DEPARTMENT OF THE AIR FORCE
HEADQUARTERS AIR FORCE CIVIL ENGINEER SUPPORT AGENCY

OCT 16 2002

FROM: AFCESA/CES
139 Barnes Drive, Suite 1
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SUBJECT: **Engineering Technical Letter (ETL) 02-16: Design, Construction, Maintenance, and Evaluation of the Pegasus Glacial Ice Runway for Heavy Wheeled Aircraft Operations**

1. Purpose. This ETL provides design, construction, and maintenance details, dimensional criteria, and structural evaluation guidance for operations of heavy wheeled aircraft at the Pegasus Glacial Ice Runway located on the McMurdo Ice Shelf near McMurdo Station, Antarctica. This runway is operated by the U.S. Antarctic Program (USAP) and primarily supports Air Force aircraft. Two potential surface conditions are considered: in the first, aircraft land on an exposed glacial ice runway; while in the second case, operations are conducted from a thin (less than 130 millimeters [5 inches]) processed snow pavement (white ice) overlying the glacial ice. A minimum level of white ice strength is prescribed for the second case. The dimensional criteria are the same for either surface condition. The Pegasus airfield has supported C-130 Hercules and C-141 Starlifter aircraft since 1993 from the exposed glacial ice surface; starting in 2002, C-130, C-141, and C-17 Globemaster III aircraft performed routine operations from the white ice surface.

This criterion, while written specifically for the Pegasus site in Antarctica, is generally applicable to any runway composed of glacial ice or compacted snow (thin layer) over a firm substrate.

Note: The use of the name or mark of any specific manufacturer, commercial product, commodity, or service in this ETL does not imply endorsement by the Air Force.

2. Application: All Department of Defense (DOD) organizations responsible for design, construction, maintenance, and evaluation of the Pegasus Glacial Ice Runway.

2.1. It is anticipated that all of the field measurements and data collection prescribed in this ETL can and will be accomplished by knowledgeable personnel within the USAP and deployed to Antarctica as part of their occupational performance. This does not preclude Air Force certification teams traveling to McMurdo Station to complete an evaluation; however, due to the logistics, coordination, cost, and uncertain nature of travel to and work in Antarctica, it is more likely that the USAP McMurdo Area Airfields Manager will be responsible for following all ETL guidelines for data collection.

2.2. Certification of the runway can only be completed by Air Mobility Command (HQ AMC). It will be the airfields manager's responsibility to deliver all data and measurements, in the format prescribed in this ETL, to the AMC contact (see paragraph 10) or his designee. AMC will review and communicate its findings and decisions back to the airfields manager, who will be responsible for any remedial action to the runway and communicating the runway status (e.g., open, closed, open with restrictions) to all impacted operational elements.

2.2. Authority: Air Force Policy Directive (AFPD) 32-10, *Installations and Facilities*.

2.3. Effective Date: Immediately.

2.4. Ultimate Recipients:

- Air Force civil engineers, USAP, and contractors responsible for planning, design, construction, maintenance, and evaluation of airfields.
- U.S. Army Corps of Engineers (USACE) and Navy offices responsible for planning, design, maintenance, and construction of airfields.

2.5. Coordination: Air Mobility Command, Operations (HQ AMC/CEO).

3. References:

3.1. Air Force:

- AFPD 32-10, *Installations and Facilities*
- Air Force Manual (AFM) 32-1076, *Design Standards for Visual Air Navigation Facilities*

3.2. Army:

- Cold Regions Research and Engineering Laboratory (CRREL) Monograph 98-1, *Construction, Maintenance, and Operation of a Glacial Runway, McMurdo Station, Antarctica*, available at http://www.crrel.usace.army.mil/techpub/CRREL_Reports/reports/M98_01.pdf.
- CRREL Technical Report 153, *Study of the Rammsonde for Use in Hard Snow*
- Waterways Experiment Station Instructional Report GL-92-3, *Description and Application of Dual Mass Dynamic Cone Penetrometer*

3.3. Joint Service:

- Unified Facilities Criteria (UFC) 3-260-01, *Airfield and Heliport Planning and Design*

3.4. American Society for Testing and Materials (ASTM):

- ASTM D1883-99, *Standard Test Method for CBR (California Bearing Ratio) of Laboratory-Compacted Soils*

4. Acronyms.

AFCESA - Air Force Civil Engineer Support Agency

AFPD	- Air Force Policy Directive
ASTM	- American Society for Testing and Materials
CBR	- California Bearing Ratio
CRREL	- U.S. Army Cold Regions Research and Engineering Laboratory
DCP	- dynamic cone penetrometer
DO	- Director of Operations
DOD	- Department of Defense
ETL	- Engineering Technical Letter
ft	- foot
HQ AMC/CEO	- Air Mobility Command, Operations
in	- inch
MAJCOM	- major command
m	- meter
MMLS	- Mobile Microwave Landing System
MOG	- maximum on ground
NAVAIDS	- navigational aid system
PAPI	- precision approach path indicator
PCASE	- Pavement Computer Assisted Structural Engineering
PLZ	- prepared landing zone
REILS	- runway end identifier lights
RSP	- Russian snow penetrometer
TACAN	- Tactical Air Navigation
VFR	- visual flight rules
UFC	- Unified Facility Criteria
USACE	- U.S. Army Corps of Engineers
USAP	- United States Antarctic Program

5. Definitions. Most airfield definitions applicable to this ETL can be found in UFC 3-260-01, *Airfield and Heliport Planning and Design*. Definitions critical to or unique to this ETL are given below.

5.1. *California Bearing Ratio (CBR):* An index test of soil strength determined using a 1935.5-square-millimeter (3-square-inch) piston forced into the soil. The load required to achieve a 2.5- or 5-millimeter (0.1- or 0.2-inch) penetration (whichever provides lowest CBR value) is compared to a standard load for similar penetrations into a well-graded crushed aggregate. The test is widely used for military structural airfield assessment, and test procedures may be found in American Society for Testing and Materials (ASTM) D1883-99, *Standard Test Method for CBR (California Bearing Ratio) of Laboratory-Compacted Soils*.

5.2. *Dynamic Cone Penetrometer (DCP):* The DCP is a portable soil field test device to allow rapid measurement of soil strength. An 8-kilogram (17.6-pound) or 4.6-kilogram (10.1-pound) sliding hammer is used to drive a 60^o, 20-millimeter (0.8-inch) diameter cone into the soil. The DCP strength index, in units of millimeters per blow, is calculated as:

$$\text{DCP Index} = (P/N)\,F$$

where P is the accumulated cone penetration after each set of N hammer blows, and F is a configuration factor (F=1.0 for 8-kilogram hammer DCP; F=1.742 for 4.6-kilogram hammer DCP). The DCP strength index has been correlated to other more time-consuming tests like CBR and is widely used in the military for expedient soil strength assessments for roads and airfields. A complete description of the DCP and its use are contained in U.S. Army Waterways Experiment Station Instructional Report GL-92-3, *Description and Application of Dual Mass Dynamic Cone Penetrometer*. See Attachment 1 for penetrometer user information.

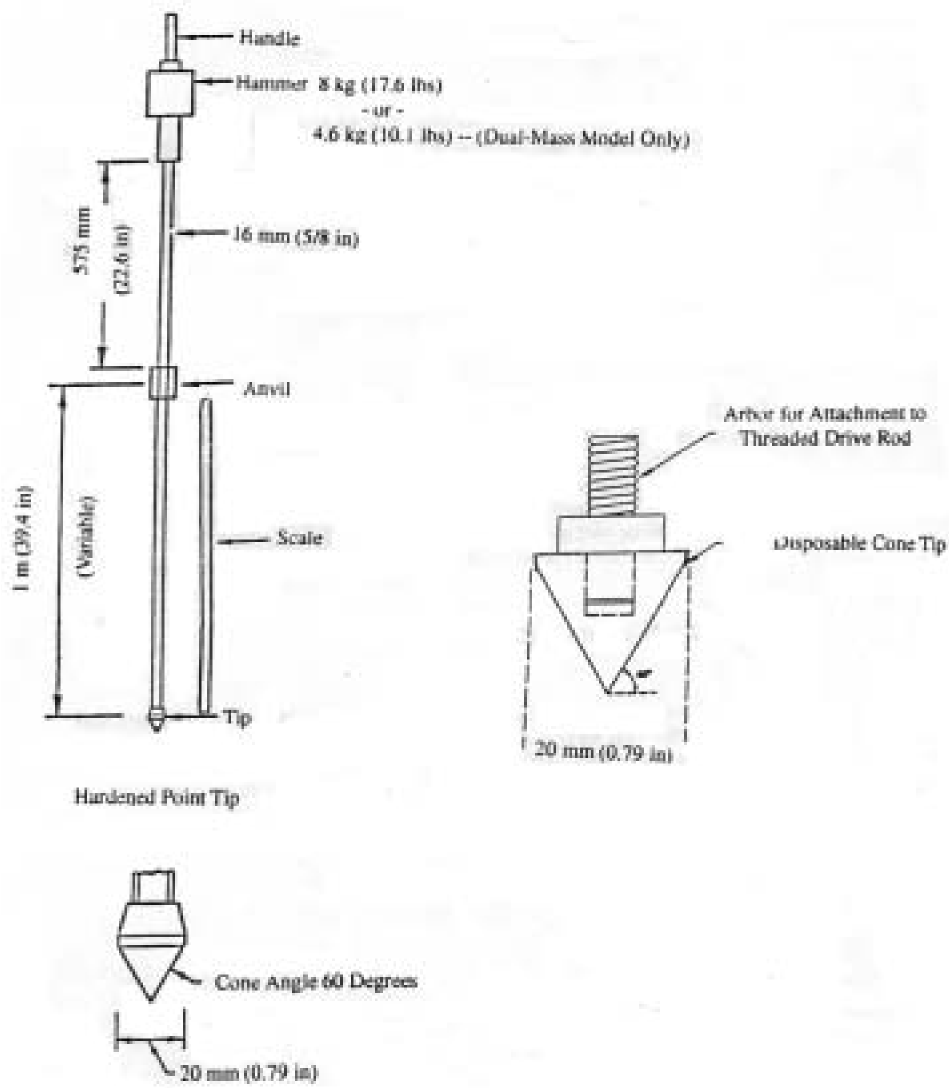

Figure 1. Dynamic Cone Penetrometer

5.3. *Glacial Ice Runway Surface:* A durable weather- and abrasion-resistant surface generated from level grading of natural glacial ice (alpine-, continental-, or shelf-type) that is derived from naturally consolidated snow. (For a more detailed description see U.S. Army Cold Regions Research and Engineering Laboratory [CRREL] Monograph 98-1,

Construction, Maintenance, and Operation of a Glacial Ice Runway, McMurdo Station, Antarctica, available at
http://www.crrel.usace.army.mil/techpub/CRREL_Reports/reports/M98_01.pdf.

5.4. *Non-Instrument Runway:* A runway intended for operating aircraft under visual flight rules (VFR). Routine operations at the Pegasus runway only occur when sunlight is present; this is roughly from late August until late March each year in the McMurdo area.

