INCH-POUND

MIL-HDBK-1011/1
31 OCTOBER 1991
SUPERSEDING
NAVFAC DM-11.01
APRIL 1980

MILITARY HANDBOOK

TROPICAL ENGINEERING

AMSC N/A

AREA FACR

DISTRIBUTION STATEMENT A. APPROVED FOR PUBLIC RELEASE: DISTRIBUTION IS UNLIMITED

ABSTRACT

This handbook provides a general overview of information that directly relates to construction within tropical regions. The handbook focuses on construction components which are directly affected by the aggressive climatological and environmental elements found in these regions. Consequently, many traditional parts of the construction trade are not reviewed herein, unless they are adversely affected by the tropical elements.

The handbook defines tropical areas and briefly discusses the adverse environmental and climatological elements unique to them. It discusses various construction materials and systems commonly in use, recommendations regarding their selection and use, and highlights problems that have resulted in failures with suggestions and recommendations regarding their elimination or mitigation.

FOREWORD

This handbook is developed from an evaluation of facilities in the tropical environment, and is based upon surveys of the availability of construction methods and from selection of the best design practices of the Naval Facilities Engineering Command (NAVFACENGCOM), other government agencies and the private sector. It offers guidance for evaluating construction within the tropical region. Do not deviate from these criteria without review by NAVFACENGCOM Headquarters (Code 04).

Recommendations for improvement are encouraged from within the Navy, other Government agencies, and the private sector and should be furnished to Commander, Pacific Division, Naval Facilities Engineering Command, Code 406, Pearl Harbor, HI 96860-7300; telephone commercial (808) 474-5349.

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.

ENGINEERING CRITERIA MANUALS

Criteria Manual	Title	PA
MIL-HDBK-1011/1	Tropical Engineering	PACDIV
MIL-HDBK-1011/2	Cooling Buildings by Natural Ventilation	PACDIV
MIL-HDBK-1011/3	Regional Engineering (Proposed)	LANTDIV

TROPICAL ENGINEERING

CONTENTS

Page

FIGURES

TABLES

Section 1: GENERAL INFORMATION

1.1 Scope. This handbook on tropical engineering is intended for use as a guide by designers and engineers who are responsible for the preparation of plans and specifications for the construction of shore facilities in the tropics. This handbook complements the requirements of NAVFACENGCOM and DOD handbooks and instructions to upgrade the quality of design and construction and thereby extend the economic life of shore facilities in an environment considered aggressive because of constant sun, rain, salt, and humidity; frequent high winds, wind-blown sand, and salt spray; tsunamis, floods, earthquakes, lightning storms, and floods; and other detrimental environmental aspects as described herein.

1.2 References. All cited references are listed in detail in the Reference section at the back of this handbook.

1.3 Cancellation. This military handbook cancels and supersedes NAVFAC Design Manual (DM)-11.01, Tropical Engineering, of March 1980 in its entirety.

1.4 Tropical Region. The tropical region officially covers a broad belt of the earth's surface bordering the equator from the Tropic of Capricorn to the Tropic of Cancer. Arid and high elevation conditions are not discussed in this handbook. It deals with those tropical regions that are hot and humid and specifically deals with those environmental concerns that need special attention in shore-based facilities. (In addition, numerous areas such as Florida, the Gulf Coast, Okinawa, as well as other areas north of the Tropic of Cancer, experience many of the same climatic conditions that are referred to in this handbook.) (See Figure 1.)

1.5 Specific Classifications of Tropical Environmental Conditions

1.5.1 High Solar Radiation. Because of high sun angles the tropics experience intense levels of solar radiation. The ultraviolet spectrum is particularly harmful to many commonly used building products. High ultraviolet exposure results in rapid deterioration of most non-metallic roofing materials, paints, sealants, elastomeric coatings, and wood. High solar radiation also causes building materials to develop high material temperatures which require careful detailing of the joints in cladding and structural systems.

1.5.2 High Humidity. Relative humidity in the range of 70 percent to 100 percent for most of the year creates ideal conditions for mold and mildew that promote wood decay. It also accelerates rusting of various metals and intensifies galvanic action in many metals. Many paints in high humidity conditions do not perform well. In addition, high humidity conditions require careful detailing of vapor barrier locations in air-conditioned buildings. Common building materials that exhibit hygroscopic properties such as gypsum, insulation, and particle board can lose their structural and functional properties in humid climates.

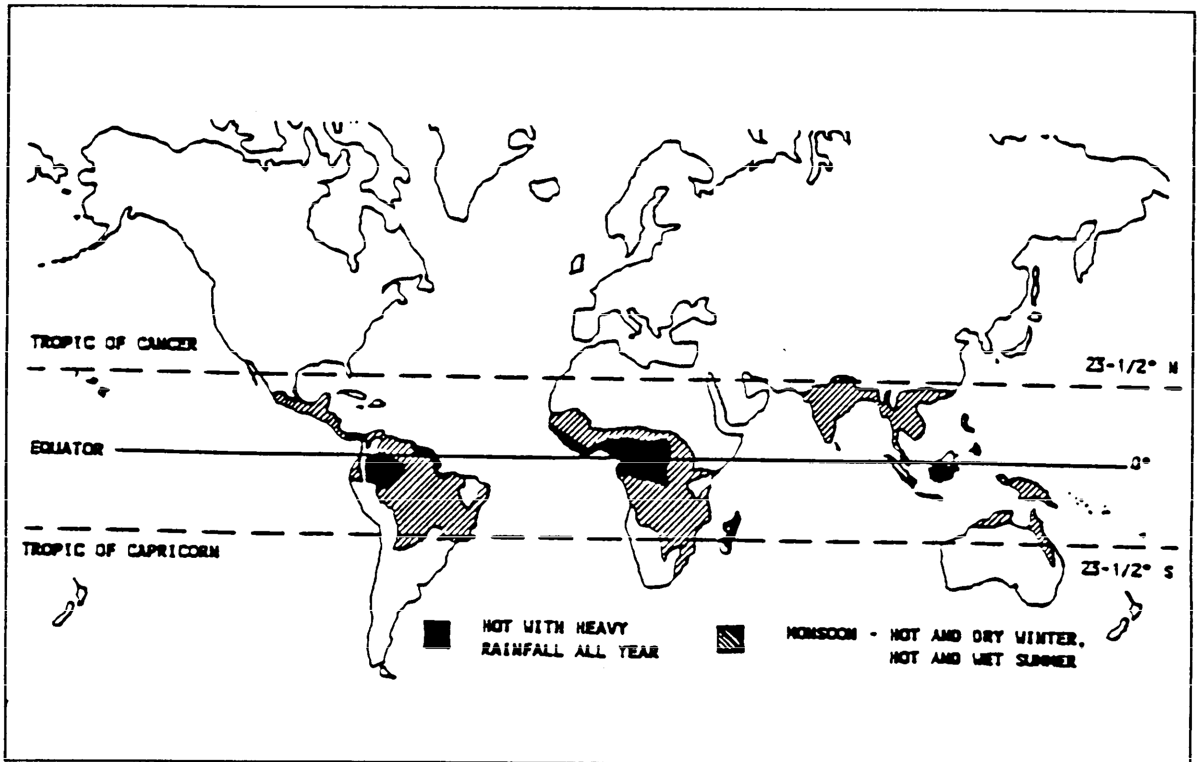

Figure 1
Tropical Region

1.5.3 Intense Rain Periods. For those tropical areas that have prolonged rain periods, specify soil treatments in addition to water infiltration control. Consider and avoid structural instability and exacerbation of rust and decay due to possible water infiltration of buildings. Because tropical areas often experience brief, intense rainfall producing flood conditions, include provisions for and consideration of ponding and runoff conditions.

1.5.4 Monsoons. These are wind systems on a continental scale which seasonally reverse their direction because of a change in temperature trends over land and sea. Generally, winds blow from cold to warm regions; for example, sea to land in summer and land to sea in winter. This occurs because atmospheric pressure is high in cold regions and low in warm regions.

Monsoons are one of the most important rain-producing currents on the globe. Intensity and duration are not uniform year to year. A heavy season with floods may be followed by several seasons with below-average precipitation, crop failure, and famine. Research and design for the extreme conditions brought on by monsoons.

1.5.5 Storm Surges. In one type of storm surge, strong winds pick up water along a coast causing sea level to rise. The approximate height of this storm surge can be predicted based on wind speed and direction, fetch, water depth, and the shape of the ocean basin. Other factors, such as currents, astronomical tides, and seiches set up by storms, complicate the calculations.

a) A second type of surge is a large wave that moves with the storm, typhoon, or hurricane which caused it. First comes a gradual change in water level, the forerunner, a few hours ahead of the storm's arrival. It is apparently caused by the regional wind system and may cause sea level to fall slightly along a wide stretch of coastline.

b) When the typhoon or hurricane center passes, it causes a sharp rise in water level called the surge. This surge usually lasts about 2-1/2 to 5 hours; rises in sea level of 12 to 16 feet have been observed -- usually slightly offset from the storm's center. Combined with extremely high waves generated by the storm surges can be extremely destructive.

c) Following the storm, sea level continues to rise and fall as oscillations set up by the storm pass. They are more or less free surface waves and have been termed the wake of the storm, like the wake left by the passage of a ship through the water. The sea surges can be quite dangerous, particularly because they are often not expected once the storm itself has subsided.

d) Tropical storms, typhoons, and hurricanes frequently cause storm surges along the Gulf Coast of the United States. In 1900, Galveston, Texas was destroyed and about 6,000 people were killed by a storm surge resulting from a hurricane. In 1969, Hurricane Camille, the second strongest recorded storm to hit the Gulf Coast, caused $1.4 billion in damage; even with advance warning, it killed 256 people. A disastrous storm surge occurred in 1876 in the Bay of Bengal when 100,000 people were killed. In 1970, another storm surge hit the same area, killing an estimated 500,000 people.

e) Designers working on projects sited near coastlines are responsible for researching past surges in the project area and evaluating the effects of future surges on their project.

1.5.6 Floods. Floods happen when water rises above a flood plain level and damage begins to occur. Flood plains can be channels, deep and wide, or many miles wide and shallow, such as an alluvial plain. The encroachment of industrial community development on natural channels has contributed to substantial flood damage, particularly when coupled with seasonal rain and high tides.

1.5.7 Earthquakes. Earthquake design is beyond the scope of this handbook. However, note that the earth's lithosphere is composed of numerous plates whose boundaries are the source of seismic activity. Many of these plates cross the tropical region. Therefore, study the history of seismic activity in these areas and design structures and facilities in accordance with applicable seismic codes.

1.5.8 Tsunamis. Although not within this handbook's scope, be aware that tsunamis, or seismic sea waves, are caused by sudden movement of the ocean bottom resulting from earthquakes or volcanic eruptions. Because of their frequent occurrence in the tropical region, and their devastating effects on life and property, consult local historical data regarding tsunamis and design accordingly.

1.5.9 Volcanoes. The majority of active volcanoes are found surrounding the Pacific Ocean (the "ring of fire") and in the Mediterranean region eastward into Indonesia. Many of these are dormant and not extinct. To be considered active, a volcano must have had an eruption within the last 500 years. A dormant volcano has had no eruptions within the last 5,000 years and an extinct volcano has had no eruption for over 5,000 years. Evaluate the potential for destruction or damage and possible injury from lava, gaseous discharges, and seismic activity when working within the area of a volcano.

1.5.10 Prolonged Elevated Temperatures. Elevated temperatures have adverse effects on building materials such as paints, woods, and many asphalt-based products. These high temperatures combined with high humidity will cause severe deterioration.

1.5.11 Salt-Laden Air. Salt rapidly accelerates wood deterioration, promotes galvanic action between metals, rusting of ferrous metals (including inadequately protected reinforcing steel), and pitting of many aluminum alloys. Salt-laden air also adversely effects the application of paints, sealants, elastomeric coatings, and asphalt roofing applications.

The severity of salt-laden environments varies throughout the tropics. The degree of intensity varies with elevation, prevailing on-shore wind, vegetation and rainfall. In addition, small, flat coral islands with sparse vegetation (such as Kwajalein, Midway, and Diego Garcia) have more potential for severe corrosion than do the larger volcanic islands with moderate vegetation and rainfall (such as Hawaii and Guam). Although all tropical design must address corrosion protection, installations in known or suspected severe corrosive environments require additional protective enclosures, materials, and coatings.

1.5.12 Poor Soil. Include requirements for soil treatment and fertilization as much of the soil in the tropical belt is low in nutrients.

1.5.13 Insects. Insects are abundant in the tropics. Many are harmful or annoying to human comfort and others are harmful to building materials. Termites, particularly the subterranean Formosan variety, are perhaps the most serious threat to buildings in the tropics. These insects can rapidly destroy a wooden building, cause severe damage to electrical equipment, and extensive damage to many roofing materials.

1.6 Air-Conditioned Buildings. For special design and material selection considerations regarding air-conditioned facilities, refer to Section 14.

Section 2: SITE WORK

2.1 Scope. This section covers earthwork, pile foundation systems, paving, soil treatment, landscape work, and landscape irrigation systems.

2.2 General Design Considerations

2.2.1 Site Materials. The earthwork materials in the tropics are dominated by three major groups: coral and coralline limestone, residual soils, and rock aggregate. Because of the warm climate, high humidity, and frequent rainfall, earthwork materials in the tropics are usually more weathered and weaker than materials found in temperate regions. In addition, erosion is a major problem. Therefore, for site work in the tropics, place high emphasis on erosion control during design.

2.2.2 Site Investigation. When planning site work for heavy foundation loads and important structures in coral and volcanic formations, site investigation by exploratory borings is required. Ground-penetration radar (GPR) can be used to locate shallow voids and cavities. Coral may have voids and solution cavities. Volcanic rock formations also may have hidden lava tubes and cavities. Therefore, the site selection as well as the type of structure may well rest on the results of the exploratory borings. And, until those results are known, no predetermination of building foundations or foundation systems can be made.

2.3 Soil

2.3.1 Coral. Abundant in tropical regions, coral is a good subgrade material. Reef coral is very dense, hard, and is an excellent source for armor-rock in breakwater construction. Reef coral can also be crushed and graded to produce good subbase and base course materials. Coralline sands and gravels commonly found along the shoreline, being softer and more porous than the reef coral, are usually only suitable as subgrade and subbase materials.

2.3.2 Coralline Limestone. Recrystallized coralline limestone can be quarried and screened to produce aggregate suitable for subbase, base course, and concrete aggregate. Coral concrete products generally have lower compression strengths than concretes made with other types of rock aggregates. It is important that coral used in concrete be free of salt. Washing of the coral produces coral that is suitable for concrete mix, but in some areas lack of adequate fresh water will make it difficult to get a thorough wash.

2.3.3 Residual Soils. Residual soils in the tropics are predominantly silty clays and clayey silts. To be technically correct, the tropical residual soils can generally be categorized into three major soil classes: oxisols, andisols, and vertisols. Oxisols are by far the most common residual soils in tropical regions. They cover approximately 50 percent of the land areas in the tropics.

Oxisols are silty clays with high contents of oxides. They are generally reddish brown to gray in color. The soils are relatively stable, with low to medium expansion potential. With proper moisture conditioning and compaction, oxisols are adequate as subgrades below lightly loaded structures.

Andisols and vertisols are suitable for agricultural use but do not have sufficient strength and stability for construction use. For foundation engineering purposes, andisols and vertisols are usually removed and replaced with more stable subgrade materials. Lime stabilization is sometimes used to improve the engineering characteristics of these soils.

2.3.4 Rocks. The most common rocks found in tropical regions are intrusive rocks such as granite, igneous rocks such as andesite and basalt, and sedimentary rocks such as sandstones and siltstones. In certain young and active volcanic areas such as Hawaii, the Philippines and Indonesia, the lava rock formations often contain large voids and cavities, such as lava tubes and chambers which are difficult to detect. For important structures to be constructed on lava formations, a thorough site investigation is required. If lava tubes and chambers are found within the foundation construction zone, collapse or fill them with appropriately engineered materials.

Depending on the degree of weathering, rocks can be excellent sources of construction aggregates when they are quarried and crushed. When andesites are used as concrete aggregate, the concrete has a lower compressive strength than concrete made with basalt aggregates. Therefore, when using andesitic rock aggregates for construction, the soundness, abrasion resistance, and moisture absorption characteristics must be carefully studied and trial batch mixes prepared and characterized before the work proceeds.

Intrusive and sedimentary rocks are often found in an extremely weathered state. Except for occasional, less weathered boulders, these rocks tend to behave as dense soils. Such rocks can be used as landfill for embankments, but not as a base for pavement or as concrete aggregate.

2.3.5 Cut and Fill. In the tropics, where rainfall intensities are typically high and the soils lack certain minerals, minimize and carefully engineer massive alterations of the landscape by cut and fill. For grading purposes, cut is preferred to fill. Limit cut and fill slope heights to a maximum of 25 feet unless the work is properly engineered and controlled during construction. The side slopes in cut and fill areas shall not be steeper than a 2 horizontal to 1 vertical ratio. Generally, the flatter the slope, the easier it is to construct, to induce natural vegetation growth, and to maintain.

2.3.6 Soil Stabilization. The basic physical characteristics of tropical soils can be modified and improved by various soil stabilization techniques as described above. For large earthwork projects, it is recommended that a drainage and erosion control plan be prepared for the site as a part of the design package.

