PDHonline Course P197 (10 PDH)

Project Management & Quality Verification

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2012

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1. PROJECT CONSTRUCTION MANAGEMENT

This section will acquaint project engineers and construction management personnel with project construction management basics. The student will learn what project construction management should be, how it works, and how to implement the construction knowledge gained in the other sections of this course.

1.1 CONSTRUCTION DESIGN REVIEWS, AND PROJECT CONSTRUCTION MANAGEMENT (PCM)

A. Project Construction Management (PCM)

PCM is the performance of tasks and personnel which ensure that construction is performed according to plans and specifications, on time, and within a defined budget. The first step is assuring the quality of the construction contract documents. The project engineer plays an important role in this review. This review is neither a substitute for a complete design review by the designers for accuracy and adequacy, nor is it a substitute for an interdisciplinary review for coordination of design documents. This review is to eliminate errors related to the biddability, constructibility, and operability review of a project.

1. Biddability, Constructibility and Operability Review (BCO)

Biddability, Constructibility and Operability review should be performed by construction, project, and operation engineers and by the construction managers who are familiar with the project location and potential site-related problems. Biddability means contract documents are free of ambiguities, omissions, and errors. Constructibility is the ease with which a project can be built and contract documents can be understood, administered, and enforced. Operability is the ease with which a project can be operated and maintained.

Reviews should include:

- Adaptation of the design to current site conditions.
- Appropriateness of contract sequencing.
- Adequacy of staging and work area.
- Clarity of bid requirements.
- Availability of labor and materials.
- Security, access, permits, and other special requirements.
- Specifications for shop drawing submittal requirements, contract performance time, etc.
- Coverage, clarity, and consistency of the plans and specifications.

BCO reviews must be thorough. The BCO review process is the key to assuring efficient construction operations and must be emphasized throughout the planning and design phases.

2. Project Engineer Responsibilities

The project engineer should check the items given above and all others related to the BCO review by examining both design documents and the final design drawings and specifications prior to project advertisement. Written comments must be submitted to the design engineers in a timely manner. This review should be accomplished at the jobsite, if possible, or should at least include a site visit. The customer, user, owner, etc., should be included in this review to assure they are involved in the latest design package and are satisfied with the documents.

3. As-Advertised Documents

The as-advertised documents should also be reviewed. This review should focus on assuring that appropriate actions have been taken to correct problems noted in previous reviews. Many times this may be the only opportunity for the construction engineer to do a BCO review. Timely and concise comments are needed to assure that amendments can be issued to correct the documents.

B. Project Engineer (PE)

PE is to assure end-product quality. The project engineer should be required to prepare a project construction plan. The project construction plan is an organizational operating plan; it addresses the overall construction operations. Supplements to the overall plan may be necessary to incorporate project-specific requirements.

1. Requirements and Significant Items

The project construction plan should include:

- Duties and responsibilities of each element of the construction personnel and respective levels of authority, including responsibilities and authorities of contractor personnel.
- Organizational chart.
- A description of policies and procedures to execute design reviews and the BCO review.
- A description of policies and procedures to execute the construction plan to include:
  - Conducting a coordination conference, also called mutual understanding conference.
  - Review/approval of the construction plan.
  - Attendance/participation in the contractor's phase-control meetings.
  - Testing requirements.
  - Reporting requirements.
  - Deficiency tracking.

2. Projects Engineers Responsibilities

The project engineer is responsible for preparing the construction plan. This provides instructions on execution of the project construction. They may request or be tasked to supplement the plan for the project(s) to which they are assigned. The plan should be specific or be supplemented to assist the construction manager in the day-to-day actions necessary to assure quality construction, i.e., attend all construction preparation-phase meetings, attend a majority of initial-phase inspections, review all tests and procedures, execute construction inspections and methods of conducting inspections.

C. Construction Management Plan

The construction management plan is prepared by the construction manager before construction activities begin. This is the contractor's plan showing how the quality requirements and construction of the contract will be met.

1. Requirements and Significant Items

- State who will be responsible for CPM (name, position, and qualifications).
- Identify all definable features of work, i.e., structural concrete, framing, electrical, earth work, etc., and state how the construction and quality of that particular feature will be controlled.
- Include procedures for scheduling and managing submittals.
- Define the testing program.
- Outline reporting procedures.
- Specifically identify a three-phase project management and inspections that are to be performed and documented by the contractor: **preparation, initial, and Review**.

1.2 PRECONSTRUCTION CONFERENCE, COORDINATION MEETINGS AND THE THREE-PHASES OF CONTROL

A. Preconstruction Conference

A preconstruction conference should be conducted as soon as possible after contract award and prior to the commencement of any physical work.

1. Attendance

Individuals attending should include personnel representing:

- The Contractor.
- Major subcontractors.
- The Project Engineer
- The Construction Manager
- The Design Engineer(s).
- The Owner.

2. Objectives

This is usually the first opportunity for all parties to meet and discuss the impending project. The preconstruction conference addresses contract requirements, personnel requirements, and procedural matters. This conference establishes ground rules for administering the contract. It must be impressed upon the contractors personnel that they will require full compliance with the contract requirements and the importance that will be placed on quality construction.

The properly conducted conference is a vital part of establishing, early in the contract, the importance and emphasis that will be placed on the quality of the finished project and how that quality is to be obtained. At this meeting roles and responsibilities are outline.

C. Three-Phase Control Concept

The three-phase control concept is the heart of an effective project management. The three control phases are preparation, initial, and review. These phased inspections should be performed on all definable features of work. A definable feature of work is one that is separate and distinct from other tasks and has the same sort of control requirements and work crew. An example is concrete for an entire project or, if a large and complex project, it may be just 4000 pounds per square inch (psi) concrete placement, with formwork being either included or separate from the concrete placement feature. A typical administration building with air conditioning (A/C), utilities, paving, interior finishes, etc., may have up to several hundred definable features of work. The three-phase inspection process and the significant features and purposes of each are given below.

1. Preparation Phase

The preparation phase inspection is in preparation for the start of a definable feature of work. This inspection meeting must be held before any construction activities have started on the particular feature of work. This meeting is held by the contractor with all associated trades (subcontractors) present. The contract requirements are reviewed, shop drawings of those items to be used for this feature are reviewed, and control requirements that the Construction Manager will use to assure quality are reviewed. Control requirements may include testing and, if so, the testing method and frequency. The Project Engineer should attend this meeting to verify that all items are correctly reviewed and that the contractor and subcontractors understand the contract requirements. Minutes of this preparation-phase inspection meeting should be prepared by the contractor and included in the daily report

2. Initial Phase

The initial-phase inspection is held at the beginning of each definable feature of work. This inspection should be conducted by the Construction Manager, accompanied by the Project Engineer. At this inspection, the workmanship quality for a definable feature of work is established for the remainder of the project. Remember that the workers who are performing the construction are, in most cases, unfamiliar with the contract's specific requirements. Examples of contract requirements that are subject to interpretation in the field are terms such as level, straight, smooth, without rough edges, completely covered, etc. The craftsmen need to be told the workmanship quality that must be attained on the project to comply with these requirements. Safety compliance should also be addressed.

It is vital that good communications be maintained between Construction Management and Project Engineers, and that satisfactory quality levels are established early in the construction activity. Separate minutes of this phase are prepared by the construction manager and submitted the project engineer.