5.5. *Prepared Landing Zone (PLZ):* For the purposes of this ETL, a prepared landing zone (PLZ) refers to a landing zone that is constructed to support routine and moderately frequent (average 1 to 2 flights per day) wheeled cargo aircraft traffic, with no adverse affect to airframes, but that is not paved with traditional construction materials (i.e., asphalt or concrete). The amount of engineering effort required to develop a PLZ depends on the planned operation and the existing surface and weather conditions. Options for surface preparation are governed by the material present at the site and may include at the Pegasus site, grading, planing, roller compaction, tilling, and vibratory compaction.

5.6. *Processed Snow Pavement:* A durable weather- and abrasion-resistant surface made from grading and processing (e.g., compaction or tilling) natural snow that overlies a firm established base like glacial ice. For the support of heavy wheeled aircraft, the processed snow must have reached a condition where it can be called white ice.

5.7. *Russian Snow Penetrometer (RSP):* The RSP is a portable test device to allow rapid measurement of snow strength. A 1.75-kilogram (3.85-pound) sliding hammer is dropped from a height of 500 millimeters (19.7 inches) to drive into the snow a 30^o cone with a maximum diameter of 11 millimeters (0.4 inch). During a test, penetration distance and the number of blows to produce it are recorded. The RSP index, in units of kilograms, is calculated as:

$$\text{RSP Index} = (W\ h\ n\ L^{-1}) + W + Q$$

where W is the mass of the drop hammer (kilograms), h is the height of the hammer drop (millimeters), n is the number of hammer blows to generate L (millimeters) penetration, and Q is the total mass of the penetrometer (kilograms) less its hammer. Details of penetrometer testing in processed snow can be found in CRREL Technical Report 153, *Study of the Rammsonde for Use in Hard Snow*. See Attachment 1 for penetrometer user information.

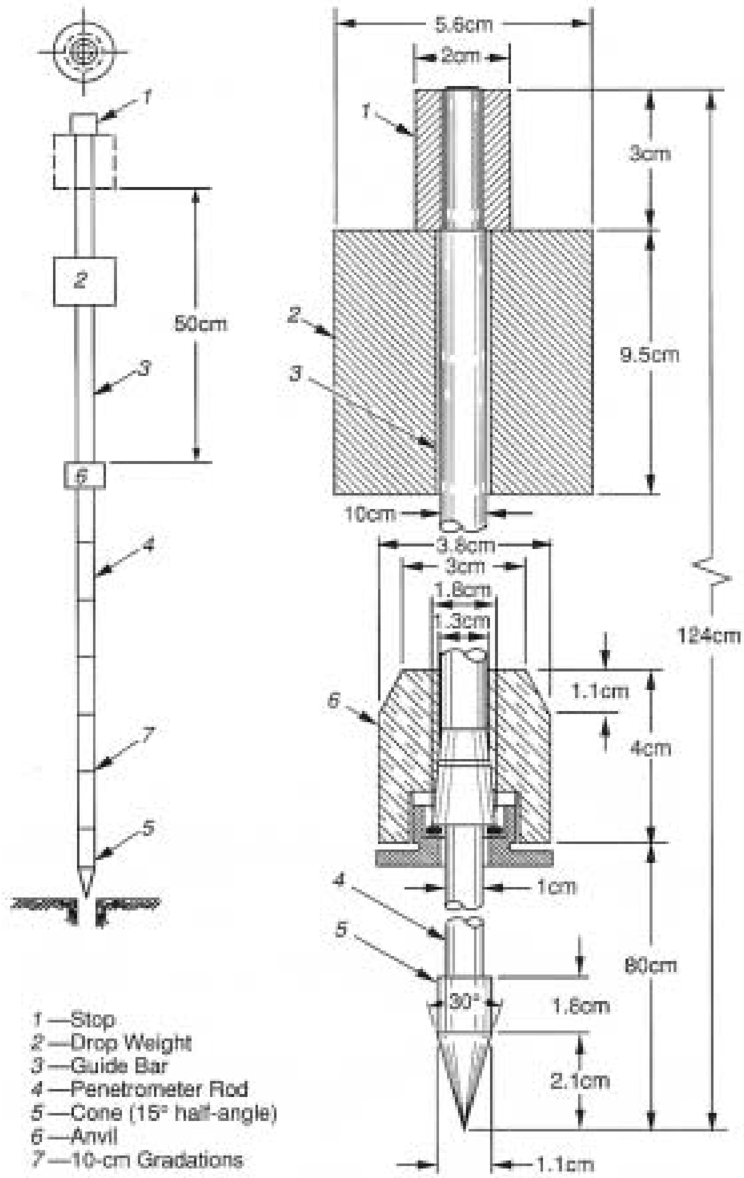

Figure 2. Russian Snow Penetrometer

5.8. *Seasonal Operations:* Normally, short-term operations conducted in support of specific local activities. Seasonal operations denote aircraft activities being confined to certain periods of the year when flight and runway conditions are most favorable and when airlift is required. The Pegasus runway is only operated when air temperatures are above -50 °C (-58 °F) and when sunlight is present.

6. Dimensional Criteria. Details for establishment of airfields for the support of routine operations of Air Force aircraft can be found in UFC 3-260-01. The Pegasus runway is unique in a number of ways (e.g., seasonal operation only, low volume of air traffic, extremely remote location, sited on level "featureless" ice shelf, limited resources available for construction and maintenance). The criteria are based for the most part on Class B runway requirements.

6.1. Table 1 provides dimensional criteria for the layout and design of the PLZ at the Pegasus site. Minimum runway length is prescribed by the MAJCOM Director of Operations (DO), but should be 3050 meters (10,000 feet) for fully loaded aircraft operations, assuming that the braking conditions are adequate. When the Pegasus PLZ exists with a thin processed snow pavement, the same length requirements exist, **assuming** that the processed snow pavement meets its structural requirements. Note that runway strength, as measured by DCP or RSP, can vary as a function of air temperature and solar insulation. Properly executed maintenance operations can mitigate this deterioration and keep strength at or above minimum levels. Runway lengths shown in Table 1 also recognize that the Pegasus PLZ is essentially at sea level.

Table 1. Pegasus Runway Dimensional Requirements for C-130, C-141, and C-17 Operations

Description	Glacial Ice or Processed Snow (White Ice) Operating Surface	Remarks
Length (minimum)	See Remarks	Minimum runway length will be determined by the MAJCOM/DO for the most critical aircraft in support of the mission. At the Pegasus runway, a runway length of 3050 m (10,000 ft) is considered adequate for all routine operations with C-130, C141, and C-17 aircraft.
Width	46 m (150 ft)	
Width of shoulders (minimum)	7.5 m (25 ft)	Remove all snow berms and snow drifts in shoulder areas. All white ice in shoulders should be prepared to required runway strength standards and, for a white ice surface, be less than 130 mm (5 in) in depth.
Longitudinal grade	2% maximum (up or down)	The maximum grade of any tangent, as well as the total elevation change from one threshold of the runway to the other, should not exceed 2%.

Longitudinal grade change	No grade change greater than 0.5% is to occur within 300 m (1000 ft) from the runway end	Hold to minimum practicable. Grades may be both positive and negative but must not exceed the limit specified. Applies to runway and shoulders.
Rate of longitudinal grade change	Maximum 0.167% per 30 m (100 ft)	Grade changes should be held to a minimum and should be gradual. Minimum distance between grade changes is 61 m (200 ft). Grade changes cannot exceed 1.5% measured at 61-m (200-ft) intervals. Applies to runway and shoulders.
Transverse grade of runway	1.5% maximum	Transverse grades can be flat, uniform slope, or crowned at the centerline (a crowned centerline is preferred).
Transverse grade of shoulders	2% maximum (down)	For an exposed ice surface, transverse grades should slope down from the runway edge. A white ice surface may slope upward to a maximum extent of 1%.
Width of graded area	Minimum 12 m (40 ft)	The graded area is measured from the outside edge of the shoulder. Graded area should have no more than 100 mm (4 in) of loose snow cover.
Transverse grade of graded area	2% maximum (up or down)	Ideally, graded area slope (up or down) should match that of runway shoulders.
Width of lateral clear area	79 m (260 ft)	The lateral clear area is measured outward from the outside edge of the graded area.
Transverse grade of lateral clear area	12% maximum (up)	Requirement is applied to imaginary plane extending from the outer edge of the shoulder outward a distance of 49 m (160 ft). No object or surface feature may penetrate this imaginary plane.
Width of primary surface	120 m (400 ft)	Primary surface is measured perpendicularly outward from runway centerline and incorporates the runway, shoulder, graded area, and clear area.

6.2. Shoulders are required along each outside edge of the runway. They must be prepared to the same strength as the runway surface (and be of the same surface material: white ice or glacial ice) and be free of obstacles. Shoulder geometric requirements are presented in Table 1. Figure 1 shows the typical layout, including shoulders, and lateral and end clear areas. Turns may take place on the prepared surface, including the shoulders.

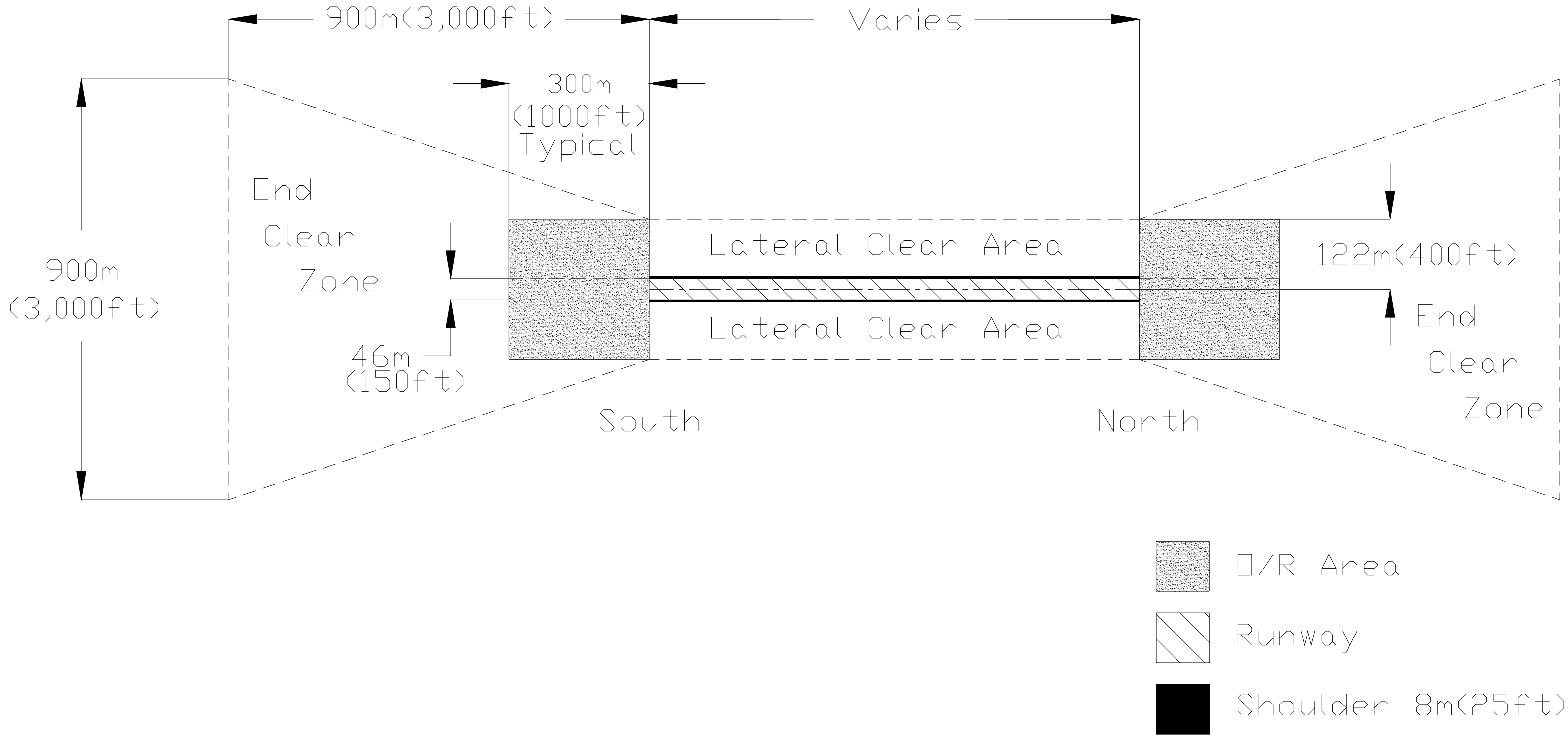

Figure 3. Typical Layout Arrangements for Pegasus Runway (Not to Scale)
Note: North runway overrun does not currently exist at the Pegasus runway.