2.4 Pile Foundation Systems. In certain coastal areas of the tropics, such as Pearl Harbor in Hawaii, Apra Harbor in Guam, and Subic Bay in the Philippines, thick layers of soft marine sediments often cause difficult design problems for naval shore facilities. Consider pile foundation systems. Design and construction guidelines and specifications for pile foundation systems are given in NAVFAC military handbooks. However, no determination or selection of a pile foundation system can be made until a thorough site investigation, including subsurface borings, has been made and evaluated.

2.4.1 Precast Concrete Piles. Concrete piles are the most often used and preferred pile foundation system in the tropics because of their durability and ease of manufacturing. The selection of pile size and casting length is often dictated by the capability and the availability of construction equipment. Therefore, determining local construction capabilities is an important factor in pile design. Prestressed, precast concrete piles, if available, are a preferred choice because of their superior corrosion resistance.

2.4.2 Timber Piles. Timber piles are often used on waterfront projects for ship mooring dolphins and wharf fender systems because of their high energy absorbing characteristics. Wood in a tropical environment is very susceptible to decay fungi, termites, and other wood boring insects and marine borers. To resist deterioration, pressure treat marine piles in areas where Limnoria Tripunctata (gribbles) are active with a waterborne arsenical salt such as chromated copper arsenate (CCA), ammoniacal copper arsenate (ACA), or ammoniacal copper zinc arsenate (ACZA) in accordance with the American Wood Preservers Bureau (AWPB) Standard MP4, Standard for Marine Pilings Pressure Treated with Creosote, for Use in Marine Waters, to a retention of 2.5 pounds per cubic foot (pcf).

In waters infested with both limnoria and teredines (shipworms), use dual treated piling with 1.0 pcf of a waterborne arsenical salt and 20 pcf creosote in accordance with AWPB MP-1, Procedure for Dual Tratment of Marine Piling Pressure Treated With Water-Borne Preservent and Creosote for Use in Marine Water. Creosote treated piling is only effective against teredines and pholads; in those waters use piling treated according to the AWPB Standard MP2, Standard for Marine Pilings Pressure Treated with Creosote, for Use in Marine Waters, at 20 pcf.

Most tropical waters will require either the waterborne arsenical salt or the dual treated piling. Properly selected marine piling can be expected to provide a normal service life of at least fifteen years. Piling subjected to excessive physical contact and damage may require more frequent replacement.

2.4.3 Steel Piles. Steel piles are often used for waterfront facilities in remote locations where concrete piles are not readily available. Since steel piles have a better capacity to weight ratio and can easily be spliced to longer lengths by welding, they are the preferred pile foundation system when high load bearing capacities and long pile lengths are required in isolated locations. Corrosion is a serious problem in the tropics, particularly if the steel is in contact with coralline soils. In such cases, protective coating and cathodic protection are required.

2.4.4 Cast-in-Place Piles. Cast-in-place piles are suitable for use in the tropic regions. They have similar qualities and construction constraints as driven concrete piles.

2.5 Paving. High precipitation, low subgrade strength, the limited choice of construction aggregate, and long distance transportation of materials and equipment, are factors which must be considered in pavement type selection as well as pavement design.

2.5.1 Coral as Construction Aggregate. Coral aggregate, with proper gradation, is a good subbase and base course material for roadway pavements. However, it may not have sufficient soundness and abrasion resistance for use as base course for flexible airfield runways. For concrete pavement, ensure that a coral base does not come into contact with wire mesh or other metal reinforcing unless the aggregate is washed prior to placement.

Coral aggregate is sometimes used in asphaltic concrete and portland cement concrete pavement. In general, coral aggregate has lower soundness, higher absorption, and lower abrasion resistance than other rock aggregate. These drawbacks can sometimes be compensated for in pavement design by slight increases in total pavement thickness and in asphalt or cement contents.

Exposed coral aggregate on the asphaltic concrete pavement surface is susceptible to abrasion. The skid resistance decreases with time, making the pavement surface slippery to traffic when it is wet. Correct this condition by pavement grooving or overlaying a new friction course on top of the pavement.

2.5.2 Pavement Repair and Recycling. Climatic influences cause asphaltic concrete pavements in the tropics generally to have a shorter service life. Consider more frequent pavement repair and resurfacing in the life cycle cost analysis during planning. In remote island facilities, a viable alternative to pavement resurfacing is pavement recycling. Pavement recycling requires a pavement grinder to remove the in-place asphaltic concrete and then crush it to proper aggregate size for reuse. Pavement recycling can often produce savings in time, cost, and energy.

2.6 Landscaping. The following includes a general description of several landscape planning and design considerations that are unique to aggressive elements found in tropical regions.

2.6.1 General. Tropical regions are usually noted for their hot and humid climate. Therefore, provide landscaping which allows for shade, not only for exterior open spaces but also to protect buildings from direct and reflected solar radiation. In addition, proper landscaping can reduce salt spray conditions by providing protection to structures. With the intense rainfall common to tropical regions, drainage and erosion are primary concerns for the landscape architect. Such conditions are successfully addressed through the careful selection of tropical planting elements that include placement of trees, hedges, and ground cover.

2.6.2 Plant Material. A major factor in preparing landscape designs in tropical regions is the availability of desired plant material in the appropriate quantities and of matching sizes. Since the sophistication of plant nurseries and landscape construction industries vary considerably throughout the world, prepare the landscape design (and accompanying details and specifications) with a good understanding of such local conditions.

a) Equally important is knowledge of local plant material. While there is a vast range of exotic plant material in tropical regions, not all plants are suitable for ornamental landscaping. Poisonous/noxious plants, root invasion at building foundations and walkways, susceptibility to insect infestation, excessive litter, and so forth, are some of the types of problems that may arise in the absence of horticultural expertise.

b) The growing season in tropical regions is year-round, resulting in larger and faster growing plants. A common mistake is to initially over-plant a site, and to later face the need for extensive plant removal as the plants reach maturity, or to place trees with aggressive roots too close to structures, underground utilities, and paving.

c) Protection against solar radiation is particularly desirable in tropical regions where outdoor activities are common. Building courtyards, playgrounds, and outdoor gathering areas, are far more usable and appreciated when adequate shade is provided. Generally, canopy or dome shaped trees are most suitable to achieve this effect.

d) Plant material may also be useful to protect buildings from excessive heat gain caused by direct or indirect solar radiation. One- or two-story buildings can be effectively screened with large canopy or dome shaped trees. Such trees are also effective in shading parking lots, roads, or other large paved surfaces, thereby reducing the reflected solar radiation. The facades of taller buildings can be shaded with vertical or columnary shaped trees, such as palm trees, planted along the face of the building.

e) Exercise care to ensure that debris from the trees does not build up on roof surfaces and in roof drains, gutters and downspouts. Salt spray and strong winds, common to coastal areas, contribute to corrosion of metal building material and uncomfortable living conditions. Such conditions may be reduced by planting windbreaks. Windbreaks consist of tight groupings of plants that can withstand salt spray and strong winds. Proper root anchoring systems are essential. Several rows of planting material may be required to achieve maximum results. Wind may be reduced along the ground for a distance of up to twenty times the height of the windbreak.

f) Periods of intensive rainfall often cause severe erosion to slopes and embankments, and to unvegetated sites. Ground covers and grasses which have good binding root systems are of primary importance in preventing erosion and can be applied fairly economically by methods such as hydro mulching. Trees and shrubs may also be used but do not substitute for the ground cover/grass protection.

2.6.3 Landscape Irrigation System. An irrigation system is often used to maintain ornamental landscaping in coastal and mid-elevation areas.

a) Generally, irrigation is necessary for areas receiving less than 50 inches of rainfall per year. Evaluate each site separately before making a decision regarding the use of an irrigation system. The amount of seasonal rainfall and the precipitation rate of soil at the site are important considerations.

b) Irrigation systems may range from an automatic sprinkler system to a series of hose bibs that are manually operated. The automatic system is the most desirable. It allows the system to be activated late at night, thereby avoiding the higher evaporation rates associated with daylight hours, and will not interfere with daytime activities. A precipitation rate of 1 to 1.75 inches of water per week is appropriate for most landscapes in tropical regions. Also, analyze soil permeability to determine the exact watering schedule. In valleys and at higher elevations, irrigation is less of a priority.

c) Irrigation systems consisting of PVC pipes and irrigation heads are highly recommended due to their resistance towards corrosive elements, cost efficiency, and simplicity in repair/modification.

d) PVC pipes will deteriorate due to exposure to ultra-violet light and may be easily damaged when used above grade. Install them at 12 to 18 inch depth. Use "pop-up" sprinkler heads in grass areas to avoid conflict with foot traffic, and mowing equipment. Other areas such as ground cover or shrubbery beds may be irrigated with fixed risers. This detail includes a flex riser and a PVC coupler to facilitate any replacement due to breakage. A swing joint detail may be used to further ensure against damage to the system.

e) For ornamental landscaping applications where local rainfall or a high water table is considered adequate, consider drip irrigation technology as a starter system to facilitate initial growth.

f) Do not use tropical fruit trees for landscaping Government facilities. The great abundance of fruit, if left unpicked, will cause a major maintenance and health problem.

Section 3: CONCRETE

3.1 Scope. This section covers concrete materials, reinforcement, accessories, curing, structural precast concrete, prestressed concrete, and cast-in-place concrete.

3.2 General Design Considerations. Concrete is an ideal construction material for permanent structures in the tropics, but like all materials, it has advantages and disadvantages. The major problem inherent in using concrete in the tropical region can be traced to the corrosion of embedded steel reinforcement. This corrosion occurs when the steel is exposed to moisture and alkaline substances. Steel must be protected from such conditions.

3.2.1 Corrosion Protection. Take care to minimize the salt content of both the water and aggregates (especially coral) used in the concrete mix. In addition, protect the reinforcing steel and accessories by specified protective coatings. Increasing the concrete cover over reinforcing steel to protect the steel is also an important consideration in areas where salt-laden air conditions are extreme. Such extreme conditions often exist on the windward sides of islands in the tropics.

3.2.2 Cracking and Salt Intrusion. Cracks in hardened concrete allow moisture and salt to come into contact with embedded steel; minimize such cracking through careful adherence to proper construction techniques and technologies.

3.3 Concrete Materials. The use of concrete for building components in tropical areas is recommended provided that material availability (cement, aggregate, and plentiful fresh water) does not make concrete construction cost prohibitive. However, in tropical areas, because concrete components are likely to be subjected to corrosive elements present in salty aggregates and water, exercise special care to ensure that corrosion is limited as much as possible.

3.3.1 Cement. Specify either Type I or Type II portland cement for general use in tropical environments. Specify either Type II or Type V for use in concrete structures continuously exposed to seawater.

3.3.2 Aggregates. Where standard aggregates, such as river gravel or manufactured aggregates, are not readily available, coral aggregates are acceptable. The specific gravity of any coralline material shall not be less than 2.40. Specify coral aggregates with higher specific gravity wherever available. Wash aggregates dredged from the ocean or lagoon with fresh water to remove as much salt as possible.

3.3.2.1 Fine Aggregates. Fine aggregate may be washed, natural beach sand, manufactured sand, or a combination of beach and manufactured sand.

3.3.2.2 Coarse Aggregate. The density of aggregates affects concrete strength, cement and water content, workability, and porosity of the concrete, all of which indirectly influence steel corrosion. Research studies have shown that satisfactory concrete, which incorporates select coral aggregate, can be produced, provided a quality control program that is well defined and closely monitored, is a mandatory requirement. Wash coral aggregate with fresh water after crushing or dredging to ensure that the cement paste bonds properly with the aggregate particles. Ensure that the aggregate is devoid of sodium chloride to the maximum extent possible.

3.3.3 Water. For any reinforced concrete, do not use non-potable water such as seawater or brackish water either in mixing or curing. Salt crystals have a very high affinity for moisture. A small amount of residual salt crystals on a seemingly dry concrete surface results in a damp surface, especially in a highly humid environment. Such damp surfaces can create painting problems, mold problems (mildew), and, most importantly, can accelerate the corrosion of steel embedded in concrete. The total chloride content of the finished mix shall not exceed 1 pound per cubic yard for any reinforced concrete.

3.3.4 Concrete Additives

3.3.4.1 Air Entrainment. Air-entraining agents are used to improve workability of concrete, minimize volume changes, reduce bleeding, and minimize the porosity of the concrete. The strength of the concrete is decreased in proportion to the amount of entrainment. The use of an air-entrainment agent is recommended under the following controlled conditions:

a) Air-entraining agent contains no chlorides.

b) Air content is within 3.5 and 6.0 percent by volume.

c) Air-entraining agent is compatible with other admixtures when specified.

d) Quality control requirements are included in the specifications.

3.3.4.2 Retardant. The use of retardant and water-reducing admixtures in concrete is recommended.

3.3.4.3 Water Reducing Admixtures. High range water reducers are categorized as a new type of admixture which can either be used to reduce the water requirement or to be added to the normal amount of water to produce flowing concrete. Tests and studies by Portland Cement Association have shown that high range water reducers are capable of lowering the net water content of concrete mixtures by 12 percent. Since less water is used, drying shrinkage will be slightly reduced. Another item of particular importance for corrosion-prone areas such as the tropics is the improvement in resistance to chloride ion penetration for concrete containing high-range water reducers.

3.4 Corrosion

3.4.1 Pre-construction Corrosion Control. Do not use salt-contaminated aggregate. The use of coral concrete devoid of salt is beneficial in retarding the rate of oxygen and chloride ion transport to the ferrous metal surface. In a few instances, cathodic protection has been used to protect reinforcing steel. The results of laboratory and field tests reveal that fusion-bonded epoxy coatings on reinforcing steel also provide adequate long-term corrosion protection; however, availability and costs must be considered. Consider an increase in the concrete cover over the reinforcing steel to reduce the risk of corrosion of the steel. Significant corrosion of steel embedded in concrete is a major problem in tropical environments. Steel corrosion occurs within concrete, regardless of the type of aggregate, as an electrochemical and oxidation-reduction reaction. Control the corrosion rate by reducing the rate of oxygen transport through the free water within the concrete to the ferrous metal surface or to the reinforcement.

3.4.2 Corrosion Treatment. After corrosion of steel reinforcement begins in an existing structure, there is no satisfactory attenuation technique. Concrete surface coatings such as coal tars, cut-back asphalts, and asphalt emulsions have been tested, but most are ineffective in preventing moisture migration in concrete over time. Properly formulated epoxy resin coatings are superior in preventing moisture migration. Completely expose and remove all rust from corroded reinforcing steel in repair operations. If corrosion is too advanced, replace reinforcing before concrete repair.

3.5 Hot-Weather Concreting. Ensure that specifications include provisions for hot-weather concreting procedures in conformance with American Concrete Institute (ACI) Recommended Practice 305, Hot-Weather Concreting.

3.6 Concrete Reinforcement

3.6.1 Precaution When Using Galvanized Reinforcement. Galvanic action occurs when freshly mixed concrete is placed in contact with galvanized and ungalvanized steel which are tied together. These metals in the presence of portland cement paste acting as an electrolyte, create an electrochemical cell. Galvanic action within hardened and fully-cured concrete may not necessarily pose a problem because of the very low currents generated. A much more severe problem exists, however, when the concrete is fresh. Until the concrete sets, very large currents may flow from zinc anodes to the iron cathodes, where hydrogen ions acquire electrons and form molecular hydrogen which is liberated along the cathodic surface. This gas generation can cause expansive pressure on the concrete encasing the steel reinforcement creating a gas-filled void along the entire surface area of the reinforcement.

3.6.2 Epoxy Coating. Reinforcing steel may be epoxy coated for tropical construction to reduce corrosion damage in land based concrete construction. Adhesion to cured concrete is higher than uncoated steel (1500 plus or minus 100 psi). Rebars can be expected to rust only where subjected to oxidation when the coating is broken, nicked, or abraded. Coatings are tough enough to withstand most construction activity without appreciable damage; however, bend and cut reinforcement before epoxy coatings. There are epoxy patch repair coatings available to touch up nicks and abrasions.

3.6.3 Synthetic Fiber Reinforcing. Synthetic fiber concrete reinforcement is useful as a secondary concrete reinforcement to reduce concrete cracking. Cracks that normally would result from drying shrinkage and temperature changes can be reduced by using this material. Synthetic fiber in concrete is alkali-resistant and experiences no known corrosion. Give special consideration to this product as attenuation of shrinkage cracks will probably result in better corrosion control of reinforcing steel. Synthetic fiber is strongly recommended for areas such as thin sections, precast units, vaults, concrete pipes, sidewalks, and especially slabs on grade.

3.6.4 Glass Fiber Reinforcing. Glass fiber reinforced portland cement concrete allows the production of architectural elements such as cladding panels without the use of reinforcing steel, resulting in virtually rust-free members. Glass fiber reinforced concrete is also suitable for use as fascia panels, soffits, sun screens, mansard roofs and interior feature panels. However, do not design glass fiber reinforced concrete to carry vertical loads nor use it as part of the lateral load resisting system of a building, although it can resist lateral wind loads and its own seismic loads.

3.7 Concrete Accessories

3.7.1 Anchors and Inserts. Protect anchors, inserts or any other type of item, such as connectors used in precast construction, against corrosion by coating with fusion-bonded epoxy. When possible, hide connectors inside concrete and grout with non-shrink, nonmetallic grout.