3. Review Phase

Review inspections are conducted as each definable feature of work is started to verify that the workmanship level established at the initial phase inspection is being maintained. The Construction Manager is responsible for making these numerous review phase inspections on a daily basis, or as needed. The Project Engineer may perform these inspections; however, the Project Engineer is not responsible for these inspections. The reports should indicate that these specific inspections have been performed and detailed results reported.

When a segment of work is complete, the construction manager should carefully examine the work and prepare a "punch list" of items that do not conform to the contract requirements. The project engineer receives a copy of this list, and then checks these items to verify that known deficiencies have been corrected.

A final (completion) inspection is the last of the review inspections. It is the contractor's responsibility to identify and correct problems. It is the construction managers responsibility to participate in pre-final and final inspections with the project engineer and the customer, and to determine that all deficiencies are corrected.

TESTING AND REPORTING

A. Testing

The contractor must perform tests to verify quality throughout project construction. Testing is an essential tool that is used to assure, verify, and maintain quality.

1. Test Labs

Contractors may use an industry-recognized (commercial) testing laboratory or may establish a laboratory at the jobsite. In either case, the laboratory must be approved by the Project Engineer

B. Reporting

The old saying "the job is never finished until the paperwork is done" certainly applies to project management. But it is also true that an efficient paper trail does not necessarily mean that a quality job has been accomplished. It is important to keep the objective of the reporting process in proper perspective.

1. Requirements

The contractor is responsible for submitting a daily report to the Project Engineer who, in turn, is responsible for reviewing this report and attaching a supplement report. The contractor must report specific action taken to control the quality. All preparation and initial inspections held should be highlighted. After these inspections, review inspections are made and results reported.

2. Purpose

The purpose of the report is to inform the Project Engineer of the results of the control activities/inspections, particularly the reviews, on a continuing basis. These results cannot just say an inspection was performed and no deficiencies were found. It must give the specifics of how the quality was controlled, i.e., concrete slump was 3 inches; measured reinforcing steel spacing on placement XYZ and they complied with plans; checked paint thickness on Tank No. 1 and it was 30 mil (wet-film); domestic waterlines being installed are 2-inch type L copper per plans, and so forth. The Construction Manager signs the report stating that it is true and correct. This report gives the Project Engineer a tool that can be used to verify the inspections. Additional inspections can then be performed on unique features of work that require special attention or on problem areas that are indicated on the report.

These reports also serve as documentation of contract compliance or of non-compliance. It may be unrealistic to expect the Construction Manager to document non-compliance; however, the Project Engineer must document assurance inspections and note results that vary from those reported. These verification reports then serve as documentation of problems for which corrective action can be taken.

C. Resolving Problems

The contractor will save time and money if problems are discovered and handled by the contractor's construction personnel and corrected immediately. Project management is there to prevent potential problems, thus such shortcomings may be avoided if it is used properly throughout the entire construction project.

1. Categories

Obviously, numerous problems can and do occur on a typical construction project. Most will fit into one or more of the following categories:

- Delays (submittals, or in the correction of deficiencies).
- Planning and control.
- Testing (improper, inadequate, or untimely).
- Documentation (late, incomplete, or incorrect).
- Contractor apathy.

2. Options

There are many options open to the Project Engineer if contractor work is unacceptable. These are explained briefly below.

- Requiring contractor removal and replacement of deficient materials and/or workmanship
- Withholding payment
- Requiring removal of unqualified personnel
- Requiring the contractor to assume personal supervision
- Halting work

Allowing a contractor to proceed with deficient work only creates more serious problems later. Timely completion is invariably impacted if action by the Project Engineer is not taken.

D. The System Works

The Construction Manager and Project Engineer are essential in controlling the quality of construction and provide a check and balance that promotes a smooth, efficient construction operation. For project construction management to be successful, all parties involved in project construction management must maintain a professional working relationship, positive attitude, and be timely in all actions. In this way, the project is delivered on time and within the budget. The contractor makes a profit and the customer is satisfied.

2. SITE UTILITIES AND PLUMBING

This section provides the basic requirements for quality verification and the proper installation of utility piping systems including sanitary sewers, storm drains, and water lines, among others. Also covered are plumbing features of construction projects, such as types of pipes and fittings, and the proper methods to test and disinfect the water system.

2.1 SITE UTILITIES

A. Site Utility Materials and Equipment

Utilities common to most buildings include electrical, water, sewer, storm drain, and natural gas supply. Other types of utility piping include force mains, which are sanitary sewers under pressure. Industrial waste drains are for the discharge of chemicals not allowed in the sewage system. Energy distribution piping is used to transfer heating or cooling water from a central energy plant to various individual buildings. When natural gas is not available, then fuel oil tanks and piping may be installed. Each separate utility piping system will have specifications, installation requirements, and testing procedures that must be verified for quality construction. This section will cover water, sewer, storm drain, and natural gas systems. Utilities are piped below ground up to 5 feet from the building.

Water is supplied to the building for irrigation, plumbing, and fire protection. When a single water supply line is installed, it must meet the strict requirements for fire protection. Codes, such as National Fire Protection Association's (NFPA) 24, cover underground fire service lines. If the plumbing system water is not to be subjected to fire protection requirements or controlled by the outside post indicator valve, then separate water supply and fire lines should be installed.

Water piping may be copper, plastic, ductile iron, concrete, or steel. Steel water pipe will be galvanized and coated, as specified, or cement-mortar lined. If cast iron fittings are used, they must be cement-mortar lined. Various types of plastic may be allowed, depending on specifications. The type and location of control valves and fire hydrants must be as specified in the contract. Water control valves are normally the gate valve type. Fire hydrants will be wet or dry barrel, depending on freezing conditions, and installed with protective posts.

Sewer piping carries domestic sewage by gravity flow. Common materials include cast iron soil pipe, clay, concrete, or plastic up to 15 inches in diameter. Manholes are installed in sewer and drain piping to permit inspection and maintenance of the pipes. They are provided at changes in elevation, pipe size, slope, or direction of pipe. Straight runs of pipe will have manholes about 500 feet apart. Manholes more than 12 feet deep will include a permanent ladder and be of the eccentric type.

Storm drain piping will carry only surface run-off water and underground seepage water by means of gravity flow. Common materials include concrete, clay, corrugated aluminum, and plastic up to 15 inches in diameter. Manholes are installed as discussed for sewer piping.

Gas distribution piping carries natural or manufactured gas under pressure. Common materials include steel and plastic. A single conductor, #14 AWG (American wire gauge) wire with type TW insulation, is installed alongside plastic pipe to aid in locating the pipe. Steel pipe will be welded except at control valves, and coated as specified at the factory. Pipe joints are coated in the field with factory supplied materials. The full coating must be seal-tested as specified. Plastic pipe must be below ground, 100 psig or less, and restricted to temperatures as specified.

B . Installation of Site Utilities

1. Trenching

Good trenching provides proper bracing for support of trench walls, bedding and bell holes for pipe grade and support, and well-compacted backfill without pipe damage (See Figure 1.1-1.).

