newly rehabilitated pavement should also be considered. One major problem with future rehabilitation is the inability to accurately predict at what time in the future rehabilitation might be required. Based on experience with the particular air station and pavement type, make the best possible estimate of when rehabilitation will be required.

5.4.3.5 Related Costs. Related costs are those costs incurred due to relocation, downtime, or other indirect costs due to construction or to the existing condition of the pavement. Related costs should only be included if there is a differential between the alternatives being considered.

5.4.4 Salvage Value. Salvage value is the residual value of the pavement at the end of the analysis period. When a pavement no longer is functional, it may still have some remaining economic value as recycled materials. Similarly, the costs of removing the pavement can be greater than any value obtained from the pavement material.

The salvage value of a new design or rehabilitation alternative is determined as follows:

EQUATION: $SV = B - R$ (9)

where
- B = Cost of building a new pavement on subgrade; this cost should be kept the same for all alternatives,
- R = Cost of rehabilitation at the end of analysis period for the alternative under consideration, so that the pavement will be equivalent to a new pavement.

If the rehabilitation cost R cannot be reasonably determined, a simplified determination of salvage value may be utilized. The simplified method is described by the equation given below:

EQUATION: $SV = (1 - L_A/L_E)\ C$ (10)

where
- SV = salvage value or residual value of the alternative,
- L_A = analysis period of the alternative in years,
- L_E = expected life of the alternative,
- C = cost or price of alternative.

This method of salvage value determination is illustrated in Figure 21.

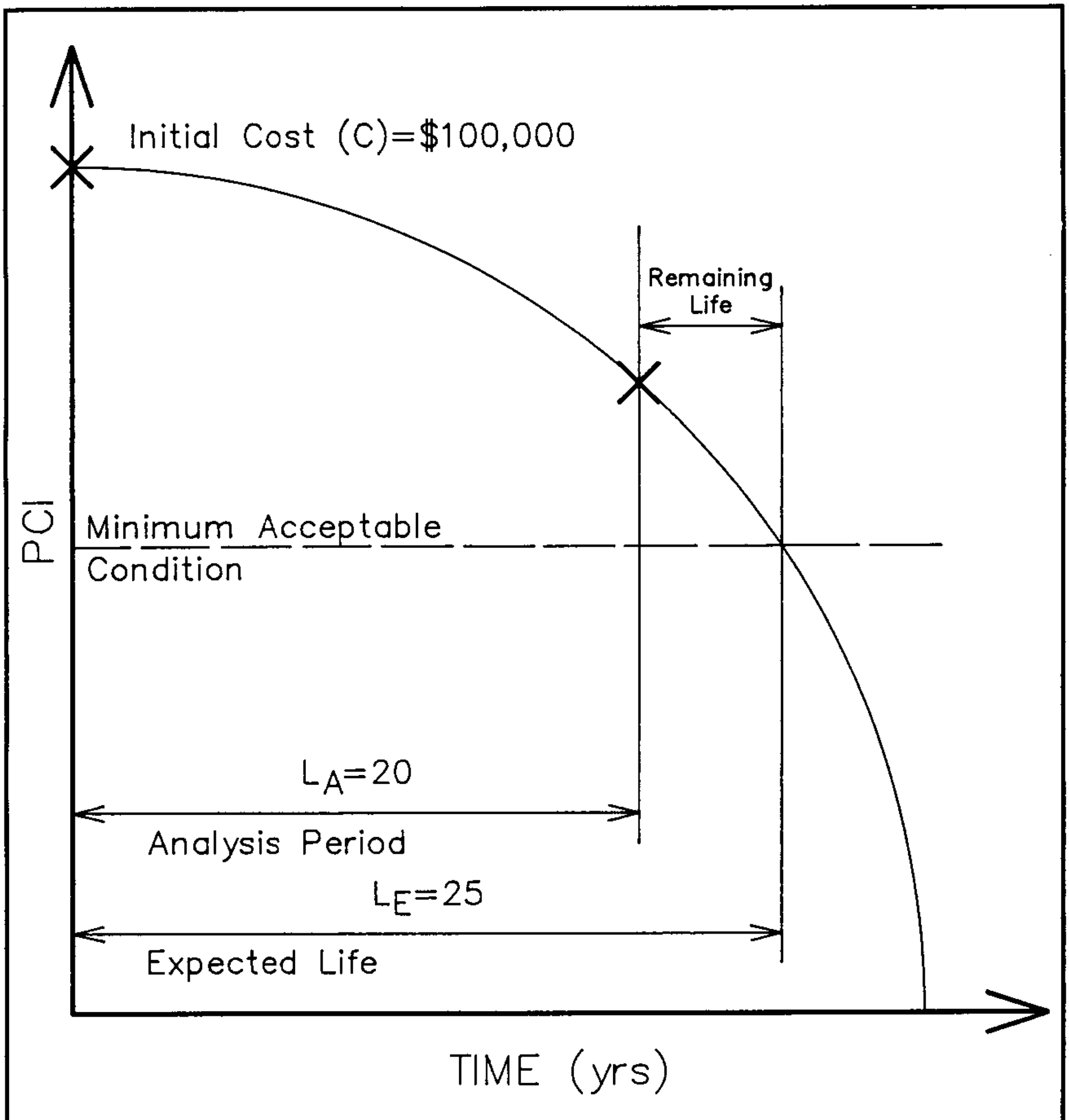
The salvage value for each alternative being considered for a particular decision shall be determined using the same method. The results from the two methods of estimating salvage value must not be compared.