3.7.2 Embedded Items. Wherever possible use hot-dip galvanized embedded ferrous metals. Follow the hot-dip galvanizing by dipping in a chromate bath. This requirement also applies to embedded ferrous pipes and conduits which will be covered with a bituminous or other protective coating before being embedded in concrete. Do not embed aluminum items in concrete construction.

3.7.3 Accessory Items. Use non-metallic plastic base material for all chairs and supports for securing reinforcing steel located within 1-1/2 inches of any concrete surface. Use non-galvanized tie wire with standard reinforcement to attenuate the galvanic action of dissimilar metals.

3.7.4 Dissimilar Metals. To attenuate the galvanic action of dissimilar metals when galvanized metal is proposed for use, take one of the following two alternative steps:

a) Eliminate the dissimilar metal condition by providing either all galvanized or all non-galvanized ferrous items, or ensure that all galvanized items are separated or insulated from all non-galvanized items before placing of concrete; or

b) Use epoxy-coated reinforcing steel. This alternative is recommended for extremely corrosive marine environments.

3.8 Concrete Curing. Timely and appropriate curing procedures are critical factors for quality control of concrete. Do not use seawater or brackish water for curing reinforced concrete. Do not use chemical additives.

3.9 Structural Precast Concrete. These paragraphs cover precast concrete, both prestressed and reinforced, including non-stressed decorative panels and precast items such as manholes and covers. Prestressed concrete includes pre-tensioned and post-tensioned structural members.

3.9.1 Prestressed Concrete Members. The use of prestressed concrete for structural members in tropical environments is recommended. However, the project design and specifications must contain adequate quality control provisions to assure proper construction and protection against corrosion.

3.9.2 Problem Areas. Consider the several major problem areas before choosing precast and prestressed concrete.

a) Corrosion of steel.

b) Water infiltration through construction joints.

c) Shrinkage and temperature cracks which can occur if proper care is not taken when designing end connectors.

d) Transportation of precast items.

e) Field erection tolerance control and difficulty of field modifications to correct out-of-tolerance items.

3.9.3 Materials. Coat reinforcing steel, including tie wires, in precast concrete panels with fusion-bonded epoxy as well as all steel accessories. The use of admixtures is encouraged to provide the most workable concrete mix with the minimum water to cement ratio.

For prestressed tendons, apply the coating as an electrostatically charged dry powder sprayed onto a grounded steel bar using an electrostatic spray gun.

3.9.4 Criteria for Design. In the design of precast and prestressed concrete items, fully detail and delineate the design of the member connections, including the proper forming and construction, to ensure maximum performance. Connections and joints for exterior wall panels must be watertight, and at the same time, allow shrinkage and temperature differential movement. Do not use welded or bolted metal connectors where exposed to the weather, unless such components are of stainless steel or fusion-bonded epoxy coated steel. Where connectors are recessed, allow a minimum 2-1/2 inches of concrete cover for epoxy resin filler.

3.10 Post-Tensioned Concrete. Give special attention to post-tension strands when designing in tropical environments. The Post-tensioning Institute has the following recommendations for unbonded tendons.

3.10.1 Tendons. For unbonded tendons use prestressing steel permanently protected against corrosion by a properly applied coating of epoxy, grease, wax, plastic, bitumastic, asphaltic mastic, or other approved material. Ensure the coating remains ductile and free from cracks and does not become fluid over the entire operating or anticipated range of temperatures. Ensure that the coating is chemically stable, and be nonreactive to steel, concrete and the material used for sheathing. Make sure the coating material adheres to and be continuous over the entire tendon length to be unbonded. Where coating material is applied before the tendons are pulled into the ducts or casings, ensure the coating material is sufficiently tough to resist abrasion.

3.10.2 Sheathing. Ensure that the sheathing for unbonded tendons has tensile strength and water-resistance sufficient to resist unrepairable damage and deterioration during transport, storage at job site, and installation. The sheathing prevents the intrusion of cement paste and the escape of coating material.

3.10.3 Anchorage. Protect the anchorage of unbonded tendons from corrosion. Encase anchorage zones in concrete or grout and ensure the encasement is free from any chlorides. Portland cement sand grout and epoxy mortars have been used for this purpose. Detailing of the concrete or grout encasement, design of the mix, and details of application are most important. Include design features permitting a watertight connection of the sheathing to the anchorage, and watertight closing of the wedge cavity in anchorages intended for use in corrosive environments. In such cases, the film thickness of the coating after curing shall be 5 to 12 mils inclusive.

3.10.4 Concrete. The use of quality concrete, adequate cover, good construction practices, and the use of limited water soluble chloride in the concrete are all necessary to assure long-term durability, particularly in aggressive environments. Extra cover cannot be a substitute for quality concrete.

3.10.5 Chlorides. Although research and experience to date have demonstrated that unbonded tendons exposed to seawater and other aggressive environments are durable, do not use unbonded tendons in applications directly exposed to seawater. In addition, do not use admixtures containing calcium or aggregates containing chlorides in posttensioned structures. This restriction refers also to the mortar used to patch or fill stressing pocket recesses.

3.10.6 Design Considerations. If higher prestress forces are used to create watertight concrete, incorporate allowances for elastic shortening as well as creep and shrinkage in the design.

3.11 Special Concrete Finishes. It is important, however, to be aware of mildew problems that exist, especially on untreated, exterior, textured surfaces. In areas subjected to salt-laden, wind borne exposures, specify long-life surface coatings, such as concrete and masonry block filler with two finish coats of exterior-grade paint, for all exposed concrete.

3.12 Concrete Cover. See Table 1 for recommended minimum concrete cover over non-coated reinforcing steel in tropical environments.

Table 1
Reinforcing Steel Concrete Cover

LOCATION	CAST-IN-PLACE	CONCRETE TYPE PRECAST	PRESTRESSED
Exposed to the Weather	3 inches	2 inches	2 inches
Interior Beams and Columns (to Ties)	2 inches	2 inches	2 inches
Interior Walls and Slabs (Except Nos. 14 and 18 Bars)	1 inch	1 inch	1-1/2 inches
Slabs on Grade (Wire Fabric)	1/2 thickness of slab but not less than 2 inches		
Waterfront (10 Feet Below and 10 Feet Above Mean Low Tide)	3 inches	3 inches	2 inches

Section 4: MASONRY

4.1 Scope. This section pertains to concrete masonry units (CMU), both solid and hollow, used in general construction. Clay bricks are not included since their use in many areas cannot be economically justified.

4.2 General Design Considerations

4.2.1 Water Infiltration. Water infiltration of concrete masonry units is the major problem associated with the use of masonry in the tropics. Give careful attention to the density of the block as well as to the tooling of joints, and applications employed to reduce water infiltration. As with concrete, avoid salt in the aggregate or water. Limit chloride concentration in the mortar mix to minimize corrosion of embedded steel items.

4.2.2 Block Selection. Avoid the use of split-face and scored-face units in outdoor or exposed applications. These units are difficult to properly seal with block filler during painting and ultimately may contribute to leaks or moisture problems. Additionally, scored-face units may accumulate dirt and provide a place for wind-born seed germination. Consider these units a maintenance problem because of the difficulty of cleaning them.

4.3 Construction/Materials Consideration. CMU is very often the material of choice in the tropical regions because of its universal availability and the familiarity of local workmen with its use. Because of the scarcity of clean water and aggregate in many areas of the tropics, it is frequently the only choice. It is ideally suited for use in low-rise and non-air conditioned structures.

4.4 Masonry Units

4.4.1 Application. Concrete masonry units are acceptable for general construction in the tropical environment. A major disadvantage for their use for exterior wall construction is high porosity. The wind-driven rain in the tropics can readily infiltrate the units and create moisture problems if appropriate action to prevent water infiltration of the masonry units is not taken. Although some success has been achieved in stopping water infiltration through masonry units, it has been on a short term basis and periodic surface treatment is necessary to ensure continued protection. CMU construction can be extensively used in the tropics; however, quality control must be ensured. Tool all joints exposed to the weather to ensure maximum compaction and density of the joint mortar. Do not specify struck joints except for interior surfaces of walls or where water infiltration will create no problems.

4.4.2 Materials. Do not use brackish water or seawater in any connection with masonry construction. Specify Type I or Type II portland cement for the manufacture of the masonry units and for the mortar and grout.

When conventional aggregates are not available locally, coral aggregate has been proven acceptable. Ensure the specific gravity of the coralline material is not less than 2.40. Fine aggregate may be washed, natural beach sand, manufactured sand, or a combination of beach and manufactured sand. Sand shall be devoid of salt to the maximum extent possible; the salt content shall never exceed 0.7 percent by weight. Specify washing with fresh water.

4.4.3 Design Requirements. The weight of masonry units for general construction in a tropical environment is not important except as it affects porosity. Direct design and production of masonry units towards reducing shrinkage, porosity, and absorption. Proper vibration and autoclave curing provide for better quality units. Admixtures to densify units are recommended. Specify load-bearing type masonry units.

a) Incorporate weep holes in exterior CMU walls to drain each ungrouted CMU cell. Provide weep holes over bond beams and other solid precast members. Indicate how to prevent inadvertent sealing of such weep holes with mortar droppings during the construction of the wall. Include field tests to ensure compliance in the specifications.

b) Galvanize embedded steel items except reinforcing bars, and closely monitor all construction to prevent steel corrosion. Separate galvanized and non-galvanized ferrous items to preclude the galvanic action when mortar is placed.

c) Use hot-dip galvanized embedded ferrous metals wherever possible. Follow the hot-dip galvanizing by dipping in a chromate bath. This requirement also applies to embedded ferrous pipes and conduits which must be covered with a bituminous or other protective coating before being embedded in concrete. Do not embed aluminum items in masonry construction.

Section 5: METALS

5.1 Scope. This section covers structural steel and metals in a generic nature and does not deal with specific products.

5.2 General Design Considerations. Since most metals deteriorate as a result of exposure to the action of oxygen, water vapor, carbon dioxide, salt and other chemical substances, the use of metals in tropical area construction requires careful consideration. High humidity and the heavy concentration of salt in the air, soil and in the water in the tropics provide an ideal environment for metal corrosion to occur. Protection of all metals from these conditions is critical.

5.2.1 Corrosion Protection. It is equally important to avoid corrosion of metals caused by galvanic action between two dissimilar metals. Some means of separating dissimilar metals must, therefore, always be found. Because of the combination of both high humidity and salt-laden air, the key to an acceptable steel structure is understanding that each steel component must be properly and adequately maintained. Any structural joints that are accessible to moisture are also be accessible for proper inspection and maintenance. (Refer to para. 15.4 for a comparison of metals exposed to various potentially corrosive environments.)

5.2.2 Moisture Intrusion. If the design of the steel structure precludes adequate maintenance accessibility, then the design also precludes moisture accessibility to such members and joints. The design of structural members provides for adequate shedding of rainwater and permits water entrapment.

5.3 Ferrous Metal. Avoid unprotected ferrous metal in exposed locations wherever possible. It is particularly unsuited for coastal salt-laden environments. For protected interior locations, hot-dip galvanizing is acceptable; for exposed exterior locations, it is not recommended. Hot-dip galvanizing does not provide adequate protection in exposed coastal salt-laden environments. If galvanized ferrous metal must be used, it is advised that a three-layered paint coating of all surfaces be applied. Consider membrane type paint (not latex), or high solids epoxy for best results. Electroplating or cadmium plating is not permitted.

5.4 Aluminum. Aluminum is subject to pitting or corrosion in salt-laden environments. It is recommended that heavy duty anodized coatings be required. For covering large expansive areas, recognize that even light shades of dark colors pick up excessive solar radiation. Because of this potential for heat gain, all designs involving color-anodized aluminum products need to accommodate expansion caused by heat. Take care to avoid galvanic action conditions, particularly in salty, wet areas.

5.5 Copper and Copper-Bearing Metal. Copper and copper-bearing metal are particularly susceptible to solar radiation build-up. Allow for excessive expansion and movement. Be cautious of galvanic action conditions.

5.6 Structural Steel

5.6.1 General. The use of structural steel in a tropical environment has been fairly successful when properly designed, protected, and maintained. However, structural steel is only one of the many construction components that requires a systematic maintenance program to provide economical service life. It is unreasonable to galvanize significant quantities of structural steel. Therefore, it is necessary to design systems that can be maintained over the life of the project. Avoid concealed and inaccessible members. Paint exposed structural steel for interior uses. For exterior uses, consider high-strength, low-alloy steel. Avoid exterior bolted connections; continuous welding with no voids is recommended. Consider epoxy paint systems or elastomeric systems. Where possible, have structural steel shipped preprimed, with prime coating touch up in the field.

5.6.2 Steel Exposure. Generally, for interior use standard structural steel with a minimum coating system of a primer and one coat finish is recommended. Ensure that the coating system is appropriate to the level of corrosiveness of the environment. Also ensure that structural steel is factory primed before being transported.

a) When structural steel is exposed to the weather and cannot be subjected to a proper maintenance program (despite having been treated with a coating system) avoid its use at all if possible. High-strength low-alloy steel may be used in exterior applications if structural and economic requirements justify its use.

b) In a tropical environment, with seawater mist, a coating system for protection against the weather and corrosive elements is required. In addition, consider galvanizing under the coating system in structures where exposure to severe corrosion is anticipated.

c) When galvanizing is cost prohibitive, on steel members use two coats of shop primer in combination with two finish coats. Surface preparation includes sandblasting or mechanical brushing to near white steel prior to paint application.

d) Where fasteners are exposed to the weather, specify galvanized ferrous metals, stainless steel, brass, bronze, copper, aluminum, or other corrosion resistant metals. In addition, consider the electrolytic action of dissimilar metals in the selection of various metallic items, particularly where concrete is a component. Do not use ferrous metal as finishing strips or as components of other securement systems, even if a protective coating is to be provided.

5.6.3 Fabrication and Construction. Where structural components are adequately protected from the elements, connectors may be made up of bolts and welds. After steel construction is completed, touch up all damaged shop prime and finish coats with the identical paint material and give one or two finish coats as necessary. As in exterior application, surface preparation includes sandblasting or mechanical brushing to near-white steel.

Welded connections are recommended where structural components are exposed to the elements. If bolted connections are required for either location, economic, or structural reasons, keep them to the minimum. In any event, specify the proper coating system.

Design connections to preclude pockets or recesses that can trap dust, debris, and moisture. Peen and powder brush welded joints and remove all trace of weld flux (slag). Avoid intermittent welds; require that welds be continuous and designed to completely seal off all contact surfaces of the structural members.

5.7 Miscellaneous Metal Items. Discussion under this section covers all types of metal products and items not covered specifically in other sections. It is also intended to augment other sections where similar base metal products and items are discussed. Miscellaneous items include anchor bolts, nuts, nails, bolts, screws, straps, connectors, fasteners, and other items used to either secure one or more structural components together or attach one construction item to another.

5.7.1 Corrosion Exposure. The areas adjacent to miscellaneous metal items are often more susceptible to corrosion than their component parts, due partly because of damage during installation. This condition is worse when dissimilar metals are used. When exposed to aggressive elements, these areas become the most corrosive locations on any project. Exposed architectural items are likewise subject to significant corrosion; these include items such as handrails, protective guards, and wire screens.

5.7.2 Corrosive Environment. In a corrosive environment, even with the proper selection of materials, the careless installation procedures of components can completely negate the quality of the designed project.

5.7.3 Dissimilar Metals. Galvanic corrosion, where dissimilar metals are encountered, creates major problem areas when not properly protected. Where dissimilar metals are specified, provide protective coating (insulation) between the items.

5.7.4 Aluminum and Concrete. Protect aluminum placed against concrete and cement masonry surfaces. Coat the contact surface of the aluminum with primer and two coats of bitumen or protect by gasketing or protective tape. Synthetic or rubber-base sealants may be used as protective barriers in addition to the coating where applicable.

5.8 Protective Coatings. The choice of coating is dependent on location, degree of sun exposure and protection from the weather, including the type of construction selected. Bituminous paints, heavy-mil plastic tape, or neoprene-type gasketing may be used as a protective coating between dissimilar metals. Use acrylic paints with zinc chromate type primers in exposed applications with a minimum of one primer coat and two finish coats of paint.

Section 6: WOOD AND PLASTICS

6.1 Scope. This section covers rough carpentry, heavy construction timber, finish carpentry, plywood, wood treatments, prefabricated structural wood and its uses and prefabricated plastics. Rough hardware, particle board and treatment and use are also included. Waterfront timber and marine piles are covered in Section 2.

6.2 General Design Considerations. Due to the high potential for decay and termite attack in the tropics, it is recommended that use of wood be minimized. If wood is used, thoroughly pressure treat and maintain accurate inspection to ensure proper treatment.

6.3 Construction/Materials Consideration. Wood materials and products in the tropics are subjected to constant exposure to moisture from humidity, rain, and wind-blown spray. Additionally, boring and nesting insects, molds and mildew, and various forms of rot are constant problems. Plastics, however, are generally not affected by these problems, but constant exposure to the ultra-violet rays in sunlight can cause structural failures ranging from delamination in fiber-reinforced resinous materials (fiberglass) to actual chemical and physical breakdowns in certain plastics such as polyvinyl chloride (PVC) shapes and films.