6.3. A runway overrun is required at the south end of the runway. The overrun must be 300 meters (1000 feet) in length and constructed to the same dimensional and structural standards as the runway surface. This limits take-offs and landings at the Pegasus runway to the south only (which has been the practice since the runway opened in 1993). If conditions warrant routine operations from the south as well (landing and take-off to the north), overruns are required at both ends of the runway.

6.4. Lateral and runway end clear areas are required and their dimensions are given in Table 2. The layout is shown in Figure 1.

Table 2. Pegasus Runway Overrun and End Clear Area Requirements for C-130, C141, and C-17 Operations

Description	Glacial Ice or Processed Snow (White Ice) Operating Surface	Remarks
End clear area length	915 m (3000 ft)	Measured along the extended runway centerline. Begins at the runway threshold.
Width at inner edge of end clear area	242 m (800 ft)	Centered about runway centerline. Begins at runway threshold.
Width at outer edge	900 m (3000 ft)	Centered about runway centerline.
Runway overrun area	See Remarks	The runway overrun area falls within the runway end clear zone. The overrun area will be 300 m (1000 ft) long and have a transverse section matching the runway (i.e., include shoulder, graded area, and lateral clear area). See Table 1 for transverse dimensional criteria. The maximum longitudinal grade (up or down) in the overrun area is 2%.
Approach departure clearance surface	50:1	Approach-departure clearance surface begins at the runway thresholds at the same elevation as the centerline elevation and extends away from the runway. During flight operations, no mobile or fixed object may penetrate this imaginary plane within the end clear area.

6.5. Taxiways, if present, will have surface strength properties matching those of the runway. Dimensional criteria for taxiways are given in Table 3.

Table 3. Pegasus Taxiways (If Present) Dimensional Requirements for C-130, C-141, and C-17 Operations

Description	Glacial Ice or Processed Snow (White Ice) Operating Surface	Remarks
Width	23 m (75 ft) minimum	
Radius of curves (C-130, C-141, C-17)	23 m (75 ft) minimum	Curves in taxiway must be no tighter than the listed minimum turning radii, measured along the taxiway centerline. Fillets at runway/taxiway/apron turns and/or intersections must be 30 m (100 ft) minimum radii.
Width of shoulder	7.5 m (25 ft)	Remove all snow berms and snow drifts in shoulder areas. Snow in shoulders will be prepared to the same strength as the taxiway.
Longitudinal grade	3% maximum	Hold to minimum practicable. Grades may be either positive or negative. Applies to taxiway and shoulders.
Rate of longitudinal grade change	1% maximum over 30 m (100 ft)	Grade changes should be held to a minimum and should be gradual. Minimum distance between grade changes is 150 m (500 ft). Grade changes cannot exceed 1% measured at 30-m (100-ft) intervals. Applies to taxiway and shoulders.
Transverse grade of taxiway	3% maximum	Transverse grades can be flat, uniform slope, or crowned at the centerline (a crowned centerline is preferred).

Transverse grade of shoulders	3% maximum	For an exposed ice surface, transverse grades should slope down from the taxiway edge. A white ice surface may slope upward to a maximum extent of 1%.
Runway clearance	75 m (250 ft)	Measured from the runway centerline to near edge of the taxiway.
Infield area		All areas located between the runway and taxiways must be cleared of obstructions.
Clearance to fixed or mobile obstacles	61 m (200 ft)	Measured from the taxiway centerline.
Width of clear area	50 m (165 ft)	Clear area is measured perpendicularly from the runway centerline. No object or surface feature may penetrate this imaginary plane.
Transverse grade of clear area	12% maximum (up)	Grades may slope up or down.

6.6. Aprons, if present, will have surface strength properties matching those of the runway. Dimensional criteria for aprons are given in Table 4 and plan views of suggested apron configurations are provided in Figure 2. **Note:** The typical operation of this runway is for an aircraft maximum-on-ground (MOG) of one. Apron, parking areas, or parallel taxiway is required if MOG will be greater than one.

Table 4. Pegasus Site Apron Requirements for C-130, C-141, and C-17 Operations

Description	Glacial Ice or Processed Snow (White Ice) Operating Surface	Remarks
Apron size	Varies	Sized to accommodate number of aircraft on ground. Maximum visibility and minimum wingtip clearance must be maintained at all times. As a minimum, the pilot must be able to clearly see all parked aircraft when taxiing.
Apron grade	3% maximum	Ideally, uniform grade should exist over entire apron area.

Width of shoulder	7.5 m (25 ft)	Remove all snow berms and snow drifts in shoulder areas. Snow in shoulders will be prepared to the same strength as the apron.
Transverse grade of shoulders	3% maximum (down)	For an exposed ice surface, transverse grades should slope down from the runway edge. A white ice surface may slope upward to a maximum extent of 1%.
Runway clearance	122 m (400 ft)	Measured from the runway centerline to the near edge of the parking apron
Clearance to fixed or mobile obstacles	38 m (125 ft)	Measured from the outer edge of the apron.
Transverse grade of clear area	12% maximum (up)	Grades may slope up or down.
Wingtip clearance	15 m (50 ft)	Parked and taxiing aircraft must maintain 15-m (50-ft) wingtip clearance at all times.

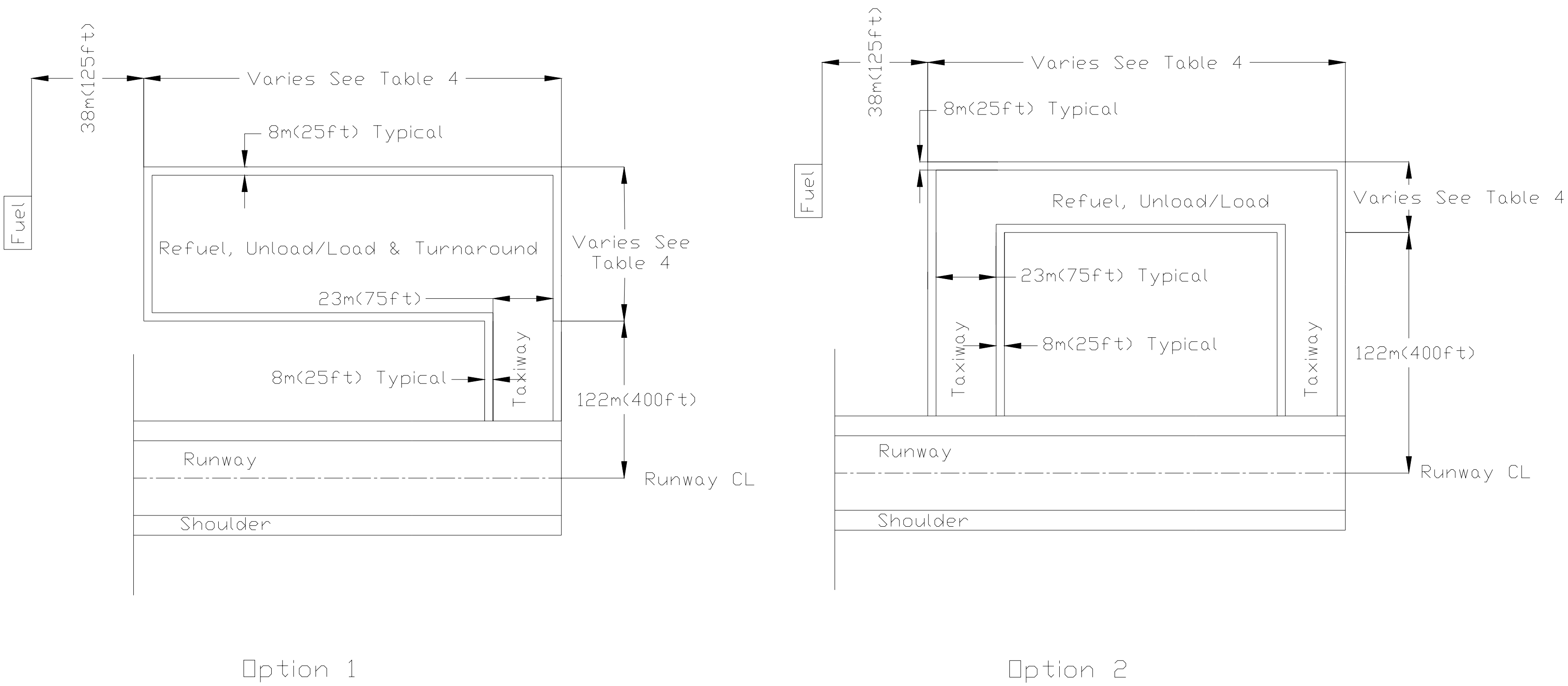

Figure 4. Typical Layout Arrangements for Taxiway and Apron (Not to Scale)

6.7. Cross-section views of the runway, taxiway, and apron—showing the dimensions from Tables 1, 2, and 3—are shown in Figure 5.