5.5 Cost Information. All costs shall be obtained from local records or contractors. Pavement cost refers to the total amount that must be spent to have a pavement structure constructed, rehabilitated, or maintained.

Since cost information is obtained from various sources at various times, it is necessary to convert these costs to a common time frame. In order to convert cost figures to a current and common date, the price or cost index method shall be used. The following equation shall be used.

EQUATION: $C_c = C_o\ (I_c/I_o)$ (11)

where
- C_c = Current estimated cost,
- C_o = Cost at other time,
- I_c = Current index number,
- I_o = Index number at other time.



$$\text{Salvage Value (SV) (at year 20)} = \left[1 - \frac{L_A}{L_E}\right] C = \left[1 - \frac{20}{25}\right] \$100{,}000 = \$20{,}000$$

Figure 21
Approximation of Salvage Value

The index number to use depends upon the type of cost being estimated. Four indices commonly available are:

a) The Engineering News Record (ENR) Construction Cost Index,

b) Bid Price Trends on Federal-Aid Highway Contracts, published quarterly by the Federal Highway Administration,

c) The ENR Equipment Price Index,

d) Cost Trends on Highway Maintenance and Operations, published quarterly by the Federal Highway Administration.

5.6 Inflation. The prescribed 10 percent discount factor includes the general inflation rate for the period over which it is applied because the discount rate is a real rate of return. A real rate of return is consistent with the use of constant dollars. When using constant dollars, all costs are stated in terms of levels at the base year.

The 10 percent discount factors only adjust for the general inflation rate. If an annual cost or cost component is not expected to escalate at or near the general inflation rate, a special adjustment for escalation may be necessary. The analysis should be performed first in terms of constant dollars. All estimates of costs and monetary benefits during the project life should be made in terms of base year prices. If inflation is deemed important to the conclusion of the study, a second computation should be made in terms of escalated annual costs and monetary benefits. Only a differential escalation rate should be applied to escalate that particular cost factor. The differential escalation rate is the expected difference between the average long-term general inflation rate and the long-term rate for that particular cost element.

Future costs can be calculated using the equation:

EQUATION: $$C_f = C_p (1 + i)^n \qquad (12)$$

where
C_f = Future cost,
C_p = Cost at the present time,
i = Differential inflation rate,
n = Number of years.

Discount factors for differential escalation rates are provided in Appendix D of NAVFAC P-442. These factors both escalate the costs and discount the costs in order to take into account the 10 percent discount factor.

5.7 Evaluation of Overall Important Decision Factors. It is normally assumed to be insignificant if the difference in the present worth of costs between two rehabilitation alternatives is 10 percent or less; the present worth of the two alternatives is assumed to be the same. Whenever the economic analysis does not show a clear advantage for one of the feasible alternatives, other factors can be used to help in the selection process.

As the following summary list shows, these factors are difficult to quantify in monetary units:

a) airfield operational requirements,

b) future rehabilitation options and needs,

c) initial construction cost,

d) future maintenance requirements,

e) safety during construction,

f) duration of construction,

g) availability of local materials and contractor capabilities,

h) continuity of pavement type, and

i) the judgment of the engineer in other factors.

Due to the difficulty of quantifying all of these factors, engineering judgment must be used in the final selection of the preferred alternative. Life-cycle cost analysis is an important tool in the decision making process. However, the alternative with the lowest life-cycle cost is not always the preferred alternative.

5.8 Example Problems. Example problems are provided to demonstrate the life-cycle cost analysis procedure. These examples are continued from the examples demonstrating the rehabilitation alternative selection process in Section 4. These problems are provided as examples only. The costs presented may not be representative of actual costs. Results should not be extrapolated for use in other situations. For each example, 1988 is used as the base year (year zero).