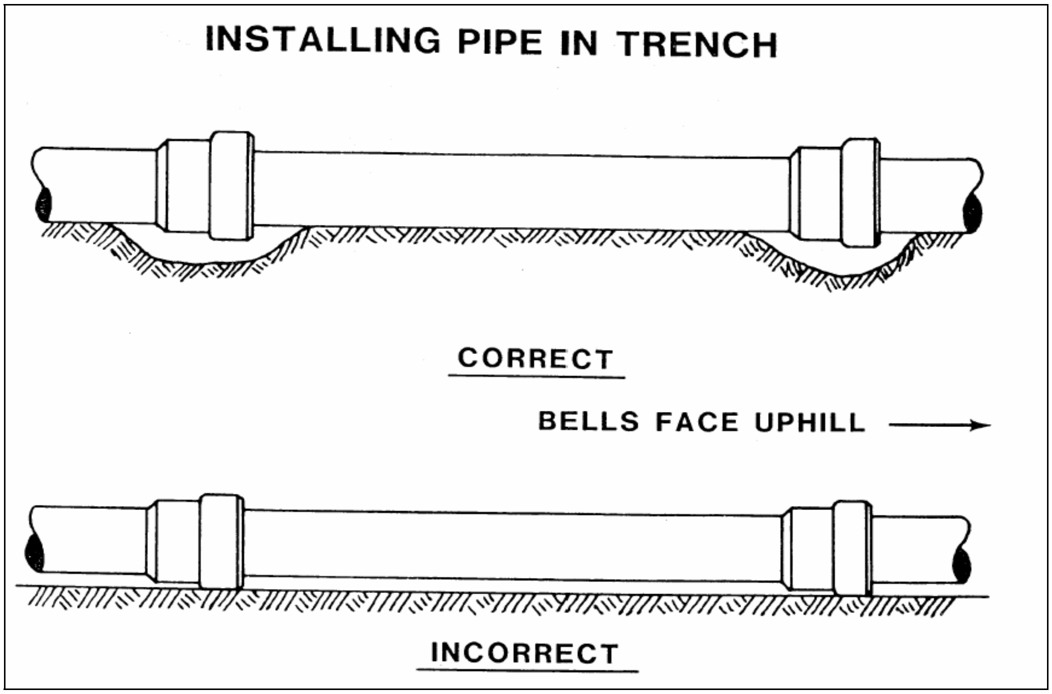


Figure 1.1-1

Excavated material must be at least 2 feet away from the edge of the trench. Trenching more than 5 feet deep may require bracing support, depending on the type of soil and amount of moisture. The contractor must have a trench safety plan.

Ladders are required in trenches over 4 feet deep, within 25 feet of workers, and must reach 3 feet above the ground surface. The trench bedding must be dry, free of rocks, graded, compacted, and must support the entire length of each section of pipe. Careful shovel work is required. The trench bed width is limited by specifications and extends from the bottom of the trench to 1 foot above the pipe. Depressions called bell holes must be dug in the trench bottom to accommodate the bell joints of the pipe and to provide space for making the joint. This will permit the barrel of the pipe to rest flat.

The backfill material is specified by the contract. It gives the maximum rock size permitted, thickness of each layer, compaction density, and moisture content. Backfill must be placed evenly on each side of the pipe.

2. Sewer and Storm Drain Piping

Bell ends must face uphill. Specified pipe slope and grade must be verified. The trench bedding of sewers and drains should be shaped to fit the lower quadrant of the pipe. The piping must be straight between manholes. Inverted siphons are U-shaped sections where a sewer line passes beneath a structure or stream and are constructed according to force main standards.

3. Water Piping

Water lines must not be in the same trench with sewer lines, gas lines, fuel lines, or electric wiring. Water lines must be 10 feet horizontally from sewage lines, or at least 6 feet if the water pipe is 1 foot above the sewage line. Bell ends must face in direction of flow with the slope required and bell holes dug. (See Figure 1.1-2.) Thrust blocks or tie rods are required at all bends of 22 1/2°or greater and at all caps, plugs, tees, and fire hydrants. Concrete thrust blocks should harden 5 days prior to applying water pressure.

Sewer lines that cross over water lines should be encased in 4 inches of concrete for 10 feet on each side of the water line. Force mains must always cross 2 feet beneath water lines.

4. Gas Distribution Piping

Gas piping is installed with the same support and backfill as water piping. Gas mains are sloped so that moisture will flow to low points where drips are installed with a valved blow-off line. Service lines should slope toward the main line.

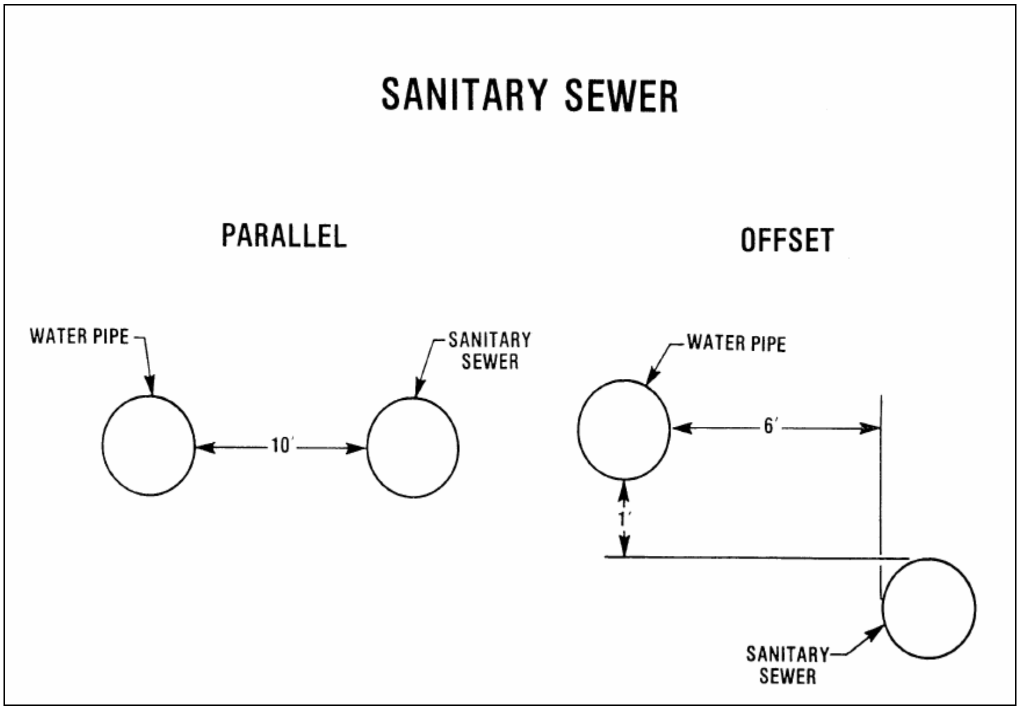


Figure 1.1-2

C. Testing of Site Utilities

1. Sanitary Sewers

a. Leakage (Exfiltration and Infiltration)
When the trench has been backfilled to at least the spring line (midpoint) of the pipe and the joints are still exposed, the pipe line must be tested for leakage by exfiltration. Each section between manholes is then tested by plugging it at the lower end. The pipe is then filled with water and a 2 foot head imposed on the upper end. The amount of water required to maintain this head during a 2 hour period is measured. The leakage must not exceed 0.2 gallons per inch diameter, per 100 feet of pipe, per hour. Visible leaks must be corrected. If the water table is above the top of the pipe, then the pipe can be tested by infiltration, which is measured for leakage by a V-notch weir (dam) at the lower end.

b. Leakage (Air Test), ASTM Standard C828-80
A low-pressure air test of vitrified clay pipe line (3 to 18 inches) is an acceptable method for determining the tightness of a sewer and is applicable to pipe materials other than clay. The sewer section is plugged at each end and pressurized with air to 3.5 pounds per square inch gauge (psig), and the time noted for the pressure to drop to 2.5 psig. If the pressure drops too quickly, then the leakage is excessive. A formula based on the surface area of the pipe and the allowed air loss rate is used to calculate the minimum time allowed. This test method is sometimes used in contracts. This

method can be used to locate a leak quickly and accurately by moving a pair of inflatable plugs through the pipe and pressurizing the section between the plugs.