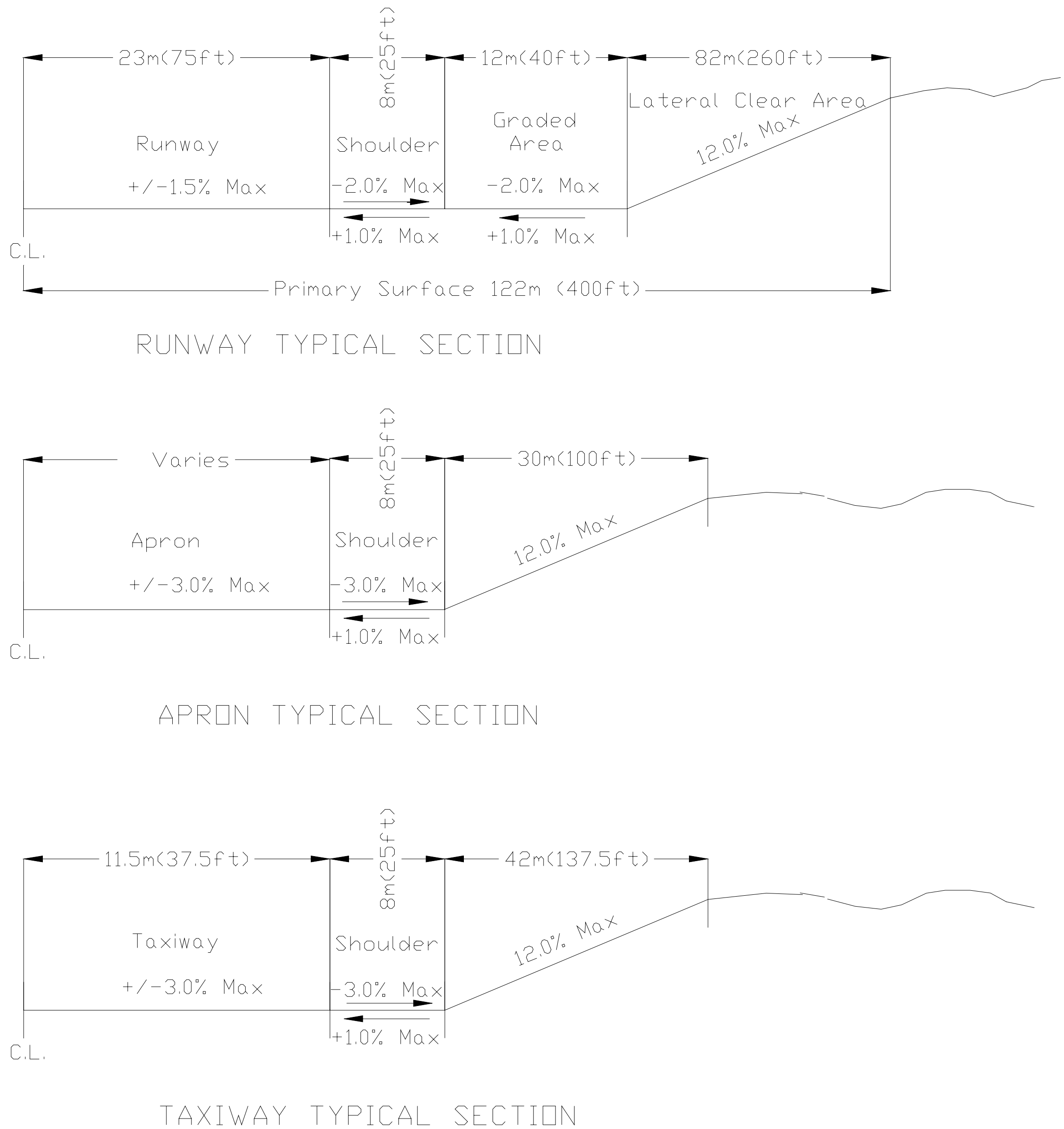

Figure 5. Typical Cross-section Dimensions for Runway, Taxiway, and Apron (Not to Scale)

7. Structural Criteria

7.1. Annually, before commencing aircraft operations, the Pegasus runway will be evaluated following the structural evaluation criteria outlined in this ETL. In addition, the airfields manager is responsible for interim evaluations of localized repairs.

7.2. Glacial Ice Operating Surface.

7.2.1. Glacial Ice Runway Surface Evaluation—Deformation Failure. The glacial ice surface must be shown to be capable of supporting C-130, C-141, and C-17 contact pressure levels for heavy wheeled aircraft without compressive or shear failure. These capacities will be demonstrated by one of the two following methods, depending on the circumstances: proof rolling to detect zones of weakness, or the experience of past operations.

7.2.1.1. Proof Rolling.

7.2.1.1.1. The primary source of ice weakness at the Pegasus site is caused by melt and re-freeze features. When they occur, they commonly show no surface expression and may give the runway a deceptive appearance of strength. Rigorous adherence to prescribed maintenance procedures can avoid such melt/re-freeze problems (see CRREL Monograph 98-1 for maintenance procedures). If there is any doubt, or if the conditions described in paragraph 7.2.1.1.2 apply, the runway must be tested for structural strength.

7.2.1.1.2. Proof rolling tests are required if the surface temperature in the ice (measured at a depth of 10 millimeters [0.5 inch]) rises to or above –4 °C (25 °F) (as confirmed by solar-shielded continuously recording temperature probes buried in the ice). If ice temperatures reach or exceed –4 °C, the potential exists for subsurface melt-pool formation and the runway surface must be inspected for such potential melt-damaged areas by proof rolling. The testing will be performed with pneumatic tire(s) having a minimum inflation pressure of 7.7 kilograms per square centimeter (760 kilopascals or 110 pounds per square inch). The vehicle should have a minimum individual tire load of 16,000 kilograms (35,000 pounds). Coverage should be at no greater than 1-meter (3-foot) lateral spacing over the entire width of the runway and shoulder surface. Successful proof rolling will generate no ice cracking that results in a removable ice piece greater in size than 0.3 meter by 0.3 meter by 0.05 meter deep (12 inches by 12 inches by 2 inches deep). Any defective areas discovered will be removed, repaired, and retested according to the process outlined in Attachment 2.

7.2.1.2. Past Operations. Previous aircraft operations at the Pegasus runway have demonstrated that the existing ice surface has sufficient compressive strength to support aircraft with tire pressures up to 13.7 kilograms per square centimeter (1350 kilopascals or 195 pounds per square inch). If aircraft operations were successfully supported by the Pegasus runway in the immediately previous flight period (as confirmed by close visual inspection of the runway for damage), and as long as the near-surface ice temperature has not risen to or exceeded –4 °C since the last flight period (as confirmed by continuously recording temperature probes buried in the ice), the ice surface will be considered adequate for aircraft with tire pressures up to the magnitude of the maximum operated during the prior flight period. If previous aircraft operations were not successfully supported, needed repairs and re-certification of the runway must be accomplished before further aircraft operations.

7.2.2. Glacial Ice Runway Surface Evaluation—Creep Failure. Long-term parking at warm ice temperatures can lead to creep deformation of the glacial ice. At ice temperatures below –4 °C creep deformation is relatively slow. Since the Pegasus PLZ is operated principally as a "turn-around" runway (i.e., arriving aircraft debark within a few hours, spending limited time onsite), it is expected that creep deformation will be negligible. However, if aircraft will be parked for extended time periods they will have to be moved periodically to avoid any difficulty during the initial rollout. It is recommended that no more than 25 millimeters (1 inch) of deformation occur below a parked aircraft tire. In general, this limit will be reached in 1 hour at an ice temperature of -2.5 °C (27.5 °F), 2 hours at -5 °C (23 °F), and 3 hours at -10 °C (14 °F).

7.2.3. Glacial Ice Runway Surface Evaluation—Flexural Failure.

7.2.3.1. The ice sheet at the Pegasus site is approximately 30 meters (100 feet) thick. Depending on the temperature, and crystallographic structure and impurities content of the ice, this ice has flexural strength on the order of 5 to 10 kilograms per square centimeter (490 to 980 kilopascals or 75 to 150 pounds per square inch). The large thickness of the ice sheet reduces the bending stresses in response to heavy wheeled aircraft to levels that can easily be carried by the ice. A Pavement Computer Assisted Structural Engineering (PCASE) analysis routine for rigid Portland cement concrete, modified for glacial ice, was used to determine the minimum thickness of glacial ice needed to support the heaviest aircraft load (a fully burdened C-17) without flexural cracking. To be conservative, a flexural strength of only 0.4 kilogram per square centimeter (39.2 kilopascals or 5.7 pounds per square inch) was used (this value is based on the weakest ice found in the area). Also, the sub-base material for this analysis is water, since the Pegasus runway is floating on the sea. The results indicate that a C-17 at 263,600 kilograms (580,000 pounds) gross load requires an ice thickness of 2.25 meters (7.4 feet) for a safety factor of 1.0. Given that impurities and closed cracks certainly exist in the ice, we recommend a factor of safety of 3.0. Thus, the Pegasus runway should have an ice thickness of at least 6.8 meters (22.3 feet) to support the anticipated aircraft and loads.

Note: Sea ice has a much greater flexural strength than glacial ice so a significantly thinner layer of sea ice is sufficient to support aircraft.

7.2.3.2. The 30-meter (100-foot) thickness of ice presently at the site now is more than adequate for all anticipated aircraft to operate on the runway; however, should the site experience appreciable thinning, or if this ETL is to be used for a site or aircraft other than the C-130, C-141, or C-17, a new analysis is prudent. (Software specifically tailored for ice is currently under development to simplify this task.)

7.3. Thin White Ice Operating Surface.

7.3.1. White Ice Pavement Thickness. This ETL is written for a maximum white ice pavement thickness of 130 millimeters (5 inches). This limitation to white ice thickness reflects the current level of understanding of its performance as a pavement for C-130, C-17, and C-141 aircraft. If white ice pavement thickness present exceeds 130 millimeters, one of the following actions must be taken:

7.3.1.1. Grade the surface back to the desirable thickness. (Grading should be done with a tool that avoids damage to the underlying material, e.g., a sharp-edge, slow-moving grader mouldboard blade.)

7.3.1.2. Contact the person(s) listed in paragraph 11 for recommendations on how to proceed.

7.3.2. White Ice Runway Surface—Deformation Failure. It is required that the glacial ice (surface and flexural characteristics) be certified (paragraph 7.2 et seq.) as part of certification of a thin processed snow operating surface at the Pegasus PLZ. Being a thin processed snow pavement overlying a thick and sufficiently strong base, the principal structural requirement of the white ice is its ability to support tire contact pressures.

7.3.3. White Ice Runway Surface—Snow Pavement Strength Determination.

7.3.3.1. A penetration resistance index will be used as the basis for evaluation of snow strength. Measurements may be taken with either a DCP (see paragraph 5.2) or an RSP (see paragraph 5.7). See Attachment 1 for test procedures for both devices. The correlation between DCP and RSP index strengths is shown in Figure 6. The correlation between DCP and the traditional pavement strength index—CBR, developed in soils—is shown in Figure 7. A correlation by calculation has been prepared to relate the RSP and CBR indices, as shown in Figure 8.