5.8.1 Example One: Portland Cement Concrete Taxiway. In Section 4, four feasible alternatives are identified for Taxiway Feature T24C. These are:

Alternative One: Reconstruction with PCC with all new materials. For a 40-year design life, the required cross-section is 12 in. (305 mm) of Portland cement concrete over a 12 in. gravel base.

Alternative Two: Reconstruction with PCC using recycled materials. The required cross-section is the same as that for reconstruction with all new materials. However, recycled PCC will be used in both the base and concrete layers.

Alternative Three: Reconstruction with AC with all new materials. For a 20-year design life, the required cross-section is 4 in. (101 mm) of asphalt concrete, an 8 in. (203 mm) crushed gravel base, and an 11 in. (280 mm) subbase.

Alternative Four: Reconstruction with AC using recycled materials. Recycled PCC will be used in both the base and asphalt concrete layers.

An analysis period of 40 years is used for the life-cycle cost analysis. The design life of the Portland cement concrete alternative is 40 years; the asphalt concrete design life is shorter, but will be extended by appropriate rehabilitation.

The costs and present worth computations are shown in Figures 22 through 25. Equivalent uniform annual costs are also computed. The salvage values are computed using the simplified method. The PCC alternatives have expected lives equal to the analysis period; therefore, the salvages values are zero. The last AC overlays have expected lives of 10 years; therefore, salvage values are computed.

Reconstruction with asphalt concrete using recycled materials (Alternative Four), has the lowest life-cycle cost. Costs of other alternatives are not within 10 percent of Alternative Four. Unless other factors dictate the use of PCC, Alternative Four should be selected.

5.8.2 Example Two: Portland Cement Concrete Apron. In Section 4, two feasible alternatives are identified for Apron Feature A18B. These are:

Alternative One: Placement of a partially bonded Portland cement concrete overlay. Following the procedures in MIL-HDBK-1021/4, a 6-in. (152 mm) overlay is required.

Alternative Two: Localized repair, including slab replacement, would be performed now and at 5-year intervals in the future.

An analysis period of 20 years is used for the life-cycle cost analysis. The design life of the partially bonded Portland cement concrete overlay is 20 years; the localized repair will be repeated regularly during the 20-year period. Using the simplified method of salvage value computation, salvage values are determined to be zero.

The costs and present worth computations are shown in Figures 26 and 27. Equivalent uniform annual costs are also computed. Alternative One, placement of a partially bonded Portland cement concrete overlay, has the lowest life-cycle cost.

ALTERNATIVE ONE: RECONSTRUCTION WITH PCC USING ALL NEW MATERIALS

ANALYSIS PERIOD = 40 YEARS DISCOUNT RATE = 10 %

YEAR	WORK DESCRIPTION	COST ($)	F	PRESENT WORTH
0	Removal of Existing Pvmt	56,675	1	56,675
0	Reconstruction - 12" PCC	249,410	1	249,410
0	Reconstruction - 12" Base	29,806	1	29,806
7	Reseal Joints	4,800	.5132	2,463
14	Reseal Joints	4,800	.2633	1,264
21	Reseal Joints	4,800	.1351	648
21	Seal Cracks	1,100	.1351	149
25	Full-depth Patching (5 Slabs)	4,500	.0923	415
28	Reseal Joints	4,800	.0693	333
30	Full-depth Patching (5 Slabs)	4,500	.0573	258
30	Slab Replacement (5 Slabs)	12,500	.0573	716
35	Reseal Joints	4,800	.0356	171
35	Full-depth Patching (15 Slabs)	13,500	.0356	481
35	Slab Replacement (10 Slabs)	25,000	.0356	890
1-40	Routine Maintenance	750/yr	9.7791	7,334
		TOTAL		$ 351,013

SALVAGE VALUE = 0 * .0221 = - 0

PRESENT WORTH $ 351,013

EQUIVALENT UNIFORM ANNUAL COST = PW / 9.7791 = $ 35,894

Figure 22
Example One: Life-Cycle Cost Analysis of Alternative One

ALTERNATIVE TWO: RECONSTRUCTION WITH PCC USING RECYCLED MATERIALS

ANALYSIS PERIOD = 40 YEARS DISCOUNT RATE = 10 %

YEAR	WORK DESCRIPTION	COST ($)	F	PRESENT WORTH
0	Removal of Existing Pvmt	21,000	1	21,000
0	Reconstruction - 12" PCC	229,410	1	229,410
0	Reconstruction - 12" Base	19,500	1	19,500
7	Reseal Joints	4,800	.5132	2,463
14	Reseal Joints	4,800	.2633	1,264
21	Reseal Joints	4,800	.1351	648
21	Seal Cracks	1,100	.1351	149
25	Full-depth Patching (5 Slabs)	4,500	.0923	415
28	Reseal Joints	4,800	.0693	333
30	Full-depth Patching (5 Slabs)	4,500	.0573	258
30	Slab Replacement (5 Slabs)	12,500	.0573	716
35	Reseal Joints	4,800	.0356	171
35	Full-depth Patching (15 Slabs)	13,500	.0356	481
35	Slab Replacement (10 Slabs)	25,000	.0356	890
1-40	Routine Maintenance	750/yr	9.7791	7,334
		TOTAL		$ 285,032