6.4 Lumber. Base selection of wood for exterior lumber and timber on strength and treatability. Strength can generally be handled by size variation. Treatability is a function of species and heartwood percentage. Heartwood of most species is almost impossible to treat effectively for the more voracious termites, so selection of a species of wood having a high sapwood content will generally produce superior treatment results. Finished moisture content of lumber and timber relates to air humidity conditions of site, but moisture content shall be not more than 19 percent.

6.4.1 Glulam Members. Fabricate glulam members from treated lumber. Do not expose glulam members to exterior climatic conditions. Sun and water exposure can deteriorate such members. Waterproof glue bonding is essential.

6.4.2 Plywood. Ensure plywood has full penetration treatment of the recommended retention for pressure treatment. Except for special applications, use only exterior type.

6.4.3 Particle Board. Do not use this material in the tropics. It is unstable in wet or humid conditions and cannot be preservative treated.

6.4.4 Hardboard Siding. Do not use this material in the tropics. Manufactured from tempered hardboard, it is usually finished with a texture to simulate wood siding. It comes in sheets like plywood siding and installation is the same as for plywood. However; it cannot be treated against termites and, although it is not preferred over wood for food and nests, they will eat through it to find wood. If wood siding is desired, specify treated plywood siding.

6.4.5 Rough Hardware. Hot-dip galvanize all ferrous metal hardware. For extreme exposed locations, consider stainless steel as a more appropriate material.

6.5 Pressure Treatments

6.5.1 Decay and Insect Resistance. Pressure treat all construction lumber timber with one of the following waterborne arsenical salts: ammoniacal copper zinc arsenate (ACZA), or chromated copper arsenate (CCA). Use the AWPB Standard LP-22 Standard for Softwood Lumber, Timber, and Plywood Pressure-Treated with Water-Borne Preservatives for Above Ground Use, or LP-2 Procedure for Soft Wood Lumber, Timber, and Plywood Pressure Treated With Water-Borne Preservatives for Above Ground Use, with a preservative retention rate of 40 and 25 percent for soil contact and above ground respectively. Prior to construction, treat the soil beneath a proposed structure with a termiticide.

6.5.2 Finish Items. For finish items not exposed to weather, usually for cabinets and millwork, one of the following waterborne preservatives may be applied: 2 percent copper napthenate, 3 percent zinc napthenate, or 1.8 percent copper-8-quinolinolate. Only the copper-8-quinolinolate is permitted for use on wood in contact with food. Always follow label directions when using any preservative.

6.5.3 Fire Resistant Treatment. Wherever fire-retardant wood is required, use a nonhydroscopic formulation in accordance with the American Wood Preservers Association (AWPA) Standard C2, Lumber, Timber, Bridge Ties and Mine Ties - Preservative Treatment by Pressure Process, and AWPA Standard C9, Plywood- Preservative Treatment by Pressure Process. Fire-resistant treated wood cannot be given a transparent finish. If a stained and clear finish is required, consider the use of intumescent, transparent varnish.

6.6 Plastics

6.6.1 Polyvinyl Chlorides (PVCs). PVC pipe is not UV-resistant and is not to be used above ground and exposed to sunlight: this includes exposure during brief storage periods. If no alternative is possible and PVC must be used above ground in rare instances, give it two coats of paint compatible with PVC. ABS (acrylonitrile-butadiene-styrene) piping is UV-resistant and is used for exposed applications.

6.6.2 Other Plastics. Most plastics (such as acrylics and polycarbonates) used in exterior applications such as signage and glazing are UV-resistant. Fiberglass materials are not UV-resistant. After prolonged exposure to sunlight, they fade, embrittle, and delaminate.

6.6.3 Interior Applications. There are no unique restrictions regarding the interior use of plastics in the tropics.

Section 7: THERMAL AND MOISTURE PROTECTION

7.1 Scope. This section covers various roofing systems and their performance in a hot and humid tropical environment of frequent winds, driving rain, and intense sun.

7.2 General Design Considerations

7.2.1 Roofing Systems. For the purpose of this handbook, roofing systems include the roof deck, insulation if used, the roof membrane, vents and drains, and any other element incorporated into the system. The following roofing types throughout the tropical humid zones are predominant because they have provided satisfactory service:

a) Built-up (Bituminous) Roofing (BUR)

(1) With Mineral-Surfaced Cap Sheet

(2) Smooth Surfaced with Reflective Coating

(3) With Gravel Surfacing

b) Elastomeric Roofing (Sheet-Applied)

c) Elastomeric Roofing (Fluid-Applied)

d) Corrugated Metal Roofing

7.2.2 Comparison of Roofing Systems. For a comparison of roofing systems and materials, see Table 2.

7.3 Built-Up Roofing (BUR)

7.3.1 General. Built-up roofing systems in tropical-humid environments have performed well, especially on roofs without insulation. Certain installations however have not performed well -- gravel surfaced roofs, roofs over insulation, and those installed on existing dead flat roofs. The gravel surface, usually coral, blackens with algae and deteriorates, becoming a growth medium for sprouting seeds.

7.3.2 Insulation. Insulating a BUR roofing system adds to the layers of an already labor intensive installation with a greater chance of moisture becoming entrapped in the system. The insulation provides a path for water infiltration from minor leaks which would have been only a local problem if the insulation were not under the roofing membrane. Where insulation is mandated, such as for air-conditioned buildings, carefully and properly install the roofing system to minimize these problems.

Table 2
Roofing Systems and Materials

ROOFING TYPE	COST RANGE	WT/ 100 SF	SERV. LIFE	WAR-RANTY	UV-RESIS-TANCE	REMARKS
BUILT-UP						
Asphalt: Base sheet, 2 plys, mineral cap	1-2	400 lb	5-20	10-15	Good	Most prone, because of complexity, to leakage and sheet moisture entrapment in system.
FLUID-APPLIED						
Acrylic Elastomer w/o foam w/1 in. foam	2-3	23 lb 47 lb	7-20	1-20	Good	Use on slopes 1/2:12 or greater. Do not use in areas with relative humidity averaging 80-85 percent annually. Recommend use of fast setting compounds.
Polyurthane Elastomer w/o foam w/1 in. foam	4-5	30 lb 53 lb	7-20	1-20	Fair Good	Moisture cured ure-thanes-use on slopes 1/4:12 or greater. Catalyzed urethanes - use on roof of any slope. Resistance to UV is good if top-coated with aliphatic urethanes.
SHEET-APPLIED						
Polyvinyl Chloride (PVC)	4-5	30 lb	10-20	5-10	Poor	Poor resistance to petroleum and solvents.
Ethylene Propylene Diene (EPDM)	4-5	35 lb	10-30+	10-25	Good	Poor resistance to petroleum, most oils, and plastic roof cement.

Table 2 (Continued)
Roofing Systems and Materials

ROOFING TYPE	COST RANGE	WT/ 100 SF	SERV. LIFE	WAR-RANTY	UV-RESIS-TANCE	REMARKS
SHEET APPLIED (Cont.)						
Chlorinated Polyethylene (CPE)	4-5	30 lb	5-15	10 max.	Fair	Poor resistance to petroleum distillates, strong oxidizers, aromatic hydrocarbons.
Modified Bitumen	3-4	130 lb	5-15	5-10	Fair	Poor resistance to petroleum distillates, hydrocarbons, solvents, and some chemicals.
FIBER REIN-FORCED CEMENT (NON-ASBESTOS)	3-5	400-560 lb	30-50	30-50	Good	Use on slopes 4:12 (w/o waterproofing).
CORRUGATED METAL						
Aluminum	3-4	60 lb	10		Good	
Galvanized Steel	3-4	180 lb	10		Good	

7.3.3 Design Guidelines. Consider the following guidelines for all BUR installations:

a) Use only glass felts. Do not use organic felts.

b) Use Type IV asphalt.

c) Use a reflective mineral surfaced cap sheet system or a reflective coated smooth surface system. Gravel surfacing is not recommended for use in the tropics and it is recommended that it not be used at all near airfields or in areas subject to hurricanes and typhoons. Where gravel surfacing is used, it is recommended that it be "double surfaced" (an additional surfacing of hot asphalt and aggregate placed over the original asphalt and gravel surfacing). This provides additional protection against lift-off and aggregate blowing during high winds. Note, however, that double surfacing adds both substantial weight and cost to the roofing system.

d) Where insulation is required for a wood deck, install the insulation inside the building under the roof instead of on top under the roofing if possible. This is not recommended for a concrete deck.

e) Install the recommended built-up roofing system only on roofs with a minimum slope of 1/2 inch in 12 inches. In new construction, provide a slope to the structural deck of 1 inch per foot for positive drainage. For existing roofs of less than 1/2 inch per foot slope, consider another roofing system.

7.4 Single-Ply Roofing Systems, Sheet-Applied. Single-ply roofing systems have been in place on roofs in tropical-humid environments for many years. Failures generally have been limited to roofs of composite preformed sheets with vinyl as part of their makeup. These sheets shrink and become brittle under the intense tropical sun. On the other hand, rubber sheets of EPDM have proven to be notably successful when applied directly to concrete roof decks or over insulation by the fully adhered method.

7.4.1 EPDM (Ethylene Propylene Diene Monomer). This material is an elastomeric rubber sheet specially formulated as a flexible, stretchable roof covering. It is applied to the substrate by one or a combination of three methods:

a) Fully-adhered with a bonding adhesive

b) Mechanically fastened

c) Loose-laid and ballasted with concrete pavers

Fully-adhered and mechanically fastened systems, only, are recommended for use in the tropics and especially in the areas subject to hurricanes and typhoons.

EPDM sheets are manufactured in 9 to 10 foot wide sheets which are cut to length, allowed to relax, and then glued to the substrate. Laps are glued with splicing cement. The black EPDM sheets are either manufactured with a light-colored, factory-laminated reflective EPDM or Hypalon sheet or can be coated with a reflective liquid coating after installation. In the tropics, coat the EPDM. Recoating will be necessary in 3 to 5 years to maintain high reflectivity. The type with the factory-laminated reflective surface is recommended as the life of the membrane will far out last the field-applied coating. After the factory-applied surface has deteriorated (about 10 years in the tropics) the EPDM membrane can be field-coated for reflectivity.

EPDM sheets are produced in various thicknesses; but only consider the 60 mil thickness for use. The usual insulation for EPDM roofing is a composite urethane/perlitic fiberboard which is installed with the perlitic fiberboard to the roof in hot asphalt and the EPDM to the urethane side with adhesives. EPDM roofing is not resistant to grease and oil and cannot be used near exhaust vents from food preparation areas.

7.4.2 Modified Bitumen. This sheet membrane roofing does not yet have an extensive track record for installation in a tropic humid environment. The single-ply membrane is composed of bitumen modified with plasticizers. Modified bitumen/reinforced (MB/R) membrane includes a reinforcement at mid-depth with a glass fiber or similar reinforcing mat. Total membrane thickness for MB/R is about 160 mils (slightly less for non-reinforced membranes). The membrane is bonded to the substrate in its own hot asphalt with a torch applied to the membrane as it is rolled into place.

If this system is applied over urethane foam insulation, first protect the insulation with another layer of rigid perlitic fiberboard insulation with joints staggered over those of the urethane board below. If insulation is required, if at all possible, place the insulation inside under the roof deck. It is recommended that modified bitumen membrane not be installed on roofs with a slope of less than 1/2 inch in 12 inches. Modified bitumen membrane is not tolerant of ponding water.

7.5 Elastomeric Roofing, Fluid-Applied

7.5.1 Elastomeric Liquid Rubber Coatings. These will provide a highly reflective surface that will remain so for many years. Such a coating will greatly reduce air conditioning loads even in un-insulated buildings. Material, whether it be urethane, silicone, or acrylic has the following properties.

a) The material has high solids liquid, 60 percent or greater, volume solids and must be resistant to ultraviolet light.

b) It must be capable of at least 150 percent elongation and recovery and must adhere to the substrate.

c) The material selected must withstand ponding water, especially if the roof slope is less than 1/2 inch in 12 inches, and if the coating is protecting topside insulation.

7.5.2 Application. Elastomeric liquids are usually applied to a clean, dry substrate with airless spray, brush, or roller. The coating is self-flashing and can be sprayed up vertical surfaces. Apply the coating to a minimum thickness of 60 mils, but 60 mils to 90 mils is recommended as a minimum if the liquid coating is over topside insulation such as sprayed in-place polyurethane foam (PUF).

Achieve the recommended thickness by applying successive coats of approximately 20 mils each. Vary each coat slightly in color (grey, tan, and white for example) so that the final coat is of the desired color and the covering of the preceding coat can be observed and measured.

7.5.3 Acrylic Elastomers. These are usually water based, which makes them easy to apply and to clean up; and they are relatively inexpensive. Select material that has a short cure time.

7.5.4 Polyurethane Elastomers. These materials can be either one- or two-component and are usually spray applied. Granules are often added to the final coat to provide traction (silicone can be slippery) and to harden the final coat. These coatings are prone to pinholing when applied in thick coats (over 30 mils wet).

7.5.5 Vinyl, Hypalon, and Neoprene. These coatings are not recommended because of their low volume solids. Butyl coatings are not recommended because they are not resistant to high levels of ultraviolet light.

7.6 Shingle and Tile Roofing. Wood shingles and shakes, clay tile, and similar roofing materials are not recommended for consideration in tropical-humid environments for various reasons, including high initial cost and short life due to rapid deterioration. Asphalt shingles, with lower initial cost, can require frequent maintenance and repair in high-wind areas.

7.7 Fiber-Reinforced Cement Roofing. Cement-asbestos roofing and siding has been a long-life, maintenance-free material which has been used successfully throughout the tropics and elsewhere. However, because of the health and environmental problems with asbestos it is no longer available. Non-asbestos similar products are now being manufactured in shingle and corrugated sheet forms and perform well in a tropical-humid environment.

7.8 Corrugated Metal. Corrugated metal roofing, as used herein, includes galvanized metal and aluminum. The material may be factory coated or unfinished. This material is generally utilized as roofing and siding for prefabricated warehouse type structures but also have been used on commercial and residential structures. Provide adequate fastenings and building tie-downs in hurricane and typhoon areas.

7.8.1 Galvanized Steel. Use 24 gauge minimum and coat on both sides to provide an acceptable long life. Factory finishing is recommended. The coating must be of adequate thickness and be ultraviolet resistant.

7.8.2 Aluminum. Aluminum roofing is 18 gauge minimum and anodized (0.7 mil) or otherwise factory coated both sides. Separate the aluminum from the steel framework by applying a bituminous coating to either the aluminum or the steel at the bearing points. Use stainless steel fasteners.

7.9 Insulation and Vapor Barrier. Give special consideration to particularly high humidity locales such as Guam, Philippines, and Diego Garcia where the 1 percent outdoor ambient dewpoint temperatures in excess of 70 degrees F may be higher than the design indoor dry bulb temperature. Where this situation exists, select the insulation to maintain its exterior surface temperatures above the ambient dewpoint temperature. Install a continuous vapor barrier at a location where its temperature will be above the ambient dewpoint temperature to prevent water vapor from infiltrating and condensing within the walls. (See Figures 2 and 3.)

7.9.1 Foam Glass. Foam glass rigid insulation board is a good insulating material with a high heat resistance (R) value, is dense enough for foot traffic, and will not absorb water. Foam glass is expensive, however, and is therefore not often used as a roof insulation.

7.9.2 Fiberglass. Fiberglass insulation is often used as a topside insulation under a built-up roofing membrane. This insulation will readily absorb, conduct, and hold water and is therefore often the cause of a roofing failure. On the other hand, fiberglass is a very good insulating material when placed inside the building on top of a suspended ceiling. Fiberglass is not recommended as a topside insulation.