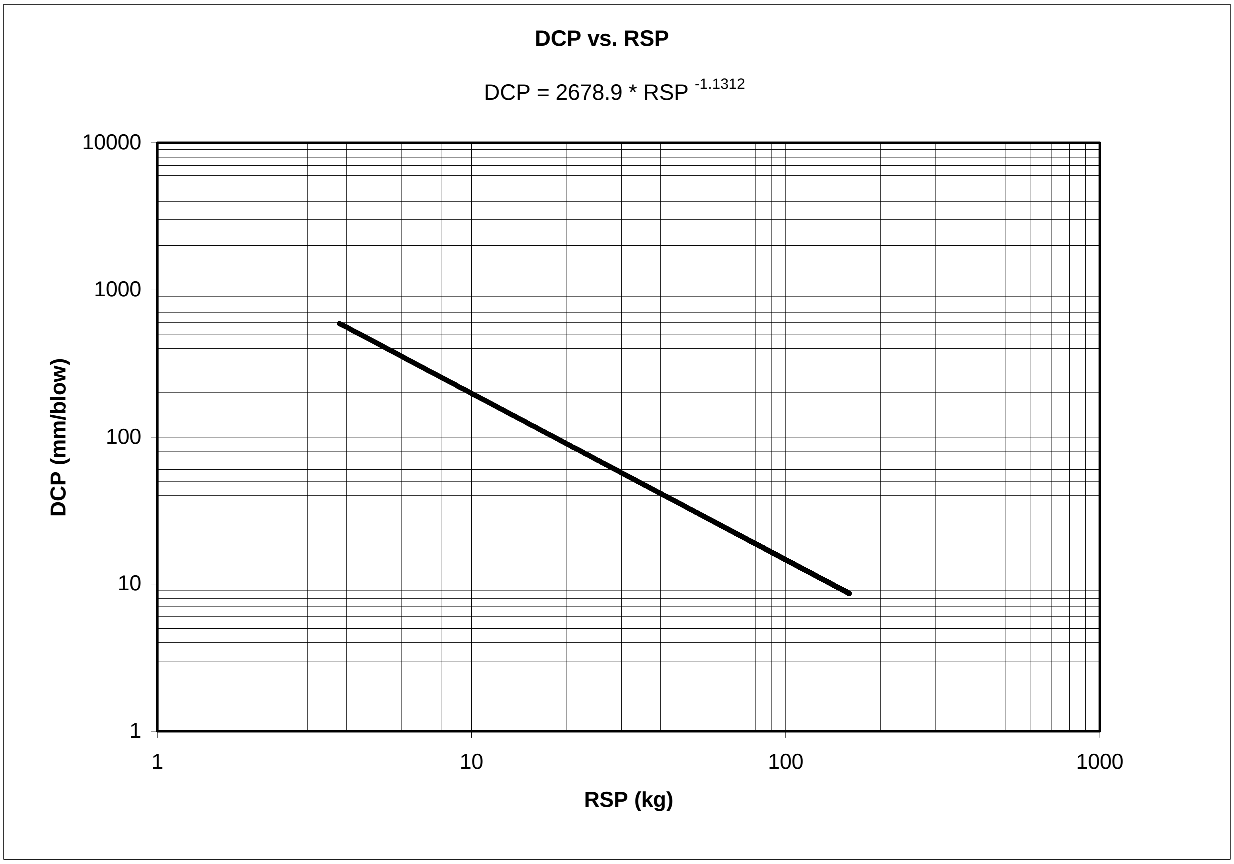

Figure 6. Correlation Between RSP and DCP

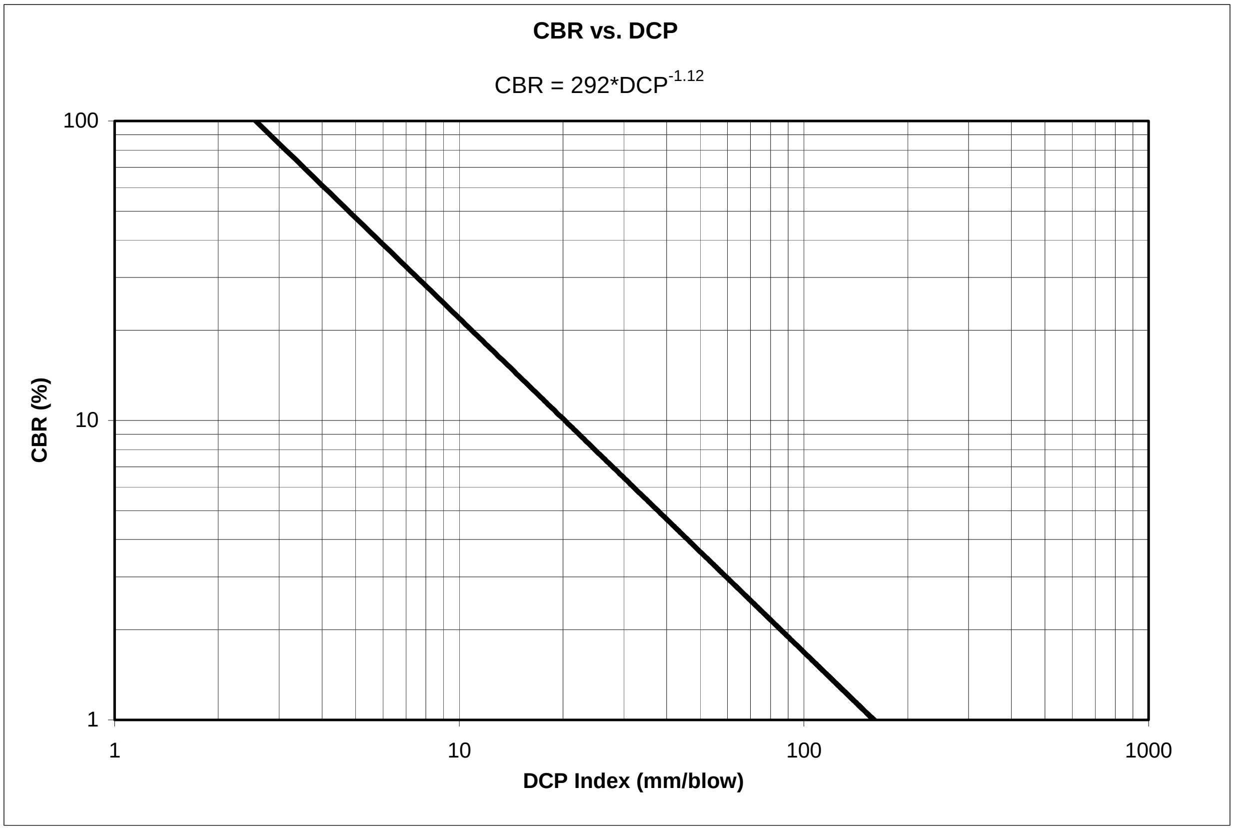

Figure 7. Correlation Between DCP and CBR

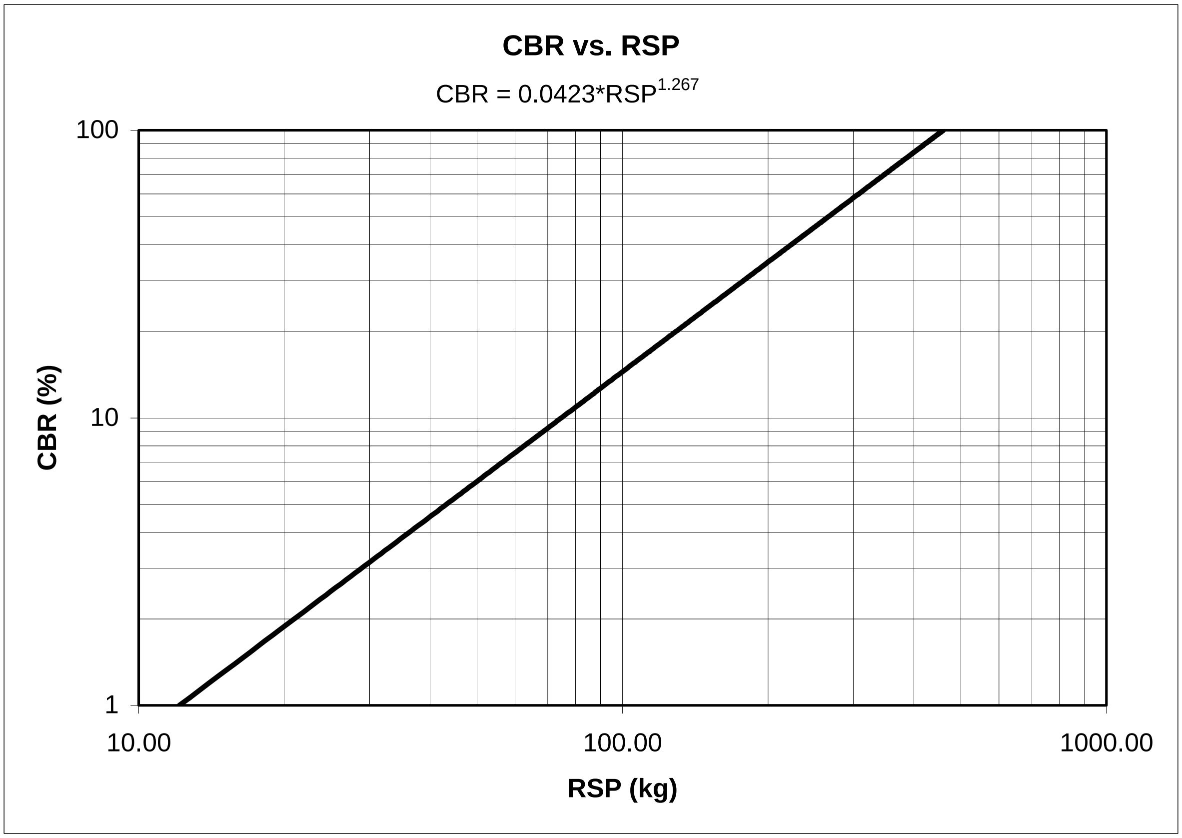

Figure 8. Correlation Between CBR and RSP

7.3.3.2. Performance of a strength survey should follow the procedure given in Attachment 3. For the runway to be considered adequate for aircraft operations, two conditions must be met, as described in paragraphs 7.3.3.2.1 and 7.3.3.2.2.

7.3.3.2.1. The average of all individual penetrometer test site values must match or be stronger than the required mean strength value listed in Table 5 and shown graphically in Figure 9.

7.3.3.2.2. Eighty-five percent of the individual penetrometer test site values must match or be stronger than the lower strength limit values given in Table 5. However, if the majority of the 15% of values that do not meet the lower strength limit are localized, then maintenance activities are required in this area to increase its strength.

Table 5. Minimum Snow Strength Required for White Ice Pavement

Aircraft	Mean RSP Index	Lower RSP Strength Limit	Mean DCP Index	Lower DCP Strength Limit	Mean CBR Index	Lower CBR Strength Limit
C-130[1]	55	45	30	37	6.5	5
C-17[2]	60	46	26	35	7.5	5.5
C-141[3]	67	49	23	33	9	6

[1] Tire pressure = 655 kilopascals (95 pounds per square inch)
[2] Tire pressure = 1068 kilopascals (155 pounds per square inch)
[3] Tire pressure = 1344 kilopascals (195 pounds per square inch)