SALVAGE VALUE = 0 * .0221 = 0

PRESENT WORTH $ 285,032

EQUIVALENT UNIFORM ANNUAL COST = PW / 9.7791 = $ 29,147

Figure 23
Example One: Life-Cycle Cost Analysis of Alternative Two

ALTERNATIVE THREE: RECONSTRUCTION WITH AC USING ALL NEW MATERIALS

ANALYSIS PERIOD = 40 YEARS

DISCOUNT RATE = 10 %

YEAR	WORK DESCRIPTION	COST ($)	F	PRESENT WORTH
0	Removal of Existing Pvmt	56,675	1	56,675
0	Reconstruction - AC Section	153,130	1	153,130
10	Seal Cracks	600	.3855	231
10	Full-depth Repairs	15,000	.3855	5,783
15	Full-depth Repairs	15,000	.2394	3,591
15	Seal Cracks	1,200	.2394	287
15	4" AC Overlay	56,000	.2394	13,406
20	Pre-overlay Repairs	20,000	.1486	2,972
25	Seal Cracks	600	.0923	55
27	Full-depth Repairs	15,000	.0763	1,145
30	Seal Cracks	1,200	.0573	69
35	4" AC Overlay	56,000	.0356	1,994
35	Pre-overlay Milling & Repair	32,650	.0356	1,162
1-40	Routine Maintenance	400/yr	9.7791	3,912
		TOTAL		$ 244,412

SALVAGE VALUE = -28,000 * .0221 = - 619

PRESENT WORTH $ 243,793

EQUIVALENT UNIFORM ANNUAL COST = PW / 9.7791 = $ 24,930

Figure 24
Example One: Life-Cycle Cost Analysis of Alternative Three

ALTERNATIVE FOUR: RECONSTRUCTION WITH AC USING RECYCLED MATERIALS

ANALYSIS PERIOD = 40 YEARS

DISCOUNT RATE = 10 %

YEAR	WORK DESCRIPTION	COST ($)	F	PRESENT WORTH
0	Removal of Existing Pvmt	21,000	1	21,000
0	Reconstruction - AC Section	123,130	1	123,130
10	Seal Cracks	600	.3855	231
10	Full-depth Repairs	15,000	.3855	5,783
15	Full-depth Repairs	15,000	.2394	3,591
15	Seal Cracks	1,200	.2394	287
15	4" AC Overlay	56,000	.2394	13,406
20	Pre-overlay Repairs	20,000	.1486	2,972
25	Seal Cracks	600	.0923	55
27	Full-depth Repairs	15,000	.0763	1,145
30	Seal Cracks	1,200	.0573	69
35	4" AC Overlay	56,000	.0356	1,994
35	Pre-overlay Milling & Repair	32,650	.0356	1,162
1-40	Routine Maintenance	400/yr	9.7791	3,912
		TOTAL		$ 178,737
	SALVAGE VALUE =	-28,000 * .0221 =		- 619
		PRESENT WORTH		$ 178,118
	EQUIVALENT UNIFORM ANNUAL COST =	PW / 9.7791 =		$ 18,214

Figure 25
Example One: Life-Cycle Cost Analysis of Alternative Four

ALTERNATIVE ONE: PARTIALLY BONDED PCC OVERLAY

ANALYSIS PERIOD = 20 YEARS

DISCOUNT RATE = 10 %

YEAR	WORK DESCRIPTION	COST ($)	F	PRESENT WORTH
0	Slab Replacement (12 slabs)	26,400	1	26,400
0	6" PCC Overlay (partial bond)	80,040	1	80,040
7	Joint Seal 3620 ft (1100 m)	7,602	.5132	3,901
10	Localized Repairs 125 yd^2 (104 m^2)	10,000	.3855	3,855
14	Joint Seal 3620 ft (1100 m)	7,602	.263	2,002
1-20	Routine Maintenance	200/yr	8.5136	1,703
		TOTAL		$ 117,901