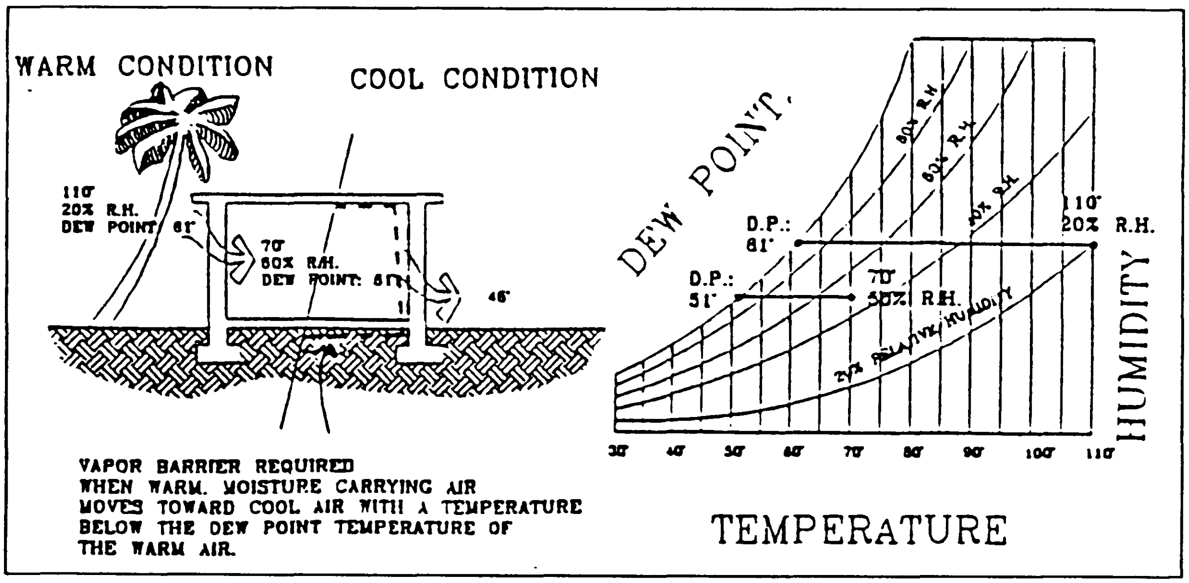

Figure 2
Moisture Migration and Dew Point

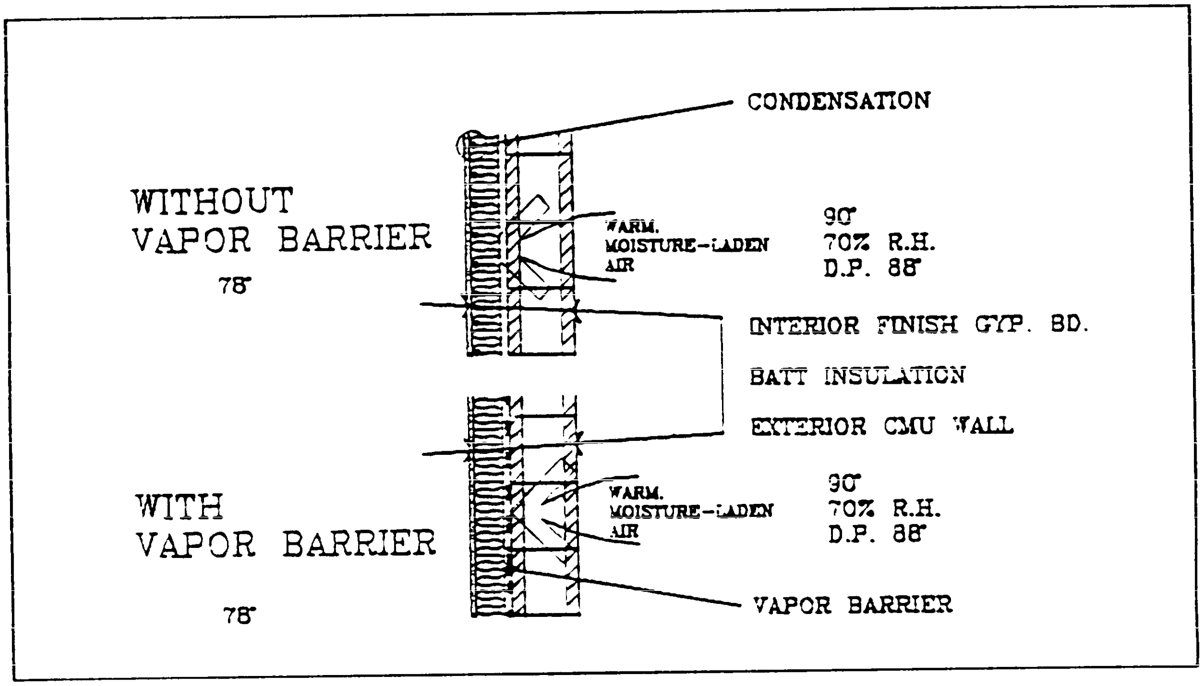

Figure 3
Moisture Migration and Vapor Barrier

7.9.3 Sprayed in Place Polyurethane Foam (PUF). Polyurethane foam has been used as roof insulation. However, the difficulty of obtaining skilled applicators and the impracticability of applying it in windy conditions limit its use in the tropics.

7.9.4 Polyurethane Board. Rigid polyurethane board insulation is manufactured faced and unfaced. Facings include foil and perlitic fiberboard. The boards are secured to the deck with mechanical fasteners or with hot asphalt. In the latter case, the urethane is faced on one or both sides with perlitic fiberboard. Rigid polyurethane insulation board is recommended for use under EPDM single-ply roofing. In this case, use board that is faced on the bottom side with fiberboard and top side with foil. When used with a BUR system, add a second layer of fiberboard with joints staggered over those of the urethane board below.

7.9.5 Fiberboard. Fiberboard is not recommended as a roof insulation in the tropics. It will absorb, conduct, and hold water. It swells when wet and deteriorates. As a result the roofing system may blow off when subjected to high winds.

7.9.6 Flashing and Sheet Metal. Many roofing systems are self-flashing or flashing materials are provided by the roofing material manufacturer.

7.9.6.1 Flashing, Gutters, and Downspouts. In an atmosphere laden with salt spray, stainless steel is recommended. Where salt spray is not severe, flashings, gutters, and downspouts may be of stainless steel, aluminum alloy (3003-N14), or copper. Where aluminum is specified, ensure thickness is not less than 0.032 inches. In hurricane and typhoon areas, ensure aluminum thickness is not less than 0.065 inches where exposed to the direct wind. Aluminum may be used over concrete construction, provided that required reglets are of stainless steel and aluminum surface in contact with concrete or masonry is coated with bituminous paint or zinc chromate primer.

Use stainless steel nails, screws, bolts, and fasteners. Also, secure flashing at one-half the normal interval to ensure a wind-resistant installation. Galvanized steel sheet is not recommended for flashing or for gutters and downspouts.

7.9.7 Vent Flashing. Lead sheet is recommended for plumbing vents and other pipe penetrations through the roof.

7.10 Sealants

7.10.1 General. Because of the constant threat to structures in the tropics caused by the intrusion of moisture and salt-laden air, incorporate adequate control joints in the structure design and properly detail joints to be sealed on the drawings.

7.10.2 Selection. There are only three unique considerations for selection of sealants and seals (preformed tapes, foams, and extrusions) for use in the tropics. They are resistent to ultra-violet light, immersion in or prolonged exposure to water, and extreme high temperatures.

7.10.2.1 UV Resistance. Rubberized bituminous material, polysulfide and polyurethane sealants, and styrene butadiene rubber closure strips all show only fair to poor UV resistance. Do not consider these materials for exterior applications where they are exposed to direct sunlight.

7.10.2.2 Water Immersion. Bituminous, butyl, polybutene, polyvinyl acetate latex, polyurethane, poly mercaptan, and polyisobutylene sealants all show poor service characteristics when immersed in water. Consider this in joints which might be subjected to periodic flooding, or which might be exposed to constant, prolonged rainfall or wind-driven spray.

7.10.2.3 High Temperatures. Although ambient temperatures may seldom exceed 110 to 120 degrees F in tropic regions, portions of structures in these areas may well reach 180 degrees F, or greater depending upon the material, when exposed to direct sunlight. Polybutene, bituminous, acrylic-latex, polyvinyl acetate latex sealants, polychloroprene (neoprene), polyvinyl chloride (PVC), and polyurethane foams, and neoprene, PVC, and styrene butadiene rubber extruded seals and closure strips have maximum recommended service temperature ranges from 130 to 180 degrees F. Do not use these materials where structural elements exposed to sunlight may exceed these temperatures.

Section 8: DOORS AND WINDOWS

8.1 Scope. This section covers exterior and interior type wood, metal, and glass doors and windows; glazing; and finish hardware.

8.2 General Design Considerations

8.2.1 Door and Window Systems. To minimize the destructive corrosive tropical elements that generally cause door and window assemblies to fail, select pre-manufactured systems combined with quality control during installation. Exterior doors may be composed of metal, aluminum and glass, all wood and all glass. Window systems that utilize factory fabrication for all components including weatherstripping are highly recommended.

8.2.2 Maintenance. A regular maintenance program is essential in the tropics to reduce the impact of the destructive elements. Weather damaged finish of wood or metal doors will expose the doors to rapid deterioration and costly replacement unless corrected promptly and properly. Design doors and frames against rain infiltration using weatherstripping, interlocking thresholds and other weathersealing devices.

8.2.3 Hardware and Louvers. Provide all metal exterior and interior doors with template hardware. Avoid louvered doors on exterior entrances; they are very susceptible to weather deterioration. Consider other means to provide the venting function. Ensure that louvers in doors are drainable, weatherproof and factory-primed. Doors with factory-installed louvers are also recommended.

8.3 Wood Doors. Treat all wood elements of exterior and interior doors.

8.3.1 Exterior Wood Doors. These types of doors are flush solid core block with type one waterproof glue, face assembly, medium density overlay (MDO) on both faces. Prior to assembly, water-repellant treat all woods used. In addition, treat all edges with two coats of water repellant after fabrication, with all surfaces being factory sealed with spar varnish or other approved sealer prior to shipment. Do not use doors subjected to weather conditions with no protection from elements. Historically, failure of wood doors can be traced to lack of proper priming and finishing on all surfaces, including edges and sides of doors.

8.3.2 Interior Wood Doors. These doors may be hollow, mineral or solid core doors with wood face veneers.

8.4 Metal Doors

8.4.1 Hollow Metal Doors. These are generally used for utility rooms, service rooms, exit doors, in areas subjected to above-normal physical abuse, and where required by local codes and ordinances. Under these conditions, all metal doors and frames are completely factory finished and salt spray, humidity, and weathering tested. Metal covered wood core doors are less desirable than hollow metal doors since the sheet metal cladding is lighter and subject to faster deterioration. Where sound transmission qualities are required, specify composite construction steel doors with a Sound Transmission Coefficient (STC) rating.

8.4.2 Fire-Rated Doors and Frames. Strict requirements for fire doors and frames (i.e., labeled doors) preclude changes or modifications except when approved by the fire protection engineer. However, to assure maximum protection for fire doors with ferrous metal components, ensure all such metals are hot-dip galvanized; and, in addition, frames are shop primed.

8.4.3 Glass Doors. Where design or the aesthetics dictate solid glass or metal framed glass doors, frames are stainless steel, type 304 or 316 in 12, 14, or 16 gauge, polished and finished except where the exterior doors are in a well protected area in which case aluminum (clear anodized after fabrication) may be considered.

8.4.4 Plastic Laminate Faced Doors. Use plastic laminate covered doors primarily for interiors; however, under given design parameters, they could be used as an exterior door where weather protection is maximized (such as where door is on the lee side of the building or where the building overhang is sufficient to protect the door from wind-driven rain). These doors are also of hollow, mineral or solid cores, with high pressure decorative laminate facings on all exposed edges. Ensure exposed edges (top and bottom) are weatherproof treated against moisture and water penetration if door is to be used for exterior purposes.

8.5 Windows

8.5.1 Window Selection. Base the selection of window types on the standard building design criteria including wind conditions and frequency of tropical storms. Operable windows of the awning or projected type are the recommended options. Jalousie type windows are less desirable for air conditioned areas because of their high air and water infiltration factors.

8.5.2 Aluminum Windows. Aluminum windows, whether fixed or operable, are the designer's only choice. Aluminum does oxidize readily and the finish specified should be anodic (clear or colored). Alternatively, factory-applied fluorocarbon or electro-deposited epoxy finishes provide excellent corrosion-resistance and color retention. For added protection to anodized finishes, select a clear aliphatic urethane finish factory-applied over the anodic coating. Use stainless steel hardware for operable parts.

8.5.3 Other Windows. Do not use steel, wood, and plastic-clad wood windows in tropic regions.

8.6 Glass and Glazing. There are few unique requirements for glass and glazing in tropical areas except for the increased use of tinted glass. Size and thickness of glass may vary from non-tropical applications because of increased wind pressure. Plastic and rubber-glazing elements, including weatherstripping must be UV-resistant.

8.7 Finish Hardware. Do not use copper alloy screws or bolts to secure or connect aluminum items, even if the copper alloy item is plated. Use stainless steel or aluminum screws. Use stainless steel Type 302 or 304 screws and bolts on items exposed to the weather. Where 6061-T5 aluminum for threshold is secured to concrete floors, protect the contact surfaces of the threshold and concrete against galvanic or corrosive action. The use of galvanized bolts and screws exposed to the weather is discouraged. Use galvanized screws and bolts to secure or connect copper alloy items.

8.7.1 Locksets. In a heavy salt spray environment, the entire lockset used on the exterior is stainless steel Type 302 or 304 including screws, bolts, and nuts. Standard commercial grade hardware is recommended for use when conditions are not as severe as direct salt spray.

Interior lock and latch sets are either bronze or stainless steel Type 302 or 304, including fronts, strike, escutcheons, knobs, bolts and all interior working parts. In an air conditioned building commercial grade I locksets are acceptable. In a non-air conditioned building, use the same locksets recommended for exterior doors, marine grade I, fully non-ferrous.

8.7.2 Hinges. Hinges on exterior doors, whether exposed on the interior or exterior side of the door, are stainless steel Type 302 or 304 with stainless steel screws, bolts and pins.

Hinges on interior doors are either cast or cold forged bronze or stainless steel Type 302 or 304. Screws, pins and bolts are bronze or stainless steel. Nylon or teflon bearings may be provided; however, use ball bearing type hinges on large heavy doors and frequently used entrance/exit doors. Except for stainless steel, do not use ferrous metal as base metal for hinges.

Fire-rated doors must have a base metal of either steel or stainless steel. Do not use bronze hinges on fire-rated doors. Use steel hinges with stainless steel pins. Do not use paint-grade hinges.

8.7.3 Closers. Use stainless steel inside bracketed or door mounted closures on exterior doors. Non-ferrous closures, such as aluminum or cast bronze, are permissible where door utilization is minimal. Use Type 302 or 304 stainless steel or non-ferrous closures on interior doors.

On surface-mounted closers use a special rust inhibiting finish on all ferrous parts. This is also recommended for concealed closers.

8.7.4 Emergency Devices. Use stainless steel or bronze base metal with plated finish.

8.7.5 Cabinet Hardware. Cabinet hardware should be brass, bronze, or chrome plated. Do not use ferrous metal items.

8.7.6 Miscellaneous Hardware. For all miscellaneous hardware for exterior doors use stainless steel, Type 302 or 304, or bronze except where aluminum doors and frames are permitted. Aluminum thresholds may be provided with the standard precautions for installation of aluminum items. Bathroom and toilet finish hardware are bronze or stainless steel. Do not use ferrous metal items.

Section 9: FINISHES

9.1 Scope. This section covers gypsum wallboard, plastering systems, acoustic tile, and metal ceiling suspension systems; flooring materials; and paints and stains, including protective coatings.

9.2 General Design Considerations. The general problems encountered after the design selection and installation of most finish materials are moisture infiltration, condensation and salt spray buildup, ultraviolet ray deterioration (of exterior finishes), and under certain design conditions, interior materials being subjected to wind penetration through exterior walls. As an example, in certain tropical areas, the primary cause of the impairment of a metal suspension system for ceilings is the high humidity level. All metal items are susceptible to "sweating" under this condition. The slightest difference in the temperature of the metal and the surrounding air temperature and dewpoint will condense moisture on the metal. If the metal is a ferrous metal, the subsequent rust and stain create a maintenance problem with the materials. Therefore, it is imperative that continual awareness of the above-addressed problems be maintained during the design stage.

9.3 Gypsum Wallboard. Gypsum wallboard is an economical wall finishing material if installed and used according to manufacturer's instructions. It is also an ideal material to provide adequate fire-rated protection for interior areas. Nevertheless, gypsum board is susceptible to damage in bachelor enlisted quarters (BEQ) and other personnel type facilities. Also, in a tropical environment, deterioration through absorption of moisture and termites attacking the paper facing may be a problem. Although 1/2-inch thick board may be used in some areas, minimum thickness of 5/8-inch is recommended. The use of polyvinyl chloride (PVC) trim, stops, screens, vents and expansion joints is recommended in lieu of zinc-coated ferrous metal in the tropics.

9.4 Cement-Fiber Board

9.4.1 General. This material, cement-fiber board, is fire-rated, asbestos-free, and highly resistant to impact, rot, and moisture. Installation materials and methodology are similar to gypsum wallboard. Its high impact resistance makes it an excellent economical alternative to plaster where the potential for damage precludes gypsum wallboard in high use/traffic areas such as living quarters and corridors and high humidity areas such as kitchens and showers. Cement-fiber board is also suitable for exterior soffits.

9.4.2 Special Board Types. Many manufacturers produce prefinished, decorative cement-fiber panels providing concrete, plaster, and fine aggregate surface appearance for exterior siding. The board may also be used as a backer board for ceramic tile and for exterior synthetic plaster finishes. (See para. 9.5.2)

9.5 Plastering Systems

9.5.1 General. A portland cement-lime mix is corrosive to metal lath in tropical envoronments. To reduce plaster and stucco cracking, which contributes to moisture and condensation infiltration delete the lime base and substitute a liquid plasticizing agent with the principal ingredient of a resin compound. The result produces a material with greater resistance to most climatic effects in the tropical zone. Include sufficient control joints to minimize structure-related cracking.

9.5.2 Exterior Insulation and Finish Systems. These systems, consisting of an insulation board with integral scrim and synthetic plaster finish, are sold as a "complete system" by numerous firms. They have the advantage of providing a "plaster" exterior with integral insulation and can be applied to existing concrete and masonry surfaces as well as to wood or metal stud systems in new construction.

Their disadvantage is that they can be installed only by manufacturer-approved installers. This may be an impossible criteria to meet in the tropics, particularly in remote areas. Additionally, damage to a large area of the surface, say in an accident involving a forklift or motor vehicle, will require repair with original materials and approved installer to maintain the manufacturer's warranty on thermal and moisture protection.