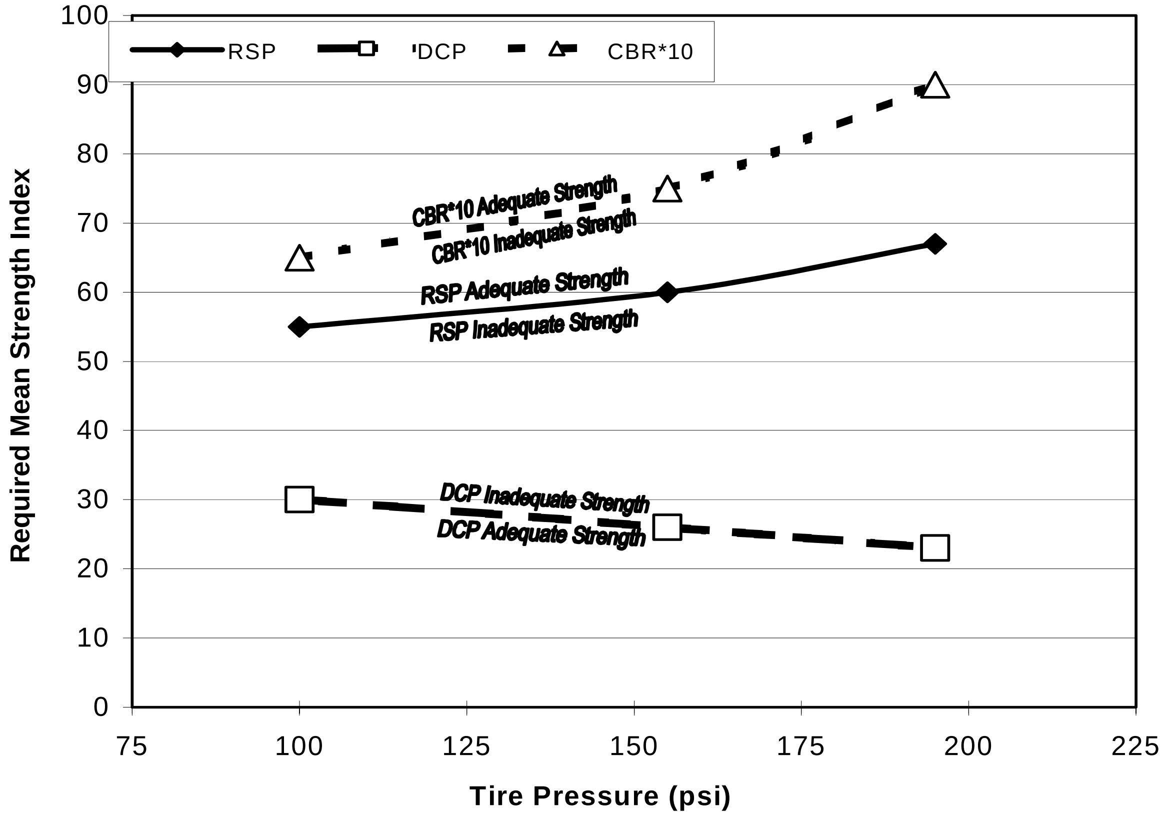

Figure 9. Strength Criteria for White Ice Pavement

7.3.3.3. Attachment 3 suggests a graphical method of quickly assessing the distribution of strength measurements using the *Ice Runway Strength Survey Tool* program (contact the individuals listed in paragraph 10 for a copy of this Microsoft® Excel-based program). **Note:** This approach makes it easier to locate regions of substandard snow strength so that maintenance and repair activities can be quickly focused on trouble spots.

7.3.4. White Ice Runway Surface—Allowable Aircraft Loads/Contact Pressures.

7.3.4.1. Physical testing and aircraft validation activities at the Pegasus PLZ during the 2001-2002 austral summer season (November to March) established the minimum thin snow pavement strength levels for C-130, C-141, and C-17 operations. These are shown in terms of several parameters in Table 5. Note that with a thin processed snow pavement over a strong base material, white ice strength requirements are sensitive to aircraft contact pressure (tire pressure) but quite insensitive to aircraft gross load (since tire and gear load is being supported by the base material). Thus, Table 5 values are for fully loaded, or partially loaded, aircraft operating at the noted tire pressures.

7.3.4.2. The allowable gross load and contact pressure will be applicable to aircraft both landing and taking-off. These criteria are based on a condition of negligible surface deformation or rutting. Negligible is defined here as surface damage in isolated areas and not exceeding 25 millimeters (1 inch) in depth. The values in Table 5 and Figure 9 are conservative with respect to the vertical bearing load of wheeled aircraft; the values chosen ensure that surface deformations do not occur as a result of other aircraft loads, particularly shear loading of the white ice when aircraft brake or turn sharply.

8. Markings and Navigational Aid System (NAVAIDS).

8.1. The Pegasus runway is a VFR-only facility, and is operated solely during daylight. However, due to its unconventional appearance (white surface, white surroundings), for compatibility with standard pilot experience, and for periods where landings are required but weather conditions are less than ideal, markings and NAVAIDS are required. Initial operation of the Pegasus runway was accomplished with an absolute minimum of markings and no NAVAIDS. The use of both markings and NAVAIDS has evolved over the years, and is expected to continue into the future.

8.2. It cannot be overstated that adopting the full extent and type of markings and NAVAIDS found at a conventional airport would create an unmaintainable runway that would be buried by drifting snow in a few seasons. Nor is it necessary for the Pegasus runway to have the full complement of available markings and NAVAIDS. Since the airspace is not congested and there are no nearby topographic or human-made obstacles, it is operated as a VFR facility.

8.3. Minimizing the number and surface area of markings is desirable for the purpose of reducing runway maintenance and increasing runway availability and longevity. Figure 10 shows the layout of the Pegasus runway, including the positions of lead-in, lead-out, ground plane, distance remaining, and threshold and mid-point markers. All markers should be made of durable, lightweight materials. Support posts must be frangible and present a tiny cross-section to the wind to minimize snow drifting, which should be accomplished by a small diameter and a minimum number of posts; bamboo canes are currently used with good results. The markers are ideally of a mesh material to minimize the impedance of the wind, both to limit wind loading on the support posts and, more importantly, to reduce snow drifting. Ideally, the base of a marker should be more than 1 meter (3 feet) above the snow surface to avoid snow drifting. This height must be balanced against the need for adequate clearance between the base of an aircraft wing, engine, or propeller and the top of the marker. Currently, black- and orange-colored plastic mesh fencing material is used for markers. Note that all markings are well above the runway surface, and that no markings are present to depict the runway centerline, shoulder edges, landing zone, or thresholds.