c. Displacement

When the trench has been backfilled 2 feet above the top of the sewer pipe, each section between manholes is examined for displacement by shining a light into one end and observing the straightness of the pipe from the other end. If the pipe is not straight, an ellipse (closed oval shape) will be seen or no light at all. Soft bedding will permit the pipe to sink, possibly breaking the pipe or opening a joint. Uneven backfill and compaction on each side of the pipe might cause it to move sideways. If the pipe between manholes is not straight and the resident engineer considers the pipe unsatisfactory, then the contractor must correct it.

d. Deflection

Flexible sewer pipe, such as single wall plastic, is inspected for deflection after the trench is completely backfilled. The Uni-Bell Plastic Pipe Association defines flexible pipe as a conduit that will deflect at least 2% without any sign of structural distress, such as injurious cracking. A plug of hard material having a diameter of 95% of the actual inside diameter of the pipe is pulled through the sewer section from one manhole to the other. If the plug will not pass freely through the pipe, then the sewer section is not satisfactory because the overburden has deformed the pipe more than 5% of its diameter. The contractor must correct this and the contract might reject this pipe. The deflection results from un-compacted backfill around the pipe which is not supporting the pipe. A device may be used that detects deflections of more than 4.5%. For many years, 5% deflection has been an arbitrary design limit for flexible pipes. PVC (polyvinyl chloride) pipe with a dimension ratio (DR) of 35 has a safety factor of 4 at 5% deflection.

2. Storm Drains

Storm drains are tested for displacement in most installations. The test is the same as for sewers if it is required. The exfiltration or infiltration test, where specified, will be the same as for sewers. The air leakage test may be used if it is approved.

When watertight joints are required, a test is performed on each type of joint in the system before the pipe is installed. Two lengths of pipe are joined, and the joint is subjected to 10 psi (pounds per square inch) hydrostatic pressure for 24 hours. Visible leaks are unacceptable.

3. Water Systems

During the preparation inspection, the contractor should submit a proposed source of water and method of disposal. Also, plans for pressure and leakage tests, flushing of the lines, and system disinfection must be submitted and approved before the tests can begin. Potable (drinkable) water must be used.

The contractor is required to apply a pressure test and a leakage test to the water piping, usually at 200 psi or one-and-a-half times the working pressure. Two things must be done before pressure is applied to the piping:

(1) The trench must be partially backfilled leaving the joints exposed. This will hold the pipe and keep it from moving when hydrostatic pressure is applied and the joints inspected for leaks.
(2) The concrete in the thrust blocks must have hardened for at least 5 days.
In the pressure test, the water pressure is held for 1 hour, and the exposed joints and piping are examined for leaks. Air must be expelled because this could prevent detection of a leak. Leaking joints must be replaced or remade. Defective pipe, fittings, and valves must be replaced. After corrections are made, the test is repeated until results are satisfactory. For certain trench conditions (see specifications), the contractor may get approval to conduct the test with the joints covered.
In the leakage test, the pressure is held for 2 hours and the leakage is measured by recording the amount of water added to the system to maintain the pressure. Pipe made of concrete or asbestos cement, or which is cement lined or has mortar joints, should be filled with water several hours before the test to permit these materials to absorb water. Air must be expelled from the system because this could maintain pressure when there is a leak. The leakage shall not exceed that determined by the following formula:

$L = 0.00025\ NDP$
L = Allowable leakage in gallons per hour.
N = Number of joints in the section under test.
D = Nominal diameter of pipe in inches.
P = Square root of the average pressure during the test in psig.

The two tests may be performed at the same time if requested by the contractor and approved by the construction engineer.

Water piping that supplies fire protection systems, or which supplies both fire protection and plumbing systems, must be tested according to NFPA 24 and 13. The water lines must first be flushed at a specified rate depending on pipe diameter. The hydro-static pressure test must be at least 200 psi and 50 psi in excess of the maximum static pressure. The amount of leakage is specified in NFPA 24. Each fire hydrant must also be tested as specified in NFPA 24.

4. Natural Gas Systems

Mains and service lines must be tested with air at 75 psi or 150% of the operating pressure, which ever is greater. Leakage is detected by a drop in pressure, with corrections made for changes in temperature between the initial and final readings. The test must continue for at least 24 hours between the times of initial and final readings of temperature and pressure. The initial reading is made at least 1 hour after the system is pressurized. The formula for temperature correction is:

$T_1P_2 = T_2P_1$.
T_1 is initial absolute temperature.
P_1 is initial absolute pressure.

T_2 is final absolute temperature.
P_2 is final absolute temperature.

Absolute temperature is the reading in degrees Fahrenheit plus 459.6.
Absolute pressure is pounds per square inch gauge reading plus 14.7.

D. Disinfection

Most codes requires that all water piping systems, including domestic utility water supply, fire lines, fire sprinkler systems, and hot and cold water plumbing lines, be disinfected with chlorine.

First, mud must be flushed from the piping. A water velocity is not stated in specifications, but the American Water Works Association recommends a velocity of 2.5 feet per second (fps). This will not scour the pipe clean, but will remove the lighter particles. It may not be practical to flush large diameter pipes at 2.5 fps because of the large volume of water required.

Plan ahead with the contractor for flushing, facilities for supply and disposal of water may not be readily available. USE POTABLE (DRINKABLE) WATER. The Construction Engineer determines when the flushing process is adequate; keep in mind factors such as how clean the contractor kept the pipe during construction, how well the ends of piping were kept closed, and the amount of flushing possible given construction site conditions.

The sterilizing dosage of chlorine must be at least 50 parts per million (ppm). The chlorine must be distributed evenly throughout the system. This must be done by feeding the chlorine into the water as the system is filled after flushing. Do not permit the contractor to throw a handful of chlorine compound into each length of pipe as it is laid, because it will be removed when the line is flushed. Chlorine compounds must be dissolved in water before they are fed into plastic pipelines. Chlorine may be obtained as liquid chlorine, sodium hypochlorite (liquid laundry bleach), or as high-test calcium hypochlorite (HTH powder). The following chart shows the amount of chlorine or its compound to add in 1,000 gallons of water to obtain 50 PPM:

• Chlorine Gas	0.42 lbs
• High test Calcium Hypochlorite (65 – 70% chlorine)	0.64 lbs
• Liquid Laundry Bleach (4.75 – 5.25% chlorine)	7.97 lbs

The chlorine must be retained in the system for 24 hours. Then there must be at least 10 ppm of chlorine remaining which shows that the system has been disinfected. If the residual chlorine is less than 10 ppm, this indicates that the system is not completely disinfected and that the process must be repeated. All valves and hydrants on the lines being disinfected must be opened and closed several times during the contact period to get the chlorine into the valve parts.

After disinfection, the system must be flushed until the residual chlorine is less than 1.0 ppm. Two days after disinfection, water samples must be taken from several points of the system in sterilized containers for bacterial examination. If the bacteria tests are satisfactory, the water in the system is drinkable. Potable water must be used for all flushing and disinfecting.