Use these materials as a combined exterior finish with built-in layered insulation board, thereby achieving two separate functions: providing the finish plus insulating, which contribute to an energy-efficient building. Application can be over any substrate, both new and existing surfaces.

9.5.3 Special Considerations. If surface is to be painted, do not use coral aggregate in the plaster system. If no option is available, use a sodium silicate system for stabilization.

9.6 Acoustical Tile and Metal Ceiling Suspension Systems. Ceiling suspension main runners and cross runners, including wall channels, miscellaneous moldings and accessories, are an aluminum alloy and finished as applicable, except where fire-rated installation is a requirement. In fire-rated areas, a concealed grid system with galvanized steel, factory finished with baked enamel, is recommended.

9.6.1 Hangar Wire. Where the hanger wires are located in attic areas vented to the outside in a salt spray environment, use stainless steel or copper-bearing alloy wires. Do not vent attic areas above air-conditioned spaces where cold water lines or A/C ducts are located. Ensure that these areas are air conditioned to preclude condensation problems.

9.6.2 Installation. Dissimilar metal installation must include standard preventive measures against electrolytic corrosion. Ensure that all aluminum material has a minimum paint coil coating of 0.7 mil thickness. Where aluminum is in contact with concrete or masonry, coat the aluminum contact surface with bituminous paint or, where appearance is a requirement, a paint system consisting of a chromate primer and two-coat enamel finish.

All nails, screws, bolts and fasteners are stainless steel or aluminum; except where galvanized steel is used (in concealed areas), galvanized screws and bolts may be used in lieu of stainless steel. Do not use aluminum for securing suspended ceiling systems onto concrete or masonry walls.

9.6.3 Special Panels. In high-humidity areas, select acoustical lay-in panels in food service and bath areas and in un-air conditioned areas based on humidity resistance. These include scrubbable mineral composition panels, mineral-fiber/cement panels, and aluminum pans. If regular cellulose composition panels are used, use them only in 2-foot by 2-foot grid systems.

9.6.4 Maintenance Considerations. Ensure that ceiling systems, including acoustical tile and concealed suspension systems employed in air conditioned facilities, are under a continual maintenance program.

9.7 Flooring Material. Do not use coral aggregate, dolemites, or limestone as a setting bed for tile or terrazzo. Wood flooring requires termite treated wood. Carpeting is secondary-backed type installed with a rubber-coated pad.

9.8 Paints and Stains. Because of the severity of many tropical environments (high solar radiation, high temperatures, high rainfall and salt spray), paints frequently will not perform well at tropical locations. Mildew defacement and deterioration of paints may occur rapidly if preventive measures are not taken. Procurement delays, inadequate storage facilities, application equipment failures and general remoteness from more populated locations with available technical help may add further problems to the painting program.

9.8.1 Material Selection. The selection of paint materials and systems is frequently determined by the list of substrates and materials listed in NAVFAC NFGS 09900, Painting. The materials or systems listed for a given substrate perform suitably in the tropics if the substrate is properly prepared and the paint material is properly stored, handled, and applied. Where the guide specification gives one or more options, it is recommended that the superior option (i.e.; an alkyd over a latex or an epoxy over an alkyd, for example) be selected.

9.8.2 Special Considerations. In cavity or double wall construction, apply a low permeable coating to exterior walls to help minimize the amount of moisture transfer through the wall. Apply a high permeable coating to interior wall surfaces to ensure that any water vapor that passes through the exterior coating and vapor barrier enters the air conditioned space and does not remain trapped within the insulation and wall material. Use vinyl wall covering in air conditioned buildings when a vapor barrier is installed as recommended in Section 7.

9.8.3 Substrate Preparation. In the tropics water infiltration and mildew growth are both problems where concrete masonry units are used, include explicit instructions for surface preparation for both new and existing concrete and masonry surfaces.

On new masonry surfaces, specify a latex block filler. The filler coat must be thoroughly brushed in, otherwise leaking will occur. Two finish coats of acrylic emulsion paint with mildewcide is recommended for both masonry and concrete surfaces.

In tropical areas, take care to assure that wood, concrete and masonry surfaces are dry before painting. Latex paints may be more tolerant of damp surfaces but they are also slow drying where the humidity is high. Efflorescence (white to gray powdery products) may occur on concrete surfaces, especially on interior walls of air conditioned buildings. Include the appropriate requirements for efflorescence removal. Where moisture migration through concrete or masonry walls from the outside to the inside presents a problem, seal the outside with a surface conditioner or concrete primer to correct the problem. If interior concrete walls are continuously damp, cracks in roofs that allow the entrance of rainwater must be suspected. Repair these and cracks around the windows before painting. Do not paint interior steel that will be fireproofed.

9.8.4 Repainting. Localized repairs to a coated surface are ordinarily best made by cleaning exposed substrate, spot priming and topcoating with the same type of material existing on the surface. Topcoating of a weathered paint is generally done with a similar type of topcoat. In tropical areas, paints must be mildew-resistant. Microorganisms may utilize the oils in oleoresinous or alkyd paints as a source of food. Dirt, pollen or other surface contamination may also accelerate the growth of microorganisms. Softgel coatings and textured coatings permit more rapid pick-up of mildew. Thus, it is desirable to obtain hard, smooth, inert paint films and keep them free of contamination. Because of the high temperatures and rainfalls in tropical areas, store all materials indoors, out of direct sunlight. Procure no more paint at one time than can be used in one year.

In topcoating weathered paint, remove all mildew, dirt, grease, chalk or other contaminants that might deter good bonding along with loose paint. Dirt, mildew and other airborne contaminants collect rapidly in protected areas such as under the overhangs of roofs; remove them by appropriate cleaning prior to repainting.

Section 10: SPECIALTIES

10.1 Scope. This section covers louvers and vents for exterior conditions, identifying devices, sun control, toilet compartment cubicles, and toilet room accessories.

10.2 Louvers and Vents for Exterior Conditions. It is recommended that all louvers and vents be aluminum, 6063-T5 or 3003 alloy, welded or fuse-welded frames, with an anodized coating of not less than 0.7 mil. Blades should be drainable and stormproof type. Design structural framework for wind loads occurring within the various areas of the tropical zone.

10.3 Signage

10.3.1 Fiberglass. These materials are fiber-reinforced, internally colored resinous plastics and will withstand most of the aggressive elements when used for exterior purposes. However, bright colors tend to fade when exposed to constant sunlight. Direct sun also causes delamination over the long run but this is not a problem for fiberglass used as signs. Fiberglass, unlike most other plastics used in signage, can be readily painted.

10.3.2 Acrylic Plastic and Phenolic. Use these for interior purposes only.

10.3.3 Porcelain Enamel. Porcelain enamel can be factory baked on to either steel or aluminum. Use aluminum backing since damage to porcelain enamel over steel can be extensive (often causing the enamel frit to separate from the steel backing in an area 2 to 10 times the size of the point of impact). Use aluminum backing, specifying that the porcelain enamel be applied to both sides of the substrate and that mounting holes be made before baking will adequately protect the substrate.

10.3.4 Installation. For exterior applications and interior use in heavy traffic areas, firmly attach signage to structure walls with tamper-proof fasteners. Mount large exterior signs on two posts set in concrete. Adhere interior signage on doors to the door surface with waterproof silicone adhesive.

10.3.5 Colors. Coordinate choice of colors with manufacturer's information as regards to color fastness when signs are subject to exterior environment. Coordinate exterior color selections with recommendations in Base Exterior Architectural Plan (BEAP), if one exists.

10.4 Sun Control. Interior and exterior sun control devices are categorized as interior blinds, both metal and woven fabrics, and woven fiberglass screens. Limit metals for sun control devices to prefinished aluminum with a minimum thickness of 0.032 inch for recommended spans.

Fiberglass woven fabric should be rot- and weather-resistant, colorfast, dimensionally and thermally stable and fire retardant where and when required.

10.5 Toilet Compartments

10.5.1 Material Selection. In consideration of the severe salt-laden air and potential rust conditions, it is recommended that only noncorrosive materials be used in toilet compartments. Recommendation includes plastic laminate covering for wood core doors, division panels and urinal screens. Cast alloy, nonferrous chrome-plated hardware with stainless steel floor and ceiling panel fittings are also recommended.

10.5.2 Phenolics. An acceptable alternate to plastic laminate-covered doors and partitions is a plastic covered solid plastic phenolic resin core for compartment divisions. This material is waterproof, steam-proof, rustproof and corrosion free. Galvanized steel with a bonderized enamel finish is not recommended, especially for urinal screens.

10.6 Toilet Room Accessories. For toilet and washroom equipment, construct all units from stainless steel, with all stainless steel moving parts, welded connections where required and with concealed mountings for vandal-proof installation. Where color is included as a requirement, specify vinyl vacuum bonded to stainless steel only, as cold-rolled steel will corrode in the tropical environment.

Section 11: EQUIPMENT

11.1 Scope. This section covers food service equipment, including electrical kitchen equipment and laundry facility equipment.

11.2 General Design Considerations. There are no unique tropical requirements for equipment. Note, however, that electrical equipment installed or used within non-air-conditioned areas will have a shorter life in the tropics as elements such as terminals and contacts will corrode much more readily. This problem can be offset to an extent by maintaining an extensive stock of replacement parts (such as motors, timers, potentiometer, and other controls) which can be readily replaced by maintenance personnel. This is costly but will ensure equipment availability. However, ultimately, the effects of the corrosion will become so pervasive that the equipment will have to be replaced as it will be no longer be economically repairable.

11.3 Product Selection. Generally, equipment manufacturers do not offer a wide selection of options. Carefully examine manufacturers' technical literature to determine what, if any, options are available and to specify those (such as stainless versus galvanized steel and special factory-applied coatings). Look for manufacturers's statements about suitability for use in humid, tropical climates.

Section 12: FURNISHINGS

12.1 Scope. This section covers manufactured casework.

12.2 General Design Considerations. The interior portions of buildings that are properly ventilated are not as adversely affected by the tropical elements. Of major concern is the potential environmental conditions that can cause some interior surfaces, such as smooth-faced cabinetwork, to be affected by fungi.

12.3 Construction/Materials Consideration

12.3.1 Wood. Use paint with mildewcide additives for all wood-fabricated items where paint finish is required.

12.3.2 Protective Coatings. A prefinished factory-applied protective coating is recommended especially where cabinetwork may be subjected to outside environment intrusion.

12.3.3 Particle Board. Because of high-humidity, do not use particle board for furniture, millwork, and cabinet work destined for use in tropical areas. Tempered or high-density hardboard is suitable for drawer bottoms. In plastic laminate covered cabinets, back doors with plastic-laminate backing sheets. Require non-ferrous metal fasteners, fittings, and hardware wherever possible.

12.3.4 Plastic Laminates. Generally, plastic laminates used in cabinet and casework perform satisfactorily in the tropics. However, thin-film decorative vinyl laminates will not; prolonged humidity causes blistering and delamination and they will fade when exposed to direct sunlight.

Section 13: SPECIAL CONSTRUCTION

13.1 Scope. This section covers pre-engineered buildings, recording instrumentation enclosures, integrated ceilings and storage tanks.

13.2 General Design Considerations. For tropical areas with high airborne salt content, pre-engineered buildings with factory-applied protected coatings over galvanized steel for the roof and siding material are still susceptible to rust and corrosion. Choose the protective coating with all the prerequisites for a lasting material and project. Color fading, chalking and pollution resistance are among the factors to consider. Metal type enclosures for recording instruments will generally fall into the same category, though by the very nature of the instrument package, the enclosure size may be quite different. For factory-fabricated items, such as roofing and siding and special enclosures, use items with a factory-finish with a baked-on coating.

13.3 Building Panels and Pre-Engineered Buildings. Specify a roofing and siding material which has a long-life fluorocarbon finish.

13.4 Recording Instrumentation Enclosures. Specify factory-fabricated enclosures for permanently installed recording equipment for measuring such things as stresses in wind energy, solar energy, rainfall, earthquake effects, and radio frequency levels, to protect them from salt conditions.

13.5 Integrated Ceilings. When design parameters allow or dictate the use of an integrated ceiling, where the suspension system, the ceiling material, the lighting and air conditioning are a homogenous unit, use the design criteria for air conditioning in the tropical area. Additionally, consider the guidance for the ceiling suspension system and tile in Section 9 in order to provide a maintenance-free and long-lasting integrated ceiling system.

13.6 Shielded Enclosures. Use either galvanized steel or non-ferrous metal elements in accordance with the recommendations in Section 5.

13.7 Storage Tanks. Wherever possible, situate metal storage tanks above ground, out of direct contact with sand and soil. Where they must be buried, consider using fiberglass or other non-metallic types. If underground steel storage tanks must be used, assure that they are cathodically protected, together with related pipelines. (See Section 14.)

Section 14: MECHANICAL

14.1 Scope. This section covers plumbing, air conditioning, and other mechanical systems.

14.2 General Design Considerations. The major design problems affecting plumbing, air conditioning, ventilation, and other mechanical systems in tropical areas include accelerated corrosion of materials due to exposure to salt-spray, condensation, and rain; and condensation on building materials, equipment, ductwork, and piping. These problems lead to subsequent problems of moisture absorption, swelling, mold, and mildew formation. These problems are compounded by the inability to maintain comfortable space conditions in buildings due to high outdoor humidity and low sensible cooling loads.

14.3 Criteria and Guidance

a) NTIS-A090145, Air Conditioned Buildings in Humid Climates, Guidelines for Design, Operating, and Maintenance.

b) NFGS-15250, Insulation of Mechanical Systems.

c) NFGS-15780, Packaged Air Conditioning Units.

d) NAVFACENGCOM P-89, Engineering Weather Data.

14.4 Corrosion Protection. Ensure adequate corrosion protection through the use of non-corrosive or corrosion resistant materials where practical, and through the proper treatments of materials susceptible to corrosion.

14.5 Piping and Fittings

14.5.1 Aboveground Piping. Use non-corrosive or corrosion-resistant piping such as copper, chlorinated polyvinyl chloride (CPVC), and fiberglass for outdoor use where appropriate.

a) Paint black steel pipe exposed to the outdoors with one coat of pre-treatment wash, two coats of zinc chromate primer, and two coats of enamel paint.

b) Use plastic, fiberglass, or copper pipe hangers when suitable.

c) Ensure that all ferrous materials, when used for pipe hangers, anchors, and other supports, are hot-dipped galvanized. Touch-up joints and damaged surfaces with a field applied zinc-rich compound.

14.5.2 Buried Piping. Use non-corrosive or corrosion-resistant piping such as copper, CPVC, and fiberglass where appropriate.

Ensure that steel and ductile iron piping has a factory-applied extruded polyethylene covering or is tape wrapped and cathodically protected.

Do not use aluminum pipe in aviation fueling systems in alkaline soils with pH greater than 8.5 due to accelerated corrosion.

14.6 Plumbing Fixtures. Use non-corrosive fixtures such as vitreous china, stainless steel, and fiberglass where applicable. Enameled cast iron fixtures are also suitable when other alternatives are not practical. The use of enamelled pressed steel fixtures is not recommended.

14.7 Ductwork. Use stainless steel for weather hoods, exhaust stacks, and vent caps. Paint galvanized steel or aluminum sheetmetal ductwork for outdoor use with one coat of polyamide epoxy primer and one coat of polyamide epoxy exterior top coat.

14.8 Air Conditioning. Provide air conditioning by an all-air type system. The system may be a central air handling type with chilled water coils or a unitary (single or multiple) direct expansion type unit capable of controlling the dew point of the supply air for all conditions of load. When required, apply reheat centrally using recovered heat or solar. Heat recovery may be double-bundle condensers or separate, auxiliary condensers; run-around closed-loop; or refrigerant hot gas. Use electric reheat only when critical space conditions must be maintained or in variable air volume terminal units to prevent over cooling of space.

14.8.1 Small Systems. For systems up to 35 tons, use single compressors with a minimum of three-step capacity.

14.8.2 Packaged Units. Use packaged unitary units with multiple reciprocating compressors (not to exceed four) for systems between 35 and 100 tons. Ensure that each compressor has separate and independent refrigerant circuits and provides multiple steps for capacity control.

14.8.3 Chilled Water Systems. Divide the cooling capacity of chilled water systems of 100 tons and greater between two chillers to ensure reliability and constant chilled water supply without temperature fluctuations and to prevent short cycling. Ensure that the combined capacity of the two chillers does not exceed the total requirement including diversity. Consider temperature rise in supply pipe to the most remote coil to ensure proper coil dewpoint in selection of chilled water supply temperature.

14.8.4 Direct-Expansion Systems. Provide the compressor, evaporator, and condenser of direct-expansion systems with necessary accessories to ensure proper oil return and uniform circuit distribution at minimum coil load. Give consideration to the need for unloading, vertical split-row coils, back pressure regulators, and hot gas bypass.

14.8.5 Cooling Towers. Select cooling towers on the basis of a 7 degree F approach temperature. Ensure that condenser water flow is as low as possible based on life cycle costs of fan energy versus compressor energy and consistent with the chiller manufacturer's recommendation. Towers with long hours of operation are of the draw-through type to reduce fan horsepower requirements.