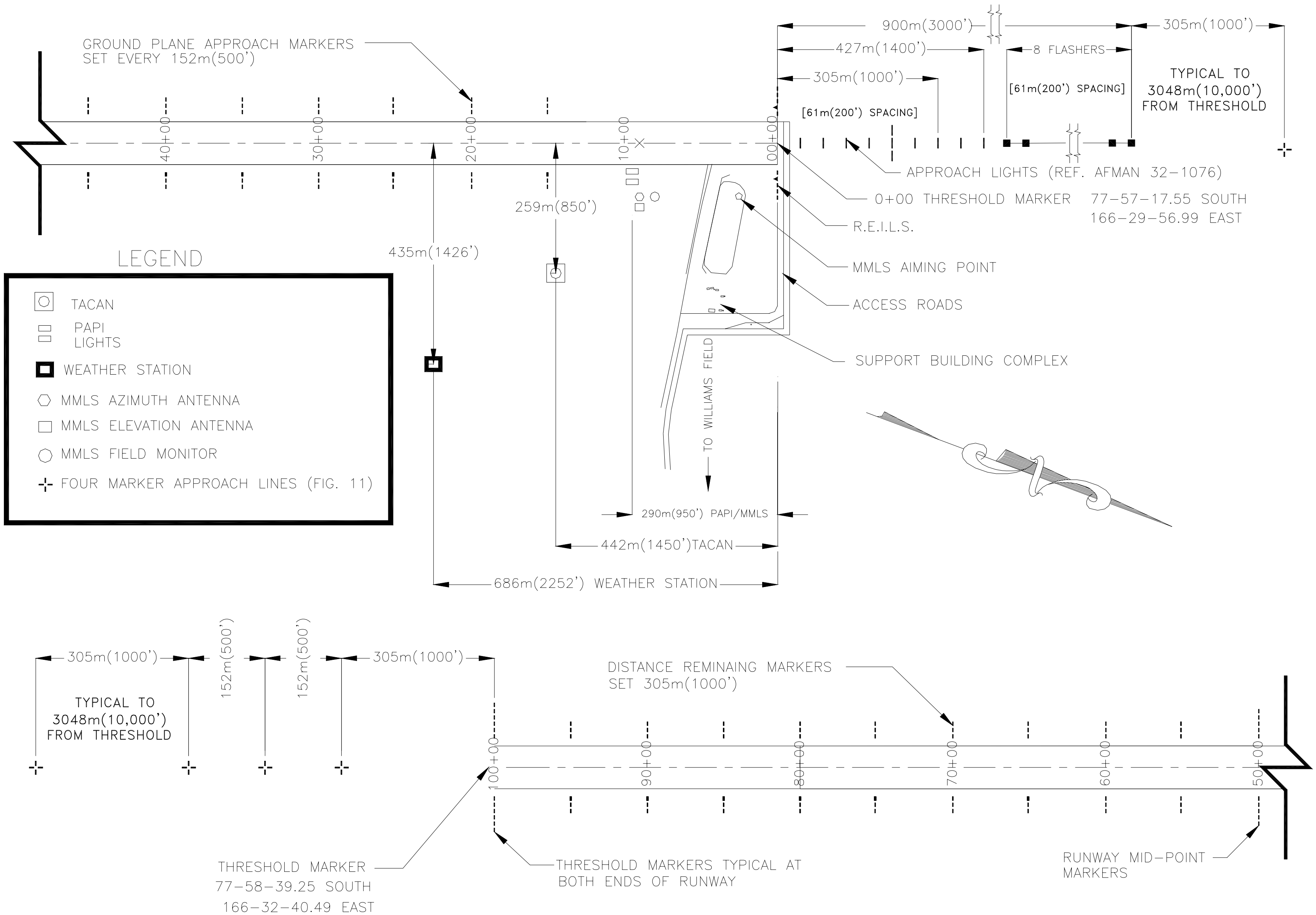

Figure 10. Pegasus Runway Layout with Dimensions, Showing Markings and NAVAIDS

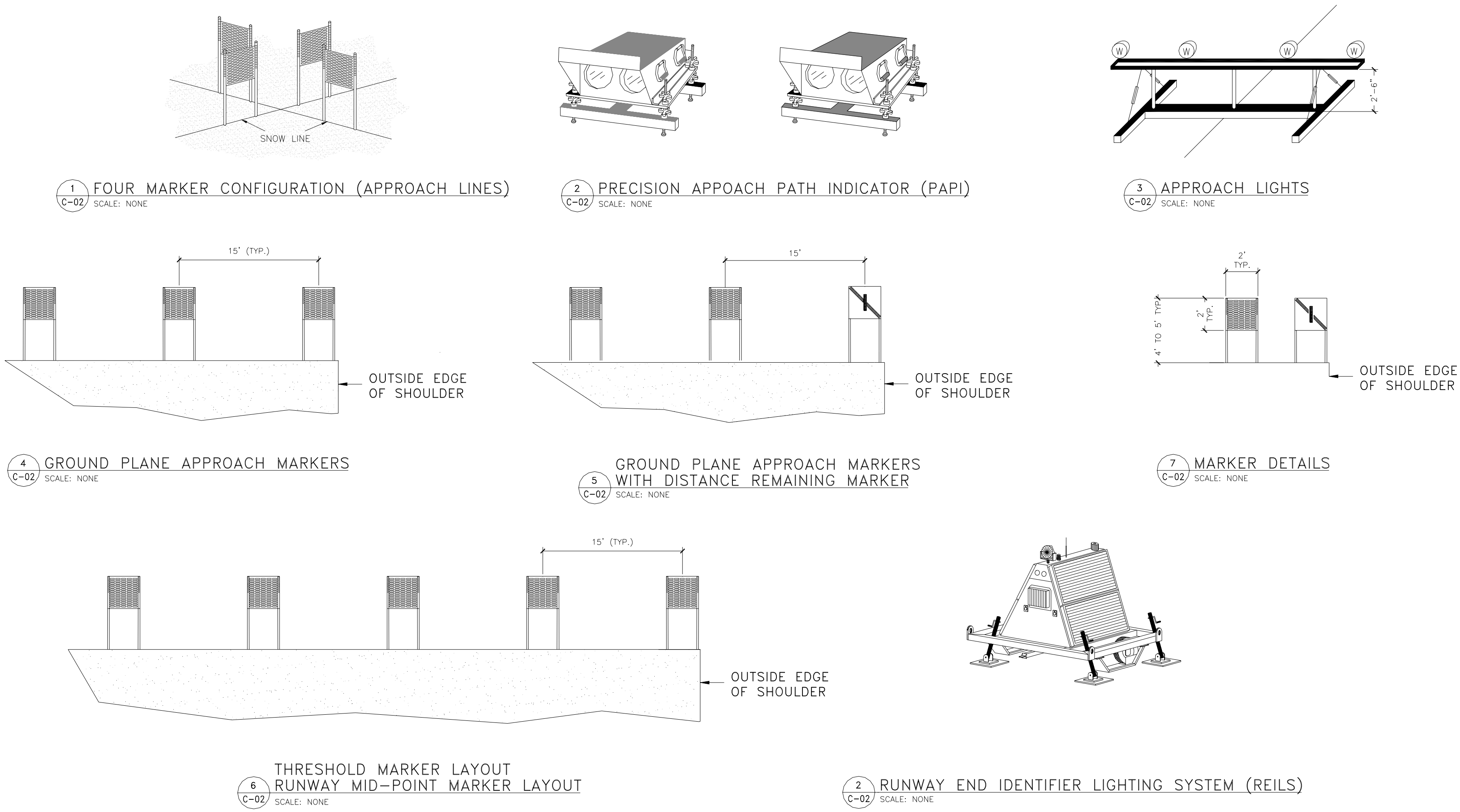

Figure 11. Details of Runway Markers and NAVAIDS

8.4. Also shown in Figure 10 are the positions of the current suite of NAVAIDS (Tactical Air Navigation [TACAN], runway end identifier lights [REILS], Mobile Microwave Landing System [MMLS], and precision approach path indicator [PAPI] lights). These are also strictly above-surface installations; however, subsurface wiring has been arranged for the NAVAIDS to allow the use of central and displaced power generation.

8.5. Figure 11 shows details of the runway markings and NAVAIDS. Note that all markings and NAVAIDS are only present at the site during the flight periods. At all other times, all surface structures, including buildings and other support structures, are removed from the site to discourage progressive snow accumulation.

8.6. This ETL will be revised to reflect changes in the markings and NAVAIDS to be used at the Pegasus site. The markings and NAVAIDS shown in Figures 10 and 11 should be considered the minimum required for routine operations. Exact placement details, including dimensional tolerances, of runway markers and NAVAIDS can be found in Air Force Manual (AFM) 32-1076, *Design Standards for Visual Air Navigation Facilities*.

9. Operational Waivers to Criteria. The criteria in this ETL are the minimum permissible for C-130, C-141, and C-17 operations. When deviations exist or occur, an operational waiver must be obtained before starting flight operations. The airfield manager will initiate a written waiver request to the HQ AMC/DO for consideration. The waiver must outline all criteria that does not meet the requirements of this ETL The appropriate airfield survey team will verify existing PLZ dimensions and grades. HQ AMC is the approval authority for waivers of all criteria contained in this ETL.

10. Points of Contact: Recommendations for improvements to this ETL are encouraged and should be furnished to:

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Director of Technical Support

4 Atchs
1. DCP and RSP Operating Instructions
2. Pegasus Runway Patching Procedures
3. Test Plan for Pegasus Runway Wheeled Operations Certification
4. Distribution List

DCP AND RSP OPERATING INSTRUCTIONS

A1.1. Device Configuration. For application at the Pegasus runway, the DCP device should be operated with a fixed 60°, 20-millimeter (0.8-inch) diameter cone, and an 8-kilogram (17.6-pound) drop hammer. The RSP will be operated with the standard 30°, 11-millimeter (0.4-inch) diameter cone, and a 0.8-kilogram (1.75-pound) drop hammer.

A1.2. Test Method. Penetrometer measurements can be taken at any time of day, at any air temperature, and in any weather conditions (but environmental conditions at the time of testing must be documented). Take snow strength measurements at the locations noted in the field data sheet (see Attachment 3). **Note:** Ideally, two persons should work together to take measurements and record penetrometer data.

A1.2.1. Verify that a measuring mechanism is available to accurately note every 25 millimeters (1 inch) of penetration of the penetrometer shaft (e.g., distance marks on the penetrometer shaft or an adjacent measuring rod). The “zero” penetration mark is located at the top of the cone’s pointed end (i.e., at the lowest point on the penetration tip where the maximum penetrometer width occurs).

A1.2.2. Gently place the tip of the penetrometer onto the snow surface, and keep the shaft in a vertical position.

A1.2.3. Push the penetrometer vertically into the snow until the widest part of the tip cone is flush with the surface of the snow (i.e., at the “zero” depth mark).

A1.2.4. Gently raise the hammer weight until light contact is made with the top handle. The hammer must not impact the handle when being raised.

A1.2.5. Allow the hammer to freely fall down onto the anvil, thus forcing the cone into the snow.

A1.2.6. Track how many hammer blows (drops) are needed to drive the penetrometer cone 25 millimeters into the surface, as measured by the markings on the shaft or detached measuring device. This will complete Blow Set 1. **Note:** 25 millimeters is the penetration goal for each blow set, but if the snow properties suddenly change and the cone quickly penetrates further than 25 millimeters, simply note the actual penetration depth and number of blows in that blow set.

A1.2.7. In the penetrometer field data sheet for that location, write down the number of blows under Blow Set 1, and the penetration of the cone (in millimeters) for that blow set.

A1.2.8. Without moving the penetrometer, begin Blow Set 2, driving the penetrometer another 25 millimeters into the snow by dropping the hammer as many times as needed to achieve this penetration.

A1.2.9. Record the Blow Set 2 data into the appropriate blocks on the field data sheet. Continue the penetration test, 25 millimeters at a time, until the penetrometer tip firmly contacts the supporting glacial ice surface.

A1.3. Errors. If the test data are suspicious or erroneous due to problems attributable to operator or equipment error, fix the problem, move the penetrometer 1 meter (3 feet) away from the original test location, and start the test again. Note the event in the "Comments or Observations" block of the field data sheet.

A1.4. Soft Snow. If the penetrometer tests indicate an area of soft snow (only one or two blows gives 25 millimeters of penetration), note the area on the data sheet and mark the location with a pole or flag for further testing and repair. Move 1 meter down the runway and start the test over.

A1.5. Strength Index. The strength index can be determined from the DCP and RSP tests using the formulas given in paragraphs 5.2 and 5.7, respectively. Alternatively, the *Ice Runway Strength Survey Tool* program, a software analysis routine, is available by contacting one of the individuals listed in paragraph 10. This software will ultimately be available in the PCASE package of applications.

PEGASUS RUNWAY PATCHING PROCEDURE

A2.1. Introduction. Infrequently, there may be damage to the runway surface from equipment gouging, solar-induced subsurface melt pool formation, or surface melting instigated by windborne or spilled contaminants. These areas will require clean-out, repair, and re-certification. The following patching procedure should be followed. Repair these areas by removing the damaged snow and ice and replacing it with a crushed ice and water "patch" (in the glacial ice) and a new snow pavement (on the surface) that provides the required hardness/strength. The repair procedure is based on information in CRREL Monograph 98-1, page 57.

A2.2. Tools. The following tools are needed:

- Long-handled chisel
- Welder's slag hammer or rock hammer
- Coal shovel
- Source of cold, fresh water

A2.3. Patching Procedure. Thoroughly remove all contaminants (including melted and/or refrozen snow and ice) at the site of the repair and dispose of in accordance with site regulations. Remove any loose but clean snow and ice from the damaged area and place it to the side for later use. Clear the faces and edges of the cavity to allow close inspection of the ice along the sides and bottom.

A2.3.1. Glacial Ice.

A2.3.1.1. Use the chisel to excavate the area surrounding the failure area to make certain that all of the weak ice has been dislodged. If a large area of the surrounding ice is weak, use one of the large-scale test methods (see CRREL Monograph 98-1, page 47) to break up the weak ice and identify its limits.

A2.3.1.2. Glacial ice removed from the failed area should be further broken up with a hammer into pieces roughly the size of a fist or smaller. The crushed ice should be packed into the cavity to fill the hole slightly above its top (approximately 75 to 100 millimeters [3 to 4 inches] higher). Any excess ice should be removed from the runway.

A2.3.1.3. Slowly fill the hole containing the crushed ice with cold water (ideally very near 0 °C (32 °F) to approximately 75% full. Fill the hole by directing the water around the perimeter of the hole. Mix the ice-water slurry in the hole with the chisel and shovel by vigorous vertical probing to ensure that all pore spaces are filled with water and to encourage water to flow into any cracks radiating into the surrounding ice. After about an hour, proceed to add water to approximately 50 millimeters (2 inches) below the ice surface. Smooth the surface with the backside of a shovel. Allow it to cool for 3 to 4 hours, after which time the surface usually will be frozen over.

A2.3.1.4. Using the chisel, break the top of the ice surface in a number of places (10% of total surface area). Slowly re-flood the patch area to fill the air gap under the ice surface with cold water.

A2.3.1.5. Use a brightly colored flag (e.g., orange) to mark the location of the patch on the ice surface. A corner of the flag can be frozen into the surface using cold water. If the runway is not in use, a bamboo or plastic pole with a flag can be pushed into the ice-water slurry to mark the location.

A2.3.1.6. Note the approximate location of the patched area using the runway markers as a guide for the long axis, and the knowledge of the runway width for the other axis. If air operations are in effect, the airfields manager, the air traffic controller, and the flight crew coordinator should be notified that a fresh patch is on the runway and that this area should be avoided for at least 48 hours.

A2.3.1.7. Allow the area to freeze for at least 48 hours before allowing traffic to resume; the flag should then be removed. If possible, the patched area should be "dressed" with the chisel-tooth grader blade to blend its edges into the surrounding ice surface and to provide a uniform surface texture.

A2.3.1.8. Following repair of the glacial ice, the site must be re-certified using the procedures given in paragraph 7.2 et seq. if the repair area is greater than 0.4 square meters (4.3 square feet).

A2.3.2. White Ice.

A2.3.2.1. For a white ice surface requiring repair, whether or not the previous procedures (paragraph A2.3.1 et seq.) were required to patch the underlying glacial ice, ensure that all weak, contaminated, or damaged pavement is stripped from the glacial ice surface.

A2.3.2.2. Fill the area with clean, fresh (no more than one-year-old) snow using hand or mechanical equipment, depending on the volume of snow required.

A2.3.2.3. Level the snow surface with a light drag or snow plane, or a wide-tire (1 meter), low-ground-pressure (tire inflation pressure of 100 kilopascals [14.5 pounds per square inch] or less) wheeled vehicle.

A2.3.2.4. Use a compaction roller (used to initially construct the white ice surface) to level the entire patched area using 85% of the final tire pressure and gross load used at initial construction. Allow the snow to "rest" for 24 hours and repeat compaction rolling at 95% of the final tire pressure and gross load. After another 24-hour rest, repeat compaction rolling at 100% of the final tire pressure and gross load used during initial construction. The patched area will be ready to accept routine aircraft traffic following another 24-hour rest period, but this must be verified with certification tests as given in paragraph 7.3 et seq.