2.2 PLUMBING

A. Plumbing Materials and Equipment

The building plumbing includes a water supply (hot and cold) of potable water and possibly non-potable water. If non-potable water is present, then a water softener system is used to produce the potable water. Make-up water is supplied to mechanical items, such as boilers, chillers, humidifiers, and evaporative coolers. Water is also supplied to plumbing fixtures, such as sinks, lavatories, faucets, drinking fountains, and water closets. Copper is the common material used to distribute domestic water to all plumbing fixtures and appliances for kitchen or laundry use. Some fixtures require both hot and cold water, while others require only cold water. Most fixtures also require drainage and vent piping. A common plumbing fixture schedule is included in Figure 1.2-1.

The plumbing drainage system is divided into soil, waste, drain, and vent piping. The soil pipe will drain water closets and urinals.

The waste pipe will drain the discharge from fixtures except water closets or similar fixtures. Storm drain piping will carry rain, subsurface water, or similar discharge without waste. Every fixture with drainage piping will have a trap and vent piping. The vent will maintain near atmospheric pressure on the downstream side of a trap, which is required to seal the building interior from drainage system gas by-products and entry by small vermin.

For hot water, a hot water heater will be provided. The common water heater will use natural gas or electric energy. Fuel oil or solar energy may also be used at some locations. The water heater is normally in the mechanical room or janitor's closet. Natural gas and fuel oil types will require flue vents and combustion air vents and, thus, they should be located in the mechanical room.

PLUMBING FIXTURE SCHEDULE									
FIXTURE	SYMBOL	WASTE		VENT	COLD WATER		HOT WATER		
		BRANCH	OUTLET		BRANCH	OUTLET	BRANCH	OUTLET	
WATER CLOSET (FV)	P-1	4"	4"	2"	1 1/4"	1"	-	-	
WATER CLOSET (FV)(HC)	P-1A	4"	4"	2"	1 1/4"	1"	-	-	
URINAL	P-2	2"	2"	2"	1"	3/4"	-	-	
URINAL (HANDICAPPED)	P-2A	2"	2"	2"	1"	3/4"	-	-	
LAVATORY	P-3	2"	1 1/2"	1 1/2"	3/4"	1/2"	3/4"	1/2"	
LAVATORY (HANDICAPPED)	P-3A	2"	1 1/2"	1 1/2"	3/4"	1/2"	3/4"	1/2"	
ELEC WATER COOLER	P-4	2"	1 1/2"	1 1/2"	3/4"	1/2"	-	-	
ELEC WATER COOLER (HC)	P-4A	2"	1 1/2"	1 1/2"	3/4"	1/2"	-	-	
SERVICE SINK	P-5	3"	3"	2"	3/4"	3/4"	3/4"	3/4"	
EMER SHOWER/EYE WASH	P-7	-	-	-	1 1/4"	1 1/4"	-	-	
KITCHEN SINK	P-6	2"	2"	1 1/2"	3/4"	1/2"	3/4"	1/2"	
FLOOR DRAIN	FD	2"	2"	2"	-	-	-	-	
FLOOR SINK	FS	2"	2"	2"	-	-	-	-	
WALL FAUCET	WF	-	-	-	3/4"	3/4"	-	-	
WASTE RECEPTOR	WR	4"	4"	2"	-	-	-	-	
SCULLARY SINK	P-8	2"	2"	1 1/2"	3/4"	3/4"	3/4"	3/4"	

Typical Plumbing Fixture Schedule
Figure 1.2-1

B. Installation of Plumbing Systems

Plumbing system installation involves water supply piping, drainage piping, and fixture installation.

1. Water Supply Piping

- Provide water piping with slope to drain.
- Provide drain point at all low points (valve, cap, union, or flange).
- Provide expansion loops as indicated on plans.
- On straight pipe runs over 50 feet, provide a pipe anchor in the center for expansion at the ends.
- Provide water hammer arresters, of proper size with an access panel, at locations indicated on the plans.
- Provide water backflow prevention devices as required on the plans. This is normally at mechanical devices, such as boilers and chillers.

- Provide shut-off valves and unions at each fixture.
- Provide a trap primer (water supply) to drain traps that are subject to drying out.
- Provide support brackets at flush valves, including backing material in the wall for the support bracket.
- Pipe pressure relief valves to drain.
- Install water heaters off the floor.
- Provide piping sleeves at all floor and wall penetrations including escutcheons.

2. Drainage Piping

Given below are typical steps that a plumbing contractor should follow for drainage piping installation:

- Provide soil and waste piping with a slope of 1/4 inch per foot in direction of flow.
- Provide a trap as close as possible to each fixture.
- Provide a vent pipe downstream of each trap.
- Provide pipe-size cleanouts in all soil and waste piping as required by contract and codes, including brass plugs.
- Cast iron soil and waste pipe must be hub-type located below floor slabs and extending 6 inches above the finished floor. Hub-type cast iron pipe is used aboveground only.
- Pipe fittings that change horizontal direction must provide an unobstructed passage for sewage flow. Check requirements for the type of fittings allowed.
- Clamp bolts for hubless type pipe shall be torqued at 5 foot-pounds.
- During construction, seal all pipe ends during inactive periods.
- Chrome-plate all exposed water and drainage piping to fixtures.

3. Fixture Support

Wall-mounted water closets are supported by chair carriers and must not touch the wall. All chair carriers must be anchored to the floor.

Wall-mounted lavatories and urinals are bolted to wall supports or chair carriers, as necessary, to prevent movement and to provide proper support. Lavatories with four or more fixtures must also be supported to prevent uplifting. Bolts to prevent uplifting are in addition to normal support bolts. Holes must be factory drilled for the additional bolts.

C. Testing Plumbing Systems

1. Water System

Water piping is tested prior to fixture installation. A pressure test of 100 psi for 30 minutes is normal. All pipe joints must be exposed for testing. No leaks are accepted.

2. Drainage System

Test piping prior to fixture installation. Pressure-test all soil, waste, and vent piping with water or air. Water is filled to the highest point and held for 15 minutes. All pipe joints must be exposed. To test pipe sections, use a head pressure of 10 feet in each section. If air is used, apply 5 psi for 15 minutes, and check the joints with soap suds. A mercury column gauge is an accurate instrument for showing a drop in pressure.