Provide cooling towers with an automatic blow down system and an automatic biocide/corrosion inhibitor feed system to ensure proper water treatment. Where adequate water treatment cannot be assured, consider using a closed loop condenser water system (e.g., an evaporative cooler, or an air-cooled condenser) in lieu of a cooling tower.

14.9 Mechanical Equipment

14.9.1 Location. Locate equipment indoors whenever possible. Roof-mounted equipment is not recommended in areas prone to hurricanes and typhoons. Additionally, roof-mounted equipment creates roof construction and maintenance problems. Where roof-mounting is unavoidable, evaluate the cost effectiveness of providing roof-top equipment rooms.

14.9.2 Material Selection. Use non-corrosive materials for outdoor mechanical equipment when feasible. For example, use stainless steel, fiberglass, or ceramic in lieu of galvanized steel for cooling towers, and aluminum in lieu of steel for exhaust fans.

Use copper tube/aluminum fin, copper tube/copper fin, or aluminum tube/aluminum fin evaporator and condenser coils.

Provide outdoor equipment casings and condenser coils with additional coating protection in accordance with NFGS-15780.

14.10 Condensation Control

14.10.1 Insulation. Prevent condensation and subsequent problems of moisture absorption, mildew and mold formation, and corrosion, by ensuring that all materials and equipment operating at temperatures below the maximum ambient dewpoint temperature are properly insulated and sealed with a vapor barrier.

14.10.2 Heat Transfer Analysis. Conduct a heat transfer analysis of the temperature profiles through the typical wall and roof sections. Refer to Section 7 for considerations regarding insulation selection.

14.10.3 Pipe Insulation. Use cellular glass in lieu of fiberglass insulation. Insulation thicknesses for piping specified in NFGS-15250 are based on 85 degree F dry bulb and 85 percent relative humidity ambient air.

Increase insulation thicknesses as required to maintain surface temperature above dewpoint of ambient air.

a) Insulate all chilled water, refrigerant suction, and condensate drain lines, including valves, strainers, and fittings when possible. Ensure that all valve stems, gauge stems, and control sensor stems are also insulated.

b) Provide a vapor barrier and coatings for all cold piping 60 degrees F and lower. Ensure that pipe insulation vapor-barrier jacket is factory-applied. Give special attention to the details of construction and to the specifications for the vapor barrier to ensure complete moisture and vapor seal where insulation terminates against metal hangers, anchors, and other projections through insulation on cold surfaces with vapor barriers.

c) Require that the ends of pipe insulation be sealed with a vapor-barrier coating at valves, flanges, and fittings and at intervals not to exceed 15 feet on long pipe runs. Coat joints of pipe insulation with vapor-barrier coating compound to ensure vapor seal of insulation sections.

d) To the maximum extent possible, install chilled water piping in accessible locations to allow for replacement of old, deteriorated insulation. Avoid installing chilled water piping in concealed, non-air conditioned spaces, including ceilings to minimize condensation problems.

e) Provide an aluminum or stainless steel jacket on insulated piping located outdoors.

f) Use pre-insulated piping for buried chilled water, steam, and other underground piping requiring insulation.

14.10.4 Ductwork Insulation. Insulation thicknesses for ductwork specified in NFGS-15250 are also based on 85 degree F dry bulb and 85 percent relative humidity ambient air. Ensure insulation thicknesses specified will maintain surface temperature of insulation above ambient dewpoint in instances where the actual ambient temperature and humidity exceed the above conditions.

a) Insulate all supply and return air ductwork.

b) Provide insulation with vapor barrier and coating.

c) Use internal duct liner insulation in exposed outdoor ducts when possible or where there is a lack of quality installation expertise for external insulation/vapor barrier on ductwork.

d) Insulate exhaust ducts passing through concealed spaces which exhaust conditioned air, and provide with a vapor barrier in areas where the 1 percent outdoor ambient dewpoint temperature is higher than the design indoor dry bulb temperature.

14.10.5 Equipment Insulation. Provide insulation with vapor barrier and coatings on all equipment associated with the chilled water, refrigeration, or air conditioning system, including chilled water pumps, air handlers and chillers.

14.11 Humidity Control. Control humidity through the use of properly designed air conditioning systems to provide adequate dehumidification.

14.12 System Selection and Sizing. Consider the capacity of the air conditioning system for cooling and dehumidification under full and minimum part load conditions in the design analysis. In general, use the one percent design wet bulb temperature from NAVFAC P-89 for equipment sizing and in the calculation of the latent cooling load.

14.12.1 Sizing. For the locations indicated, size the comfort air conditioning systems on the criteria in Table 3.

14.12.2 Cooling Coils. Ensure cooling coils have adequate latent, as well as sensible, cooling capacity under full and minimum part load conditions.

14.13 System Design Considerations. Where possible, design the air conditioning system to provide cooling for the entire building as follows.

14.13.1 General. Air condition toilets, corridors, closets, and storage rooms. Provide circulation of conditioned air through enclosed spaces.

a) Use excess air from the air conditioned space to make up air exhausted from the bathrooms. Do not include the bathroom cooling loads in the sizing of the air conditioning equipment. Locate exhaust grilles over or close to shower areas.

b) In Guam, Philippines, and Diego Garcia and other high humidity tropical areas where the 1 percent ambient dewpoint temperature exceeds 70 degrees F, seal the mechanical equipment rooms. Size the air conditioning equipment to supply one to two air changes/hour of conditioned air to slightly pressurize the mechanical room spaces and to maintain the room conditions in the range of 80 degrees F to 85 degrees F dry bulb and 50 percent to 60 percent relative humidity. Exhaust all air supplied to the mechanical spaces through room exfiltration.

c) Treat space above ceilings as a conditioned space in areas where the 1 percent ambient dewpoint temperature exceeds the indoor dry bulb temperature. Circulate conditioned air in the ceiling plenums to prevent formation of condensation.

Table 3
Air Conditioning System Sizing Criteria

DESIGN ROOM CONDITIONS		
Location		Temp. (Dry Bulb)/ Relative Humidity
Philippines, Guam, Diego Garcia and other areas with 1 percent ambient dewpoint temperatures equal to or greater than 70 degrees F		75 degrees F/55 percent
Areas with 1 percent ambient dewpoint less than 70 degrees F		75 degrees F/55 percent
OUTDOOR CONDITIONS		
Location		NAVFAC P-89 Summer Design Temp. Columns
Philippines, Guam, Diego Garcia and other areas with 1 percent ambient dewpoint temperatures equal to or greater than 70 degrees F		1 percent dry bulb and 1 percent wet bulb
Areas with 1 percent ambient dewpoint less than 70 degrees F		2-1/2 percent dry bulb and 1 percent wet bulb
SAFETY FACTOR		
All Areas	5 percent sensible and 5 percent latent	
CONDENSER SIZING		
Location	Air Temperature	Entering Refrig. Condensing Temp.
Philippines and other areas with 1 percent ambient dry bulb temperature equal to or greater than 94 degrees F	100 degrees F	120 degrees F
Guam, Diego Garcia, and other areas with 1 percent ambient dry bulb temperature equal to or greater than 89 degrees F and less than 94 degrees F	95 degrees F	115 degrees F
COOLING TOWER SIZING		
All Areas	1 percent wet bulb with 7 degrees F approach	

14.13.2 Controls. Consider the following when designing the air conditioning controls.

a) When reheat is used with systems controlling humidity, let the thermostat control the flow to the cooling coils under normal conditions. On an increase in humidity, the humidistat overrides control of the flow to the cooling coils and, simultaneously, the thermostat assumes control of the reheat coil to prevent over cooling.

b) Whenever possible, provide modulating, in lieu of on/off controls. Provide proportional-derivative-integral controls in lieu of simple proportional controls, when space temperature and humidity must be maintained within narrow limits.

c) Specify chillers and air conditioners with hot gas bypass on the last stage when the anticipated air conditioning load may drop below the lowest stage capacity of the unit.

14.14 Design Practices

14.14.1 Design Analysis. The basis of design analysis includes the use of air conditioning systems such as variable-volume constant-temperature, variable-temperature constant-volume, and terminal-air blenders. In addition to first-cost and life-cycle cost considerations, base system on the capability of the air conditioning system to control the humidity in the conditioned spaces continuously under full-load and part-load conditions.

14.14.2 Energy Analysis. Support system selection by an energy analysis computer program, where applicable, in accordance with current energy conservation design guidelines. Evaluate latent heat gain due to vapor flow through the building structure and air bypassed through cooling coils, and the dehumidification performance of the air conditioning system under varying internal and external load conditions to ensure proper system performance. The computer program includes a printout of the space temperature and relative humidity under various internal and external loads.

14.14.3 Outside Air. Condition outside air at all times through a continuously operating air conditioning system using a 4-row minimum cooling coil. Use a 6- or 8-row coil in lieu of a 4-row coil, if required to control dewpoint. Prevent outside air from bypassing the cooling coil when possible. Ensure that outside air is adequate in quantity to slightly pressurize the building under most wind velocity and building exhaust conditions. The amount of outside air over exhaust air is generally in the range of 10 to 30 percent.

14.14.4 Cooling Load. In addition to calculation of the cooling load at maximum design conditions, make a cooling load calculation for the low-temperature, high-humidity conditions to determine the greatest dehumidification load that may be encountered on cloudy, humid days.

14.14.5 Other Considerations

a) Select main cooling coils with 6 coil rows minimum and 12 fins minimum per inch where feasible. Consider selecting main cooling coils with 8 coil rows whenever possible to ensure adequate coil contact time for improved dehumidification.

b) Ensure chilled water supply temperature is low enough for proper dehumidification.

c) Keep face velocity through the cooling coils below 550 fpm. Specify intertwined or vertical split-row cooling coils in lieu of horizontal split-row cooling coils to ensure that the entire air passage area in the coil comes in contact with active cooling surfaces for proper dehumidification. Ensure that coils have low-bypass factors.

d) Select air conditioning equipment to ensure the minimum anticipated cooling load is larger than the capacity of the lowest stage of the equipment. Use multiple air conditioning units if this is not possible.

e) Keep building under slight positive pressure by providing slightly more make up air than the amount of air exhausted through the bathroom exhausts and other exhaust systems.

f) Provide adequately sized condensate drains for all air conditioning coils and insulate the waste lines.

g) Consider the use of heat recovery to reduce operating costs.

h) Do not use economizer cycles.

i) Use draw through air handlers where possible.

j) Locate exhaust registers as close as possible to the source of the moisture.

k) Consider the use of air cooled condensers in lieu of cooling towers.

l) Keep system and controls simple. Do not over design, especially in areas where the lack of qualified maintenance may make sophisticated systems and controls an upkeep problem.

m) For variable air volume systems, use electric- or pneumatic-powered versus system-powered variable air volume terminal boxes. Select terminal boxes so design CFM is within 75 percent maximum CFM in capacity range. Provide minimum CFM limit stop for minimum air recirculation in accordance with American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) standards.

n) Do not use outside air to ventilate plenum spaces above suspended ceilings in air conditioned buildings.

Section 15: ELECTRICAL

15.1 Scope. This section covers electrical materials, equipment, and installation techniques used in general construction in a tropical environment.

15.2 General Design Considerations. Salt-laden air, high temperatures and relative humidity, insect infestation, and heavy rainfall are the primary causes of electrical maintenance problems and system failures in a tropical environment. In addition, during hurricanes and typhoons, driven rain and winds in excess of 100 miles per hour cause extensive damage to overhead pole lines and insufficiently protected switchgear, transformers and circuit components. The interiors of air conditioned buildings are not subject to the harsh elements of the tropical climate; design them in accordance with NFGS-16402, Interior Wiring Systems.

15.3 Application Guidelines

15.3.1 Equipment. Installing equipment under building eaves or canopies, within enclosed equipment rooms, and on the prevailing downwind sides of buildings contributes to a more durable system with less maintenance costs. Locating switchboards, panelboards, starters, motor control centers and other major electrical items indoors improves system reliability during hurricanes and typhoons and reduces the need for exotic, expensive enclosures.

15.3.2 Distribution. Underground distribution and 600 volt wiring are highly recommended to ensure superior protection from hurricanes and typhoon wind damage. However, direct buried cables are difficult to replace, subject to termite damage, and are not recommended. Design in accordance with MIL-HDBK-1004/2, Power Distribution Systems. In hurricane and typhoon areas, prestressed concrete poles are recommended as an alternative to wood poles, funds permitting.

15.4 Construction/Materials Consideration. Table 4 is a comparison of stainless steel, aluminum, polyethylene, fiberglass-reinforced concrete (FRP), and copper in various environments and their relative abilities to resist corrosion.

15.4.1 Non-corrosive Materials. Generally, use corrosion-resistant materials such as plastic, fiberglass, copper or aluminum coated steel, or anodized or copper-free aluminum for installations exposed to the elements. Where corrosion resistant materials lack sufficient physical strength, or are subject to deterioration from the sun, or are not available, provide ferrous materials with protective enclosures and coatings.

Table 4
Corrosion Resistance Comparison

APPLICATION	STAINLESS STEEL	COPPER	ALUMINUM	POLY-ETHYLENE	FRP
General Outdoor	Very Good	Very Good	Very Good	Very Good	Very Good
Marine Outdoor	Very Good	Very Good	Good	Very Good	Very Good
General Industrial	Very Good	Very Good	Good	Very Good	Very Good
Fresh Water	Very Good	Good	Very Good	Very Good	Very Good
Sea Water	Very Good	Good	Fair	Very Good	Very Good

15.4.2 Aluminum. Where the use of 6061 and 6063 series aluminum alloy materials is permitted, anodize such materials after the cutting, bending, forming, and drilling of the parts are completed. The item can then be assembled. Do not use aluminum alloy where movement or contact of bearing surfaces is expected.

15.5 Underground Facilities. Underground installations in the tropics are characterized by high salt water tables, and high earth moisture content. On small South Pacific islands, the entire underground system and embedded materials are subject to constant salt water exposure and inundation. It is not uncommon for ductlines, handholes and manholes to contain standing water throughout the year. Select materials, cables, and splices on the basis of resistance to chemical deterioration and submersion. Aluminum conduit is especially subject to corrosion from salt and coral; therefore, do not use it in underground situations. Note that underground cable is extremely susceptible to subterranean termite damage. During installation of underground cable, soil treatment with termiticide is recommended.

15.6 Protection Against Humidity, Moisture, and Temperature

15.6.1 Electrical Components. Do not treat switches, fuses, contacts, oil-immersed transformer windings, and heater elements with fungus-resistant coating. Other materials and components which are inherently fungus-resistant or are protected by hermetic sealing need not be treated nor coated.

15.6.2 Circuit Elements (Low Temperature Rise). Coat circuit elements not covered above and which have a temperature rise of not more than 75 degrees F when operating at full load with a fungus-resistant varnish conforming to

Specification MIL-V-176, Varnish, Moisture and Fungus Resistant (for Treatment of Communication, Electronics and Associated Equipment). Circuit elements include solenoids, relays, terminal and junction blocks, capacitors, and control coils.

15.6.3 Circuit Elements (High Temperature Rise). Do not coat circuit elements such as motor coils, generator and dry type transformer windings, and similar electrical components, which have a temperature rise exceeding 75 degrees F when operating at full load, with a fungitoxic compound. Instead, give such components two coats of varnish and one sealer coat. Apply the coats by the vacupressure, immersion, centrifugal or pulsating-pressure, or built-up method so as to fill all interstices in the coils and preclude the entrapment of air or moisture. The sealer coat may be applied by brushing or spraying.

15.6.4 Ferrous Items. Where steel is necessary as a base material, use material which is galvanized, plated, or cladded. Use stainless steel where applicable, with type specified to provide for mechanical, structural and non-corrosive characteristics. Clear epoxy coatings and metallized coatings provide satisfactory additional corrosion protection.

15.6.5 Ambient Temperature. Give due consideration to high ambient temperatures when specifying and sizing electrical equipment. Derating of components is necessary where normal operating temperatures exceed 86 degrees F, such as rooftop installations and the interiors of protective enclosures. Derate outdoor transformers in accordance with ANSI temperature loading guides. Precautions such as ventilation fans may be necessary to assure reliable operation with long service life.

15.7 Wiring Systems. The climatic conditions in most tropical areas are such that all non-enclosed locations are classified as "wet" locations as defined by the National Fire Protection Association, Inc. (NFPA) No. 70, National Electrical Code (NEC).

15.8 Raceways. Design raceway systems in accordance with MIL-HDBK-1004/2.

15.9 Conduits and Fittings. On piers and in other hostile environments where galvanized steel conduits are normally specified, use PVC-jacketed galvanized steel conduits and fittings. Other documents which form a part of the specification for the plastic coated galvanized steel rigid conduits and fittings are American National Standards Institute Inc. (ANSI) Standard C80.1, Specification for Rigid Steel Conduit, Zinc Coated, and Underwriters' Laboratories Inc., (UL)-6, Conduit Electrical, Rigid Metal.

15.10 Enclosures and Boxes. Ferrous metal enclosures and boxes exposed to salt-laden air provide service for only a few years. Use cast copper-free aluminum or PVC outlet bodies or boxes in lieu of cast ferrous metal. In very severe corrosive environments, the use of stainless steel (Type 316 or 326), fiberglass enclosures, or aluminum alloy 5052 enclosures are recommended over sheet metal raintight enclosures. Pressed steel outlet boxes set in any concrete that is high in alkaline content are subject to corrosion. The use of non-metallic outlet boxes and non-metallic conduit is recommended.