TEST PLAN FOR PEGASUS RUNWAY WHEELED AIRCRAFT OPERATIONS CERTIFICATION

A3.1. Introduction. This test plan documents and explains the required steps, methods, and tools required to certify the Pegasus runway for wheeled aircraft operations. The primary attributes that govern certification are dimensions and grades, markings, pavement strength (hardness), and snow and ice temperature profiles. Use this test plan, the accompanying charts (Figures A3.1 and A3.2), and the *Ice Runway Strength Survey Tool* program to achieve a satisfactory runway evaluation and analysis.

A3.2. Certification Process.

A3.2.1. Dimensions and Grades.

A3.2.1.1. Measure features in the runway area (as depicted in Figures 3, 4, and 5). Use available and expedient survey methods and tools (e.g., taping, measuring wheel, transit, laser) to verify that the dimensions and grades of the following characteristics are as required in Tables 1 through 4.

- Runway
- Shoulders
- Overrun area (each end, if present)
- Taxiway
- Apron (refuel, load/unload, turnaround)
- End clear areas
- Lateral clearance areas

A3.2.1.2. Dimensions and grades of each feature are to be verified at the approximate locations shown in Figures 3, 4, and 5. Note that some areas and zones will blend seamlessly (without indication) into other areas, such as where the runway width transitions to the shoulders. In these situations, simply measure and verify that the combined dimensions of the features are per specification.

A3.2.1.3. On Figures 1, 2, and 3, place a checkmark (✓) by each dimension and grade that has been measured and approved, and place an **X** by any dimension that fails the inspection, noting where the failure is located. Measurements that fail the inspection must be documented and brought to the attention of the airfields manager.

A3.2.2. Markings and NAVAIDS. Markings and NAVAID placement is governed by AFM 32-1076.

A3.2.2.1. Check that markings and NAVAIDS are in the correct positions and properly annotated as shown in Figure 10. **Note: Direct on-snow marking is prohibited.**

A3.2.2.2. Verify that the bottom of the marker (flag) is at least 1 meter (3 feet) above the snow surface. Marker dimensions (which vary depending on required markings) must conform to Figure 11.

A3.2.2.3. Check that flagging is attached to frangible (break-away or bend-away) poles. Suitable poles can be made of common bamboo or lightweight plastic, but must not be metal or large, solid wood (e.g., 102-millimeter by 102-millimeter [4-inch by 4-inch] posts).

A3.2.2.4. Each flag will be stretched out between two poles and attached to the poles by means that are wind-proof and sturdy (but removable), such as with clamps and cords.

A3.2.2.5. On Figures 10 and 11, place a checkmark (✓) by each flag that is properly placed and marked, and place an **X** by any missing, misplaced, or improperly marked flags. Flagging problems must be documented and brought to the attention of the airfields manager.

A3.2.3. Pavement Hardness (Strength).

A3.2.3.1. Measure snow pavement hardness with a DCP or RSP at the locations shown in Figure A3.1 (on the circles). Penetrometer measurements can be taken at any time of day, at any air temperature, and in any weather conditions, following the procedures presented in Attachment 1. A field data sheet (Figure A3.2) is provided for logging measurements made with a DCP. The various Pegasus runway surfaces are comprised of a compacted snow pavement built upon a very thick, solid ice base. All runway surface features meant to carry an aircraft wheel load will be required to achieve the same strength rating.

A3.2.3.2. The layout of data entry in the field data sheet (Figure A3.2) is designed to allow the certification team to walk the runway in an efficient path while taking DCP or RSP hardness and temperature measurements. This field data will later be entered at McMurdo Station into a computer database for analysis and results.

A3.2.4. Snow Temperature.

A3.2.4.1. Surface and subsurface temperatures will be measured with a portable thermometer on the day of review at the locations shown in Figure A3.1 (marked with an X). Enter these data into the field data sheet (Figure A3.2). Snow temperature measurements can be taken at any time of day, at any air temperature, and in any weather conditions, but ideally should coincide with strength measurements.

A3.2.4.2. For the portable thermometer test, a stainless steel temperature probe is pushed into the snow on the surface and at depths of 50 millimeters, 100 millimeters, and 150 millimeters (or the base of the white ice pavement), and is held against the snow for 30 seconds to gain an accurate reading. If the snow is too hard to insert the probe, a small trench should be cut out of the snow pavement to allow the probe to be inserted horizontally. The temperature probe should be calibrated yearly.

A3.2.4.3. If glacial ice temperatures (from either the buried probes or portable thermometer measurements) are above or have been above –4 °C (25 °F), proof rolling tests are required to inspect for potential melt damage in the warm areas. Proof rolling is described in paragraph 7.2.1.1 and further described in CRREL Monograph 98-1.

A3.2.5. Data Reduction and Analysis. With the field data sheet in hand, re-enter the penetrometer data (blows, and penetration per blow set) and the portable thermometer temperature data into the *Ice Runway Strength Survey Tool* program (contact the individuals listed in paragraph 10 for access to this Microsoft® Excel-based program). The program will process the data and graph the DCP index value for each runway location tested, and the results will also be automatically compared to the strength go/no-go criteria given in Table 5. Finally, the temperature data will be automatically compared to the upper limit of –4 °C, with a final result provided.

A3.2.6. Approval and Documentation Storage. The certification team leader and the airfields manager will sign the final results from the data analysis. These signed approvals and the electronic and hardcopy data and analysis results will be provided to and maintained by the airfields manager, and will also be provided to the certification team leader for forwarding to HQ AMC.

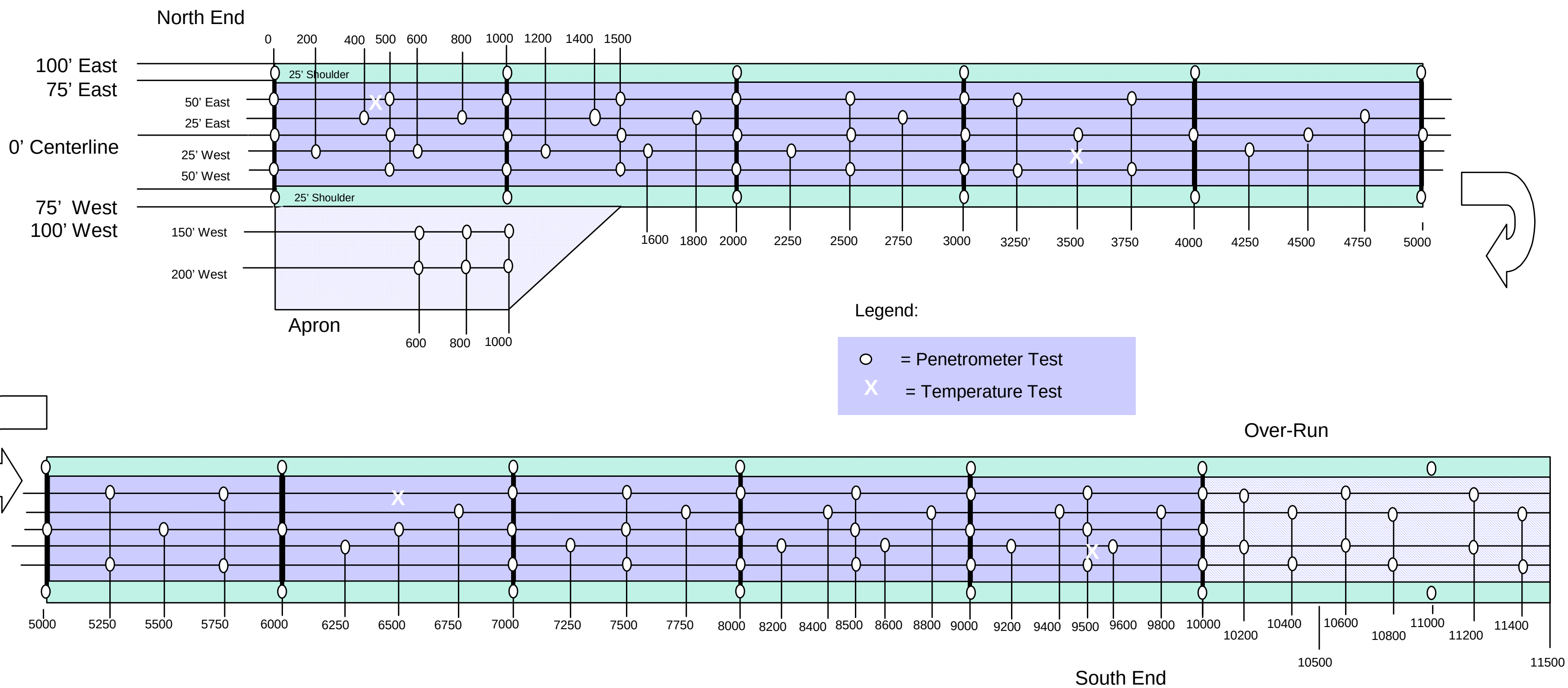

Figure A3.1. Locations for Surface Properties Measurements

Pegasus Runway Hardness and Temperature - Field Data Sheet

DCP - Dynamic Cone Penetrometer

1. Read Separate Instructions On Proper Use and Care Of The DCP Device
2. Obtain Penetration and Temperature Data at Locations Shown Below (Also See Fig. XX).
3. Re-enter all Field Data (Blows, Accumulated Depths, Temperature) into the Runway Hardness and Temperature Analysis Program (Excel).
4. Print out Field Data Sheet and Analysis Program Results and retain at on-site location.

The Data Entry Block
(See Example Data in chart below)

Number of Blows (Blow Set) → | 6 | 25 | ← Accumulated Penetration Depth (mm) Per Blow Set (goal is a minimum of 25 mm for each blow set)

DCP Penetrometer Field Data

DCP Data Collected By: ____________________ Date: ____________ DCP Drop Weight: 17.6 lb (8.0 kg)

Accumulating Depth (mm) ——→ (Note: The depth achieved with each Blow Set should be at least 25 mm)

Data Collection Locations		Blow Set 1		Blow Set 2		Blow Set 3		Blow Set 4		Blow Set 5		Blow Set 6		Blow Set 7		Blow Set 8		
Distance Down Runway, Feet (Starting at North End)	Lateral Location, Feet (From Runway Centerline)	Number of Blows	Accum. Depth	Number of Blows	Accum. Depth	Number of Blows	Accum. Depth	Number of Blows	Accum. Depth	Number of Blows	Accum. Depth	Number of Blows	Accum. Depth	Number of Blows	Accum. Depth	Number of Blows	Accum. Depth	Comments or Observations
	Example Data →	7	25	8	50	8	75	7	100	5	125	5	150	6	175	6	200	Gas spill 2' away - soft, needs patch
(-) 1000 North OverRun	0																	
(-) 500 North OverRun	0																	
0	(+) 50																	
0	0																	
0	(-) 50																	
200	(-) 25																	
400	(+) 25																	
500	(+) 50	Temperature Test. Surface:_______°C, 5cm:_______°C, 10cm:_______°C, 15cm:_______°C																
500	(+) 50																	
500	0																	
500	(-) 50																	
600	(-) 25																	
800	(+) 25																	
1000	(+) 50																	
1000	0																	
1000	(-) 50																	
1200	(-) 25																	
1400	(+) 25																	

(partial data sheet shown)

Figure A3.2. Sample Field Data Sheet (Configured for DCP Measurements)

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