3. Fixture Testing

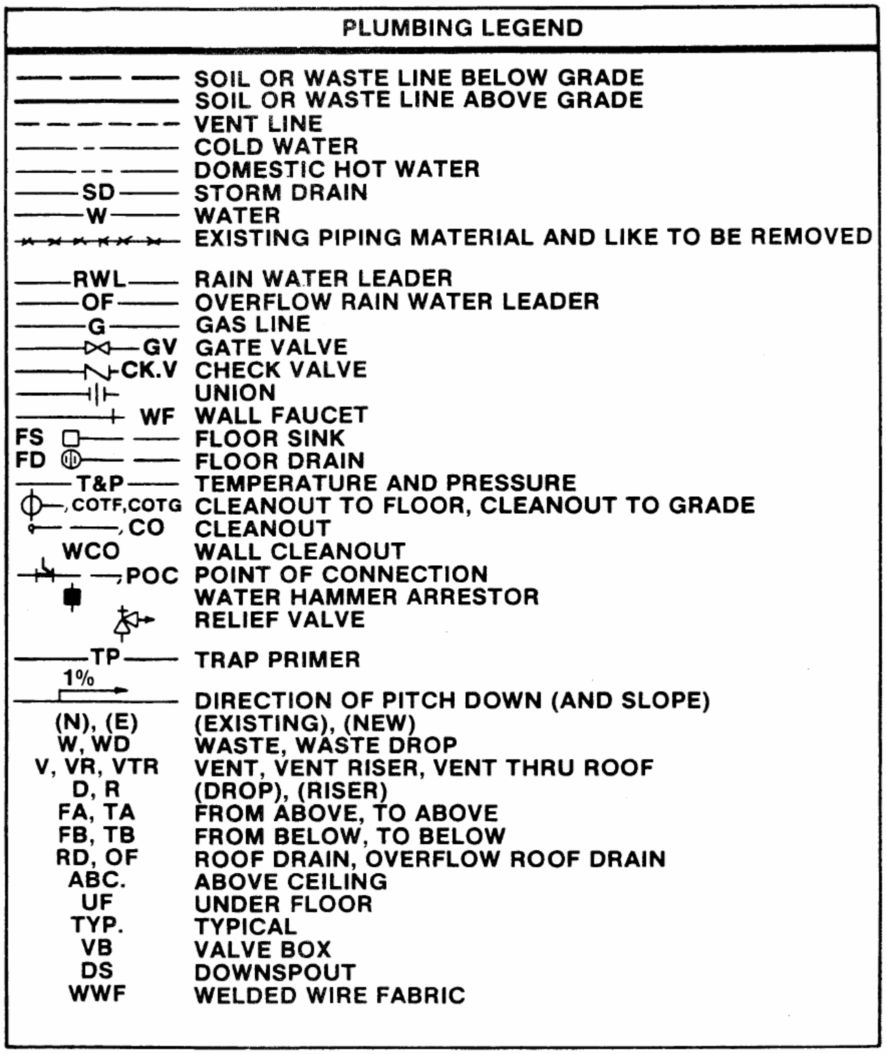
The drainage system is tested after all fixtures are installed. Traps must be filled with water, and smoke or peppermint used to detect leaks.

For the peppermint test, the contractor pours 2 ounces of oil of peppermint into the each stack, followed by 10 quarts of hot water. Then, each fixture is checked for peppermint odor at the joints. A word of caution about the peppermint test: do not permit any of the peppermint to get inside the building, as this will cause a false detection of a leak. To conduct this test, witness the pouring of the 2 ounces of oil of peppermint into each stack. The worker who handles the peppermint must remain outside the building while the trap joints are checked.

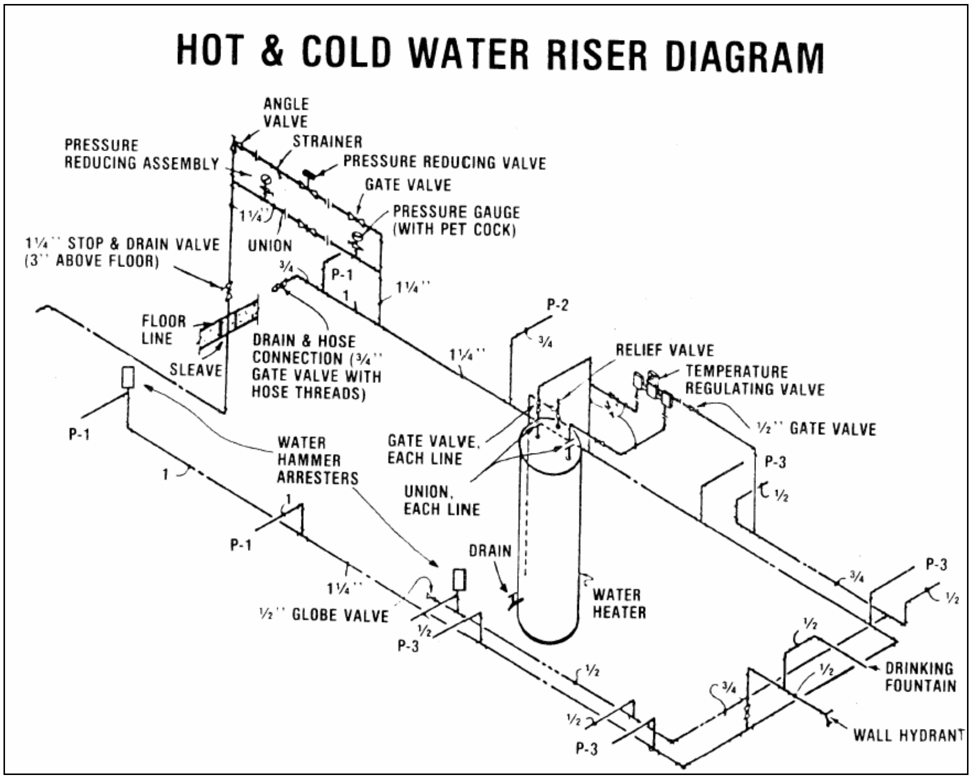
The water system is tested before the fixtures are connected. This is done by hydrostatic pressure test of 100 pounds psi. The system must hold this pressure for at least 30 minutes. Leaks in lead joints may be repaired by caulking. A leak in a threaded joint may be closed by tightening the joint; if this fails, the joint must be remade. A solder joint must be remade to stop a leak.

D. Verification Skills

To compare contract drawings with shop drawings and to verify the piping installation with approved drawings, skills in blueprint reading must be developed. Become familiar with standard symbols used in plumbing drawings. A common plumbing legend and a typical water riser diagram is provided for review. (See Figures 1.2-2 and 1.2-3.) The riser diagram is a schematic-only drawing indicating piping sizes and relative location of plumbing materials and equipment. The plumbing installation should vary whenever to properly locate, support, and coordinate all items.



Typical Plumbing Legend
Figure 1.2-2



Typical Riser Diagram
Figure 1.2-3

3. CONCRETE AND MASONRY

Concrete is used extensively in construction projects due to its availability and versatility. Masonry materials are used in buildings worldwide because they are both durable and adaptable. Masonry is found in interior as well as exterior building components. It is commonly used for foundations, retaining walls, fire-rated walls, and partitions. This section will help understand the materials and processes used in basic concrete and masonry operations for quality verification in compliance with most job plans and specifications.

3.1 MATERIAL REQUIREMENTS FOR CONCRETE MIX DESIGN

A. Materials

Concrete is one of the most used construction materials because it is versatile, durable, and economical. Concrete is a manufactured material meeting rigid standards. Its plastic quality allows it to conform to the wide variety of forms or molds into which it is placed. Concrete is a heavy material, approximately 150 pounds per cubic foot. It is a mixture of aggregates, such as sand and stone, and a paste of cement, water, and air. Most of the materials will be available locally.

Portland cements harden through the chemical reaction of cement and water. When the portland cement paste is mixed with the correct proportions of aggregate and water, it acts as an adhesive, binding the aggregates, forming concrete. The quality of hardened concrete varies according to the needed strength. This is determined by the quantity of cement used and the ratio of water to the amount of cement. Project engineers and construction management personnel must assure that materials are of proper quality and quantity. These must be mixed, placed, finished, and cured in compliance with the contract plans and specs.

All aggregate used in portland cement concrete, with the exception of lightweight concrete, must conform to the requirements of ASTM C33. Grading is determined by sieve analysis.

- Fine aggregate is natural sand, manufactured sand, or a combination of these. It is graded from a 3/8-inch sieve to a No. 100 sieve.
- Coarse aggregate consists of crushed stone, crushed or uncrushed gravel, air-cooled iron-blast-furnace slag, or combination of these. The maximum grading size is specified.

