An Introduction to Tropical Engineering: Concrete, Wood and Metals

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1. CONCRETE

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

1.2 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.

1.2.1 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.

1.2.2 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.

1.3 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.

1.3.1 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.

1.3.2 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.

1.3.2.1 FINE AGGREGATES. Fine aggregate may be washed natural beach sand, manufactured sand, or a combination of beach and manufactured sand.

1.3.2.2 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.

1.3.3 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.

1.3.4 CONCRETE ADDITIVES

1.3.4.1 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; and
d) Quality control requirements are included in the specifications.

1.3.4.2 RETARDANT. The use of retardant and water-reducing admixtures in concrete is recommended.

1.3.4.3 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 the 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.

1.4 CORROSION

1.4.1 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.

1.4.2 CORROSION TREATMENT IN AN EXISTING STRUCTURE. In an existing structure, after corrosion of steel reinforcement begins, 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 the corroded reinforcing steel in repair operations. If corrosion is too advanced, replace the reinforcing steel before concrete repair.

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

1.6 CONCRETE REINFORCEMENT

1.6.1 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, thereby creating a gas-filled void along the entire surface area of the reinforcement.

1.6.2 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.

1.6.3 SYNTHETIC FIBER REINFORCING. Synthetic fiber concrete reinforcement is useful as a secondary concrete reinforcement to reduce concrete cracking. Cracks that would normally 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 the reinforcing steel. Synthetic fiber is strongly recommended for areas consisting of thin sections, precast units, vaults, concrete pipes, sidewalks, and especially slabs on grade.

1.6.4 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, neither 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.

1.7 CONCRETE ACCESSORIES

1.7.1 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 the concrete and grout with non-shrink, non-metallic grout.

1.7.2 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.

1.7.3 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.

1.7.4 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.

1.8 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.

1.9 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.

1.9.1 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.

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

1.9.3 MATERIALS. Coat reinforcing steel and tie wires in precast concrete panels, as well as all steel accessories, with fusion-bonded epoxy. 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.

1.9.4 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 elements, 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.

1.10 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.

1.10.1 TENDONS. For unbonded tendons use prestressed 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 nonreactive to steel, concrete and other 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.

1.10.2 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.

1.10.3 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 the application are the 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.

1.10.4 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.

1.10.5 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 post-tensioned structures. This restriction refers also to the mortar used to patch or fill stressing pocket recesses.

1.10.6 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.

1.11 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.

1.12 CONCRETE COVER. See Table 1 for the recommended minimum concrete cover over non-coated reinforcing steel in tropical environments.

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

Table 1

Reinforcing steel concrete cover

2. CONCRETE MASONRY

2.1 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.

2.2 GENERAL DESIGN CONSIDERATIONS

2.2.1 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, tooling of joints, and the applications employed to reduce water infiltration. As with concrete, avoid salt in the aggregate or water. Limit the chloride concentration in the mortar mix to minimize corrosion of embedded steel items.

2.2.2 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.

2.3 CONSTRUCTION/MATERIALS CONSIDERATION. CMU is very often the material of choice in the tropical regions because of its universal availability and the familiarity of the local workmen with its applications. 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.

2.4 CONCRETE MASONRY UNITS

2.4.1 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.

2.4.2 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.

2.4.3 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 with 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.

3. METALS

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

3.2 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 heavy concentration of salt in the air, soil and water in the tropics provide an ideal environment for metal corrosion to occur. Protection of all metals from these conditions is critical

3.2.1 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 should also be accessible for proper inspection and maintenance.

3.2.2 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

3.3 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.

3.4 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.

3.5 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.

3.6 STRUCTURAL STEEL

3.6.1 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.

3.6.2 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 the structural steel is factory primed before being transported.

a) When structural steel is exposed to the weather elements 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, use two coats of shop primer in combination with two finish coats on steel members. Surface preparation includes sandblasting or mechanical brushing to near white steel prior to paint application.

d) Where fasteners are exposed to the weather elements, 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 metals as finishing strips or as components of other securement systems, even if a protective coating is to be provided.

3.6.3 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 a 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.

3.7 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.

3.7.1 CORROSION EXPOSURE. The areas adjacent to miscellaneous metal items are often more susceptible to corrosion than their component parts, 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, such as handrails, protective guards and wire screen, are likewise subject to significant corrosion.

3.7.2 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.

3.7.3 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.

3.7.4 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.

3.8 PROTECTIVE COATINGS. The choice of coating is dependent on the 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.

4. WOOD AND PLASTICS

4.1 SCOPE. This section covers rough carpentry, heavy construction timber, finish carpentry, plywood, wood treatments, prefabricated structural wood and its uses, as well as prefabricated plastics. Rough hardware as well as particle board treatment and use are also included.

4.2 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 inspections to ensure proper treatment.

4.3 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.

4.4 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 the air humidity conditions of the site, but moisture content shall not be more than 19 percent.

4.4.1 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.

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

4.4.3 PARTICLE BOARD. Do not use this material in the tropics. It is unstable in wet or humid conditions and cannot be preservative treated.

4.4.4 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, the termites will eat through it to find wood. If wood siding is desired, specify treated plywood siding.

4.4.5 ROUGH HARDWARE. Hot-dip galvanize all ferrous metal hardware. For extreme exposed locations, consider stainless steel as the more appropriate material.

4.5 PRESSURE TREATMENTS

4.5.1 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.

4.5.2 FINISH ITEMS. For finish items not exposed to the weather elements, 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.

4.5.3 FIRE RESISTANT TREATMENT. Wherever fire-retardant wood is required, use a non-hydroscopic 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.

4.6 PLASTICS.

4.6.1 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.

4.6.2 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.

4.6.3 INTERIOR APPLICATIONS. There are no unique restrictions regarding the interior use of plastics in the tropics.

5. SITE WORK

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

5.2 GENERAL DESIGN CONSIDERATIONS

5.2.1 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.

5.2.2 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. Therefore, until those results are known, no predetermination of building foundations or foundation systems can be made.

5.3 SOIL

5.3.1 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.

5.3.2 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, the lack of adequate fresh water will make it difficult to get a thorough wash.

5.3.3 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.

5.3.4 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 a landfill for embankments, but not as a base for pavement or as concrete aggregate.

5.3.5 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.

5.3.6 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 part of the design package.

5.4 PILE FOUNDATION SYSTEMS. In certain coastal areas of the tropics, thick layers of soft marine sediments often cause difficult design problems for shore facilities. Consider pile foundation systems. 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.

5.4.1 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 the 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 the preferred choice because of their superior corrosion resistance.

5.4.2 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 Treatment of Marine Pilinq 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.

5.4.3 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.

5.4.4 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.

5.5 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 the pavement type selection as well as pavement design.

5.5.1 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.

5.5.2 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.

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

5.6.1 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 the 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.

5.6.2 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 the 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 overplant 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, embankments and vegetated 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 (or grass) protection.

5.6.3 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 or 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 facilities. The great abundance of fruit, if left unpicked, will cause major maintenance and health problems.