SALVAGE VALUE = 0 * .1486 = 0

PRESENT WORTH $ 117,901

EQUIVALENT UNIFORM ANNUAL COST = PW / 8.5136 = $ 13,849

Figure 26
Example Two: Life-Cycle Cost Analysis of Alternative One

ALTERNATIVE TWO: LOCALIZED REPAIRS AND SLAB REPLACEMENT

ANALYSIS PERIOD = 20 YEARS

DISCOUNT RATE = 10 %

YEAR	WORK DESCRIPTION	COST ($)	F	PRESENT WORTH
0	Slab Replacement (12 slabs)	26,400	1	26,400
0	Full-depth Patching (14 slabs)	24,990	1	24,990
0	Crack Seal (27 slabs)	1,200	1	1,200
5	Slab Replacement (26 slabs)	57,200	.6209	35,515
5	Full-depth Patching (8 slabs)	14,280	.6209	8,866
7	Joint Seal 3620 ft (1100 m)	1,448	.5132	743
10	Slab Replacement (26 slabs)	57,200	.3855	22,051
10	Full-depth Patching (8 slabs)	14,280	.3855	5,505
14	Joint Seal 3620 ft (1100 m)	1,448	.2633	381
15	Slab Replacement (26 slabs)	57,200	.2394	13,694
15	Full-depth Patching (8 slabs)	1,448	.2394	347
1-20	Routine Maintenance	300/yr	8.5136	2,554
		TOTAL		$ 142,246
	SALVAGE VALUE =	0 * .1486 =		- 0
		PRESENT WORTH		$ 142,246

EQUIVALENT UNIFORM ANNUAL COST = PW / 8.5136 = $ 16,708

Figure 27
Example Two: Life-Cycle Cost Analysis of Alternative Two

5.8.3 Example Three: Asphalt Overlaid Runway Interior. In Section 4, two feasible alternatives are identified for Runway Interior Feature R7C. These are:

Alternative One: Placement of a 2 in. (51 mm) asphalt concrete overlay.

Alternative Two: Milling of 2 in. heater scarification of the top in. (25 mm), and placement of a 2 in. asphalt concrete overlay.

An analysis period of 10 years is used for the life-cycle cost analysis. The overlay placed directly over the existing pavement is assumed to deteriorate more rapidly and require replacement in 8 years (similar to the previous overlay). Placing another overlay also raises the elevation of the runway to the point that the runway lights have to be reset and tapers to the taxiways provided. Therefore, a contingency fee is included.

The costs and present worth calculations are shown in Figures 28 and 29. Equivalent uniform annual costs are also computed. The simplified method of salvage value calculation is utilized.

Based on this economic analysis, Alternative Two is identified as having the lowest life-cycle cost.

ALTERNATIVE ONE: ASPHALT CONCRETE OVERLAY

ANALYSIS PERIOD = 10 YEARS

DISCOUNT RATE = 10 %

YEAR	WORK DESCRIPTION	COST ($)	F	PRESENT WORTH
0	Crack Seal	28,500	1	28,500
0	2 in (50 mm) AC Overlay	215,705	1	215,705
0	Contingency Costs	45,000	1	45,000
3	Crack Seal	28,500	.7513	21,412
8	Crack Seal	28,500	.4665	13,295
8	2 in (50 mm) AC Overlay	215,705	.4665	100,626
8	Contingency Costs	45,000	.4665	20,993
		TOTAL		$ 445,531

SALVAGE VALUE = -161,779 * .3855 = - 62,851

PRESENT WORTH $ 382,680

EQUIVALENT UNIFORM ANNUAL COST = PW / 6.1446 = $ 62,279

Figure 28
Example Three: Life-Cycle Cost Analysis of Alternative One

ALTERNATIVE TWO: MILL, HEATER SCARIFY, AND REPLACE

ANALYSIS PERIOD = 10 YEARS

DISCOUNT RATE = 10 %

YEAR	WORK DESCRIPTION	COST ($)	F	PRESENT WORTH
0	Mill 2 in (50 mm)	62,500	1	62,500
0	Heater Scarify	26,963	1	26,963
0	Replace 2 in (50 mm) AC	200,000	1	200,000
5	Crack Seal	17,000	.6209	10,555
8	Crack Seal	28,500	.4665	13,295
		TOTAL		$ 313,313
	SALVAGE VALUE =	0 * .3855 =		- 0
		PRESENT WORTH		$ 313,313

EQUIVALENT UNIFORM ANNUAL COST = PW / 6.1446 = $ 50,990

Figure 29
Example Three: Life-Cycle Cost Analysis of Alternative Two

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NFGS-02559	Portland Cement Concrete Pavement for Roads and Airfields
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