B. Contract Specifications

Satisfactory concrete construction performance requires that it conform to specific properties, which are given in the specifications. Quality is monitored by use of certificates, mill test reports, mechanical and chemical analysis, mix designs, by slump and entrained air tests for workability, and by cylinder or beam breaks for design strength. Materials are described in the individual job contract specifications and in publications under the U.S. Department of Commerce, the National Bureau of Standards, the American Concrete Institute, the American Iron and Steel Institute, and the American Society for Testing and Materials. The Portland Cement Association's Design and Control of Concrete Mixtures is an excellent reference book. It gives in-depth information on many aspects of concrete construction.

The specifications describe the requirements for the cement to be used, the fine aggregate (sand), the coarse aggregate (gravel), and admixtures that may be required to improve workability or weatherability. Air-entraining admixtures, for example, improve concrete durability in freezing conditions.

The contractor prepares a mix design, which is submitted to the project engineer for approval. On larger projects, the contractor may be required to submit material samples. Approvals are required for the following:

- Mix designs, including cements and aggregates.
- Batching and handling procedures.
- Form materials and procedures, including reinforcing materials.
- Curing materials and procedures.

There are other materials, depending upon contract requirements, which may require submittal data. Some are listed below:

- Air-entraining admixtures.
- Perimeter insulation.

- Joint sealers.
- Grout for steel columns.
- Vapor barriers.

C. Handling and Storage

Handling, storage, and protection of materials used in concreting operations must be monitored. In addition to the provision for proper protection of the materials, consideration must be given to traffic flow, appearance of the area, and safety. All of these are important and must be considered at the time of approval of the contractor plant layout. Project engineers and construction management personnel must have access to the storage facilities to obtain samples for testing purposes.

3.2 CONCRETE MIXING REQUIREMENTS

A. Batching and Mixing

To ensure that concrete satisfies intended performance requirements, concrete must be properly proportioned (batched) and mixed. The required strength determines the characteristics of the mixture proportions. The quality of the cement paste greatly affects the strength of the hardened concrete. The water-cement ratio is a major influence on strength. Concrete becomes stronger with time as long as there is moisture available for hydration to continue and a favorable temperature. This is achieved in the curing stage.

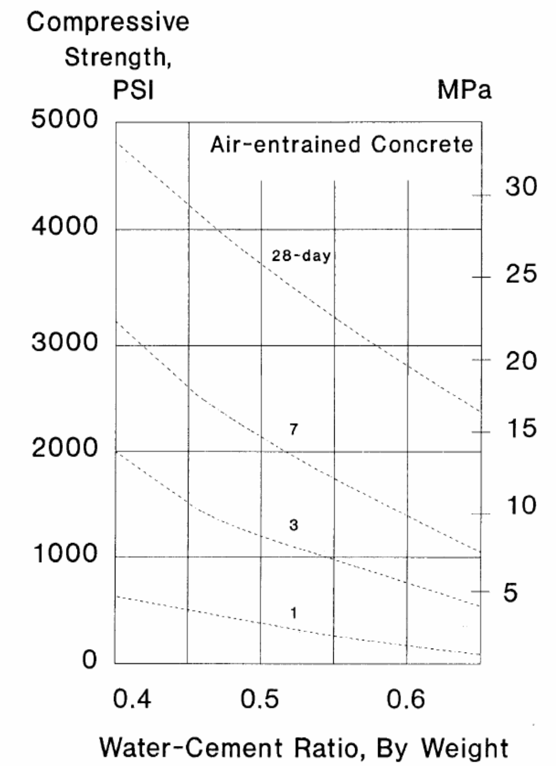
Since compressive strength is easily determined, it is frequently used as a test of quality. Figure 3.2-1 charts the typical age to strength relationships of air entrained concrete based on compression tests of cylinders, using Type 1 portland cement and moist-curing at 70°F. Compressive strength is directly proportional to days cured. Several samples are tested, and the results averaged, to allow for variable factors such as changes in aggregate size.

B. Testing

Testing provides methods for determining consistencies of concrete mixes and their strengths. These methods are used in the laboratory as a basis for the design mix to be used, and then in the field as a check to maintain consistency in the performance of the manufactured mix.

1. Sampling Procedures

Sampling procedures must be consistent and representative of the freshly mixed concrete. When sampling from revolving-drum truck mixers or agitators, take two samples from the middle of the batch. To ensure a representative product sample, do not take the sample at the beginning or end of the discharge. The receptacle for collecting the sample must be repeatedly passed through the discharge stream, or the stream must be completely diverted to discharge into the receptacle.



Typical Age-Strength relationships of concrete based on compression tests of cylinders, using Type 1 Portland cement, moist cured at 70 F (21 C).

Typical Age to Strength Chart
Figure 3.2-1

After the sample has been transported to the place where the test specimens will be molded, it must be remixed with a shovel to ensure uniformity. Protect the sample from sunlight and wind. The time from taking the sample to molding must not exceed 15 minutes.

Test specimens should be cast as near to the storage place as possible. If molded away from the storage area, move the completed mold immediately after being struck off, taking care to avoid distortion to the bottom, jarring, striking, tilting, or scarring the surface. Such disturbance can adversely affect test results.

2. Compression Test

Compression test specimen molds are cylindrical, have nonabsorbent surfaces, and are strong enough to hold their shape during molding. The standard cylinder size is 6 inches in diameter by 12 inches high. Larger molds for aggregate sizes over 2 inches should comply with ASTM C31.

When placing the compressive test specimen into the mold, place the concrete in three layers of approximately equal volume when consolidating with a tamping rod, and in two layers when consolidating by vibration. The tamping rod must be a round, straight steel rod 5/8 inch in diameter and approximately 24 inches long. One end must be rounded to a hemispherical tip. If the tamping rod is used, the number of strokes required depends upon the diameter of the mold (refer to ASTM C31). For the standard 6 inch diameter mold, each layer is to be rodded 25 times. Distribute strokes uniformly over the layer area and penetrate approximately 1 inch into the underlying layer.

Test specimens must be properly cured. While curing, prevent loss of moisture, rapid temperature change, and damage from rain or flowing water. To cure compression test specimens, place the molds on a rigid horizontal surface free from vibration and disturbances. For the first two hours, store under conditions that maintain a range of 60°F to 80°F and prevent loss of moisture.

3. Flexural Test

Flexural test specimen molds are rectangular in cross-section. Their length should be 3 times the depth of the beam plus 2 inches. The mold must be watertight and made of rigid, nonabsorbent material.

When making flexural test specimens, place the concrete into the molds with a shovel or scoop in two equal layers for molds 8 inches deep or less, and in three equal layers for molds over 8 inches deep. Symmetrically distribute the concrete into the mold with the help of the tamping rod. Take care to minimize segregation. Each layer must be rodded uniformly, once for each 2-square inches of area, rod the bottom layer for the entire depth. Rod the upper layers, penetrating approximately 1 inch into the underlying layer. Vibrators can also be utilized for consolidation (refer to ASTM C31).

After consolidation, the surface of the concrete must be struck off with a straightedge or trowel; the flexural test specimen is struck off with a wood float. Again, take care to avoid disturbing the specimen. All specimens must be covered immediately with glass or metal plates, polyethylene film, or other such covering to prevent evaporation.

4. Curing

After the initial 24 hour curing period, all specimens are taken to a central curing area where they undergo curing that approximates the laboratory conditions used while designing the mix. Test specimens remain under controlled conditions for the entire curing period of 7 days or 28 days, as appropriate.

5. Slump Test

The slump test is used to measure the consistency of the concrete mix. This consistency, or slump, is a measure of the fluidity, workability, plasticity, or stiffness of the mix. The higher the slump value, the wetter (more fluid) the concrete.