15.11 High Voltage Distribution (Above 600 Volts)

15.11.1 Underground Distribution. To achieve superior protection against hurricanes and typhoons and salt-laden air, design power distribution for underground installation, funds permitting. If direct buried cables are used, protect the cables from physical damage with route markers, treat the soil within 12 inches of the cable for termites, and install plastic polyethylene warning tapes in the trench over the cables. Ensure that all ferrous materials used in manholes or handholes are hot-dipped galvanized and coated with epoxy or bituminous paint.

15.11.2 Overhead Distribution

15.11.2.1 Poles. Poles may be wood, metal, or prestressed concrete. (The requirement for prestressed concrete poles is much more critical in hurricane and typhoon areas than in areas where these extremely high winds occur.) Protect all checks and cracks in wood poles and fill with a preservative grease of 10 percent pentachlorophenol or other preservative. During or immediately following pole installation, treat the soil 12 inches around and down to the base of the pole with termiticide in areas infested by termites. Ensure that wood poles are line-guyed and every fifth pole is guyed 4 ways, and pole-top transformer banks are limited to sizes recommended in MIL-HDBK-1004/2.

15.11.2.2 Pole Caps. To minimize leaching of wood preservative and to prevent pole top decay, install pole caps on all pole tops prior to installation. Circular, low density polyethylene cover caps are commercially available. The cover caps are secured by driving a 2 inch aluminum nail through each of the tabs. Prior to securing the caps, apply a filler or preservative paste material to eliminate any air space between the pole top and the cover cap.

15.11.2.3 Conductors. Use aluminum AAAC conductors in lieu of Type ACSR.

15.11.2.4 Insulators and Terminators. Insulators and terminators are subject to flashover as a result of airborne salt build-up. Rate all insulators and terminators for the next higher voltage level above the system voltage. After installation, coat insulators and terminators with silicon grease for additional protection against flashover. Heat shrinkable skirt type creepage extenders, in accordance with MIL-HDBK-1004/2, may be used to provide additional flashover protection in high salt-air environments.

15.11.2.5 Hardware. Ensure that ferrous metal hardware are hot-dip galvanized, and that aluminum guys with concrete anchors are in accordance with MIL-HDBK-1004/2.

15.11.3 Transformers and Switchgear

15.11.3.1 Distribution Transformers. Generally, use pad-mount type transformers, undercoated where installed outdoors. Use liquid-filled sealed type transformers, without the breather pipe, or dry type, totally enclosed self-cooled, for less than 600-volt application. Where transformers are located in a vault, cast core dry transformers are recommended for their inherent fungus resistance and lack of fire-rated enclosure requirement.

15.11.3.2 Switchgear. Enclose switchgear in metal. Include all switchgear enclosures with thermostatically controlled space heaters for humidity control. Due to fewer exposed contacts, primary vacuum breakers are recommended over air breakers or fusible interrupters. Seal control relays where provided in dusty or humid environments.

15.11.3.3 Protective Shelters. In the tropics all ferrous items are highly susceptible to accelerated corrosion when exposed to the weather. Also, damage to the protective coating on equipment can be expected during routine operational inspection and maintenance of transformer and switchgear facilities. Furthermore, hurricane and typhoon damage reports indicate that these exterior type installations are very susceptible to damage by flying debris. Protect pad-mounted transformer and switchgear installations in hurricane- and typhoon-prone areas from the weather with a structural shed-type enclosure of either concrete and masonry.

15.11.3.4 Fiberglass Reinforced Enclosures. In areas with severe corrosion potential, provide reinforced molded one-piece fiberglass enclosures for pad-mounted switchgear and transformers if they are installed outdoors.

15.12 Service and Distribution (600 Volt and Below)

15.12.1 Switchboards and Motor Control Centers. Switchboards and motor control centers may be of the standard manufacturers design. It is recommended that all switchboards and motor control centers be installed in enclosed buildings. If installed outdoors, provide a fiberglass housing. Standard factory-finished ferrous weatherproof housings do not provide satisfactory service life.

15.12.2 Panelboards. For panelboards use the circuit breaker type, copper bussed, located in the interior of buildings or within enclosed spaces. Use bolt-on rather than plug-on breakers to minimize contact corrosion problems. If a panelboard is located on the exterior of a building, provide a fiberglass enclosure around the panelboard. Standard rain caps on factory modified panelboards do not afford sufficient protection against driven rain.

15.12.3 Engine Generators. Engine generators by their inherent critical nature must be protected from the elements by installation in an enclosed room. Exhaust pipes, mufflers and standard weatherproof housings installed outdoors will not provide satisfactory service life in a tropical environment.

15.13 Cathodic Protection. Provide cathodic protection for underground ferrous pipelines and storage tanks and steel (sheet) piles. Cathodic protection systems may be of the sacrificial anode, rectifier type or a combination of the two. Locate rectifier control boxes in enclosed rooms or within fiberglass enclosures with ventilation provisions where separate dedicated rooms are not available. For connections to tanks and pipelines use the exothermic weld types to prevent contact corrosion. When performing calculations, use in-situ resistivity test results since ground resistivity in the tropics varies from high (dry coral) to very low (volcanic clay).

BIBLIOGRAPHY

Belt, Lemmon and Lo, Study and Evaluation of Building Designs in the Western Pacific Ocean Area, Okinawa, Honolulu, Hawaii.

Belt, Lemmon and Lo, Study and Evaluation of Building Designs in the Western Pacific Ocean Area, The Marianas, Honolulu, Hawaii.

Belt, Lemmon and Lo, Study and Evaluation of Building Designs in the Western Pacific Ocean Area, The Philippines, Honolulu, Hawaii.

Carmichael, A. J.; Roberts, A. W.; Scott, O. J.; and Singh, R., Bond Characteristics of Concrete Reinforcing Tendons Coated With Zinc, Progress Report No. 1, June 1975 - March 1976, International Lead Zinc Research Organization, Inc., March 1976.

Christensen, Kenneth A.; and Williamson, Robert Brady, Solving the Galvanic Cell Problem in Ferro-Cement, Structural Engineering Laboratory, University of California, Berkeley, California, July 1971.

Cornet, Israel; and Bresler, Boris, Corrosion of Steel and Galvanized Steel in Concrete, University of California, Berkeley, California, April 1966.

Cornet, Israel; and Bresler, Boris, Corrosion of Steel in Prestressed Concrete, University of California, Berkeley, California.

Corrosion Control by Cathodic Protection (Subsurface Metal Structures) MO-307, Naval Facilities Engineering Command, Washington, D.C.

Dallaire, Gene., Designing Bridge Decks that Won't Deteriorate," American Society of Civil Engineers Journal, Vol. 43, No. 8, New York, NY, August 1973.

Design of Post-Tensioned Slab, Second Edition, First Printing 1984, pg. 26, Post-Tensioning Institute, Phoenix, AZ 85021.

Engineering and Construction in Tropical and Residual Soils, Proceedings of the ASCE Geotechnical Engineering Division Specialty Conference, American Society of Civil Engineers, Honolulu, Hawaii, January 1982.

Epoxy Coated Seven-Wire Strand for Prestressed Concrete, PCI Journal, Prestressed Concrete Institute, Vol. 29, No. 4 (July/August 1984), pp 120-129.

Galvanized Reinforcement for Concrete With Supplement, Zinc Institute, Inc., and International Lead Zinc Research Organization, November 1970.

Gebber, S. H., The Effects of High-Range Water Reducers in the Properties of Freshly Mixed and Hardened Flowing Concrete, PCA Research and Development Bulletin RD 081.01T, Portland Cement Association, Chicago, IL 60077.

Harding-Lawson Associates, Prestressed Concrete Reinforcements in Coral Aggregate Concrete Bibliography, Agana, Guam, Pacific Division, Naval Facilities Engineering Command, (PACNAVFACENGCOM).

Harding-Lawson Associates, Study of Prestressed Concrete Reinforcements in Coral Aggregate Concrete Testing of Specially Prepared Beam Samples on Guam, Mariana Islands, Agana, Guam, Pacific Division, Naval Facilities Engineering Command, (PACNAVFACENGCOM).

Hockaday, Robert C., FCSI, Causes and Cures for Leaky Roofs in Hawaii, Hawaii Architect, Vol. 18, No. 8 (August 1989), pp 26-31, Honolulu, Hawaii.

Howdyshell, P. A., The Use of Coral as an Aggregate for Portland Cement Concrete Structure, Technical Report M-88, Construction Engineering Research Laboratory (CERL), Department of the Army, June 1974.

Lessons Learned from Inspection-Evaluation of Damages to Facilities Caused by Typhoon Pamela, Naval Facilities Engineering Command, Pacific Division.

Long Range Systematic Study of Construction Materials in the Marianas Area, Officer in Charge of Construction, Marianas Area, July 1964.

Masonry Construction for Buildings, Department of the Army, TM 5-809-3.

Munson, Albe E., Construction Design for Landscape Architects, McGraw-Hill Book Co., Chicago, IL, 1974.

Nine-Year Program on Marine Atmosphere Exposure of Protective Coatings For Steel, Technical Reports R501 and R501S, January 1967 and Supplement November 1967, Naval Civil Engineering Laboratory, Port Hueneme, California.

Prestressed Concrete Institute, Recommended Practice for Glass Fiber Reinforced Concrete Panels, prepared by PCI Committee on Glass Fiber Reinforced Concrete Panels, Chicago, IL.

Recommended Practice for Shotcreting, (ACI 506-66), American Concrete Institute, 1972.

Robinette, Gary O., Plants/People and Environmental Quality, U.S. Department of Interior, National Park Service, Washington, D.C., in collaboration with the American Society of Landscape Architects, 1972.

Stark, David; and Perenchio, William, Performance of Galvanized Reinforcement in Concrete Bridge Decks, Final Report, July 1974 -October 1975, ZE-206, Construction Technology Laboratories.

Steel, Marcus D.; and Drisko, Richard W., Fungal-Resistant Organotin Resins, Naval Civil Engineering Laboratory, Port Hueneme, California.

Super Typhoon Pamela, After-Action Report, Commander, U. S. Naval Forces, Marianas, Guam, 1976.

Zinc Inorganic Silicate Coating: Five Years marine Atmospheric Exposure, Technical Report R776, Naval Civil Engineering Laboratory, Port Hueneme, California.

Zollo, Ronald F., Collated Fibrillated Polypropylene Fibers in FRC, Research Paper prepared for presentation at ACI-Fibre Reinforced Concrete International Symposium, September 1982.

REFERENCES

NOTE: THE FOLLOWING REFERENCED DOCUMENTS FORM A PART OF THIS HANDBOOK TO THE EXTENT SPECIFIED HEREIN. USERS OF THIS HANDBOOK SHOULD REFER TO THE LATEST REVISIONS OF CITED DOCUMENTS UNLESS OTHERWISE DIRECTED.

FEDERAL/MILITARY SPECIFICATIONS, STANDARDS, BULLETINS, HANDBOOKS, AND NAVFAC GUIDE SPECIFICATIONS:

Unless otherwise indicated, copies are available from Naval Publishing and Printing Service Office, (NPPSO), Standardization Documents Order Desk, Building 4D, 700 Robbins Avenue, Philadelphia, PA 19120-5099.

HANDBOOKS

MIL-HDBK-1004/2	Power Distribution Systems

GUIDE SPECIFICATIONS

NFGS-09900	Painting
NFGS-15250	Insulation of Mechanical Systems
NFGS-16402	Interior Wiring Systems

SPECIFICATIONS

MIL-V-173	Varnish, Moisture and Fungus Resistant (For Treatment of Communications, Electronics and Associated Equipment)

NAVY MANUALS, P-PUBLICATIONS, AND MAINTENANCE OPERATING MANUALS:

Unless otherwise indicated, copies are available from Commanding Officer, Naval Publications and Forms Center (NPFC), 5801 Tabor Avenue, Philadelphia, PA 19120-5099. To order these documents, Government agencies must use the Military Standard Requisitioning and Issue Procedure (MILSTRIP), using the stock control number obtained from NAVSUP Publication 2002; the private sector must write to NPFC, ATTENTION: Cash Sales, Code 1051, 5801 Tabor Avenue, Philadelphia, PA 19120-5099.

NAVAL FACILITIES ENGINEERING COMMAND (NAVFACENGCOM) PUBLICATIONS

NTIS-A090145 Air Conditioned Buildings in Humid Climates, Guidelines for Design, Operating and Maintenance, April 1980. [Prepared for Southern Division, Naval Facilities Engineering Command, P.O. Box 10068, Charleston, South Carolina 29411]

P-89 Engineering Weather Data

NON-GOVERNMENT PUBLICATIONS:

Unless otherwise specified, the issues of the documents which are DoD-adopted are those listed in the Department of Defense Index of Specifications and Standards (DODISS). Copies of these publications can be obtained from the issuing organization addresses indicated.

AMERICAN CONCRETE INSTITUTE (ACI)

305 Hot-Weather Concreting

(Unless otherwise indicated, copies are available from American Concrete Institute (ACI), P.O. Box 19150, Redford Station, Detroit, MI 48219.)

AMERICAN NATIONAL STANDARDS INSTITUTE INC. (ANSI),

C 80.01 Specification for Rigid Steel Conduit, Zinc Coated

(Unless otherwise indicated, copies are available from American National Standards Institute Inc. (ANSI), 1430 Broadway, New York, NY 10018.)

AMERICAN WOOD PRESERVATIVE ASSOCIATION (AWPA)

C2 Lumber, Timber, Bridge Ties and Mine Ties - Preservative Treatment by Pressure Process

C9 Plywood - Preservative Treatment by Pressure Process

(Unless otherwise indicated, copies are available from American Wood Preservative Association (AWPA), P.O. Box 849, Stevensville, MD 21666.)

AMERICAN WOOD PRESERVATIVE BUREAU (AWPB)

LP2	Procedure for Soft Wood Lumber, Timber, and Plywood Pressure Treated With Water-Borne Preservatives for Above Ground Use
LP22	Standard for Softwood Lumber, Timber, and Plywood Pressure-Treated with Water-Borne Preservatives for Above-Ground Use
MP1	Procedure for Dual Tratment of Marine Piling Pressure Treated With Water-Borne Preservent and Creosote for Use in Marine Water
MP2	Standard for Marine Pilings Pressure Treated with Creosote, for Use in Marine Waters
MP4	Standard for Marine Pilings Pressure Treated with Water-Borne Preservatives, for Use in Marine Waters

(Unless otherwise indicated, copies are available from American Wood Preservative Bureau (AWPB), P.O. Box 6085, Arlington, VA 22206.)

NATIONAL FIRE PROTECTION ASSOCIATION, INC. (NFPA)

NFPA No. 70	National Electrical Code (NEC)

(Unless otherwise indicated, copies are available from National Fire Protection Association, Inc. (NFPA), Batterymarch Park, Quincy, MA 02269.)

UNDERWRITERS' LABORATORIES INC. (UL)

UL-6	Conduit Electrical, Rigid Metal

(Unless otherwise indicated, copies are available from Underwriters' Laboratories Inc., 333 Pfingston Road, Northbrook, IL 60017.)

CUSTODIAN
NAVY - YD

PREPARING ACTIVITY
NAVY - YD

PROJECT NO.
FACR-1057

STANDARDIZATION DOCUMENT IMPROVEMENT PROPOSAL

INSTRUCTIONS

1. The preparing activity must complete blocks 1, 2, 3, and 8. In block 1, both the document number and revision letter should be given.
2. The submitter of this form must complete blocks 4, 5, 6, and 7.
3. The preparing activity must provide a reply within 30 days from receipt of the form.

NOTE: This form may not be used to request copies of documents, nor to request waivers, or clarification of requirements on current contracts. Comments submitted on this form do not constitute or imply authorization to waive any portion of the referenced document(s) or to amend contractual requirements.

I RECOMMEND A CHANGE:	1. DOCUMENT NUMBER	2. DOCUMENT DATE *(YYMMDD)*
	MIL-HDBK 1011/1	91/10/31

3. DOCUMENT TITLE
TROPICAL ENGINEERING

4. NATURE OF CHANGE *(Identify paragraph number and include proposed rewrite, if possible. Attach extra sheets as needed.)*

5. REASON FOR RECOMMENDATION

6. SUBMITTER

a. NAME *(Last, First, Middle Initial)*	b. ORGANIZATION	
c. ADDRESS *(Include Zip Code)*	d. TELEPHONE *(Include Area Code)* (1) Commercial (2) AUTOVON *(If applicable)*	7. DATE SUBMITTED *(YYMMDD)*

8. PREPARING ACTIVITY

a. NAME	b. TELEPHONE *(Include Area Code)*
Commander Pacific Division	(1) Commercial (808) 474-5349 (2) AUTOVON
c. ADDRESS *(Include Zip Code)* Naval Facilities Engineering Command Pearl Harbor, HI 96860-7300	IF YOU DO NOT RECEIVE A REPLY WITHIN 45 DAYS, CONTACT: Defense Quality and Standardization Office 5203 Leesburg Pike, Suite 1403, Falls Church, VA 22041-3466 Telephone (703) 756-2340 AUTOVON 289-2340

DD Form 1426, OCT 89 *Previous editions are obsolete.* 198/290