The specification usually requires following the slump test procedure specified in ASTM C143. The instruments required are a non-absorbent rigid surface (either permanent or movable) used as a base, a 24 inch long tamping rod, and a mold (slump cone) made of at least 16 gauge metal formed into a 12 inch high cone with a 4 inch diameter top and an 8 inch diameter bottom. The slump cone is open at each end. Foot pieces and handles must be rigidly affixed to the wall of the mold.

Fill the slump cone in three layers of equal volume (not equal height). The first layer will be 1 1/2 inches and the second will be to the halfway point (4 1/2 inches more). Rod each layer 25 times.

Once again, penetrate about an inch into the layer below when rodding. After striking off the excess, carefully lift the cone straight off the sample, without twisting the cone.

Measure the distance that the top of the sample slumps down from its original height. The sample should contain aggregate 2 inches or smaller.

6. Entrained Air Test

Another test performed on concrete indicates the amount of entrained air. In this case, the test instrument consists of a can filled with concrete obtained in the same manner as for the slump test. The cover is then latched in place and the remaining space filled with water. Air is then pumped into the can and released. The manufacturer's step by step procedures should be followed to perform the test. A pressure gauge indicates the percent of air entrained in the concrete. Specifications usually require between 2 and 7 percent air when air-entrained concrete is used.

These tests are usually performed each day that concrete is placed. After the cylinders are cured for the required time, they are broken in a commercial laboratory. Figure 3.2-2 shows an example of a commercial lab test report.

REPORT OF CONCRETE CYLINDER TEST

Licensee Company Name

Report Date: 11/17/03

Project Number: S91003-24 Report Number: 1
Project: Fort Collins Zoo - Primate Habitat 1
Client: Advanced Professional Eng.
Address: 363 West Drake, Suite 10
Fort Collins, CO 80526
Attn: Harold Jenkins

FIELD TEST CONDITIONS AND RESULTS (ASTM C31)

Date Placed: 2/28/2003
Time Sampled: 3:45 AM
Location of Sample: Caisson A-3-1, plains regions animal habitat
Supplier: AJ-Mix
Truck Number: 103 Ticket Number: 8342
Mix Number: 3000-C
Design Strength: 4000
Time Batched: 10:15 AM Time Placed: 10:45-11:15
Batch Size: 2
Slump: 5.5 (ASTM C 143) Air Content: 2.3 (ASTM C 173)
Concrete Temp: 82° Ambient Temp: 54°
Water Added: 12 Technician: Harvey

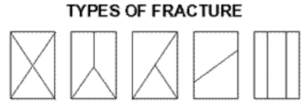
LABORATORY TEST RESULTS (ASTM C 293)

Specimen	Test Date	Age	Load	Diameter	Area	Strength	Percent of Design	Type of Fracture
123-1-2-2	3/7/2003	7	76000	6.00	28.27	2685	134%	A
123-1-2-3	3/7/2003	7	98000	6.00	28.27	3465	173%	A
123-1-2-4	3/28/2003	28	120300	6.00	28.27	4255	106%	A
123-1-2-5	3/28/2003	28	119700	6.00	28.27	4230	106%	A
123-1-2-6	3/28/2003	28	117100	6.00	28.27	4140	104%	A
123-1-2-9		hold						

Remarks: first cage broke
setting, used another
during placement
used another

Copies to:
Cage Construction
Jungle Jazz Architects
Newt Holdings
Major Mix
City of Fort Collins
Grandview Metropolitan

TYPES OF FRACTURE



A Cone **B** Cone & Split **C** Cone & Shear **D** Shear **E** Columnar

Reported by: ____________________

Mack Holloway
Concrete Laboratory Supervisor

Figure 3.2-2 Lab Test Report

3.3 REPLACEMENT OF REINFORCING STEEL/FORMWORK

A. Reinforcing Steel

The reinforcing steel consists of bars (rebar) and wire fabric (mesh). Figure 3.3-1 is a chart that gives bar size numbers. Note that they are in 1/8 inch increments, a ½ inch bar is size 4, a 1 inch bar is size 8. Reinforcing steel must be correctly positioned to give concrete its maximum strength. Project management and construction management personnel must have thorough knowledge of the contract requirements, including shop drawings, and insist upon the placement of reinforcing steel to detail and in conformity with all specification requirements.

Before placement, reinforcing steel must be thoroughly cleaned of loose or flaky rust, mill scale, ice, oil, or any other substance that might reduce or prevent bonding. This includes cleaning any steel that may have been contaminated while awaiting concrete placement. The cross-sectional area of the reinforcing material must not be reduced in any way.

All bends, hooks, radii, and so forth, should be made by the fabricator to eliminate the possibility of damaging the steel by bending in the field. Bars that have bends or kinks not shown on the drawings must not be used.

Approved shop drawings should indicate the length and location of laps. All splices and laps must conform to the requirements of ACI 318.

Concrete placement over steel reinforcement is very critical because of the protection afforded the steel, the bond that must be developed between the steel and concrete, and the clearance for proper concrete consolidation around the steel. Reinforcing steel must be supported, tied, and retained either with removable or permanent spacers to prevent displacement during the concrete placement. When concrete is deposited against earth, there should be at least 3 inches of concrete between the steel and the earth.

CONCRETE REINFORCING STEEL INSTITUTE

38 SOUTH DEARBORN STREET, CHICAGO 3, ILLINOIS

STANDARD A305 REINFORCING BARS

BAR SIZES		WEIGHT	NOMINAL DIMENSION — ROUND SECTIONS		
OLD (INCHES)	NEW (NUMBERS)	POUNDS PER FOOT	DIAMETER INCHES	CROSS SECTIONAL AREA — SQ. INCHES	PERIMETER INCHES
1/4	2	.167	.250	.05	.786
3/8	3	.376	.375	.11	1.178
1/2	4	.668	.500	.20	1.571
5/8	5	1.043	.625	.31	1.963
3/4	6	1.502	.750	.44	2.356
7/8	7	2.044	.875	.60	2.749
1	8	2.670	1.000	.79	3.142
1 1/8	9	3.400	1.128	1.00	3.544
1 1/4	10	4.303	1.270	1.27	3.990
1 3/8	11	5.313	1.410	1.56	4.430

THE NEW BAR NUMBERS ARE BASED ON THE NEAREST NUMBER OF 1/8 INCHES INCLUDED IN THE NOMINAL DIAMETER OF THE BAR.

BAR NUMBER 2 IN PLAIN ROUNDS ONLY. BARS NUMBERED 9, 10 AND 11 ARE ROUND BARS AND EQUIVALENT IN WEIGHT AND NOMINAL CROSS-SECTIONAL AREA TO THE OLD TYPE 1" 1-1/8" AND 1-1/4" SQUARE BARS.

CONCRETE REINFORCING STEEL INSTITUTE C.P.S.I. FOUNDED 1924

THE ABOVE WEIGHTS WERE ADAPTED AS STANDARD BY THE INSTITUTE IN 1934.

THESE WEIGHTS HAVE BEEN APPROVED THROUGH THE U.S. DEPARTMENT OF COMMERCE SIMPLIFIED PRACTICE RECOMMENDATION 26.

Typical Reinforcing Bars
Figure 3.3-1

Reinforcing mesh is normally continuous between expansion joints in slabs and must be lapped at least one full mesh. Welded wire mesh must be supported on standard accessories or on precast concrete blocks. These supporting accessories are frequently overlooked. Mesh normally used in building slabs and for temperature reinforcing will usually be furnished in rolls. It is difficult to support and hold roll-type mesh in position.

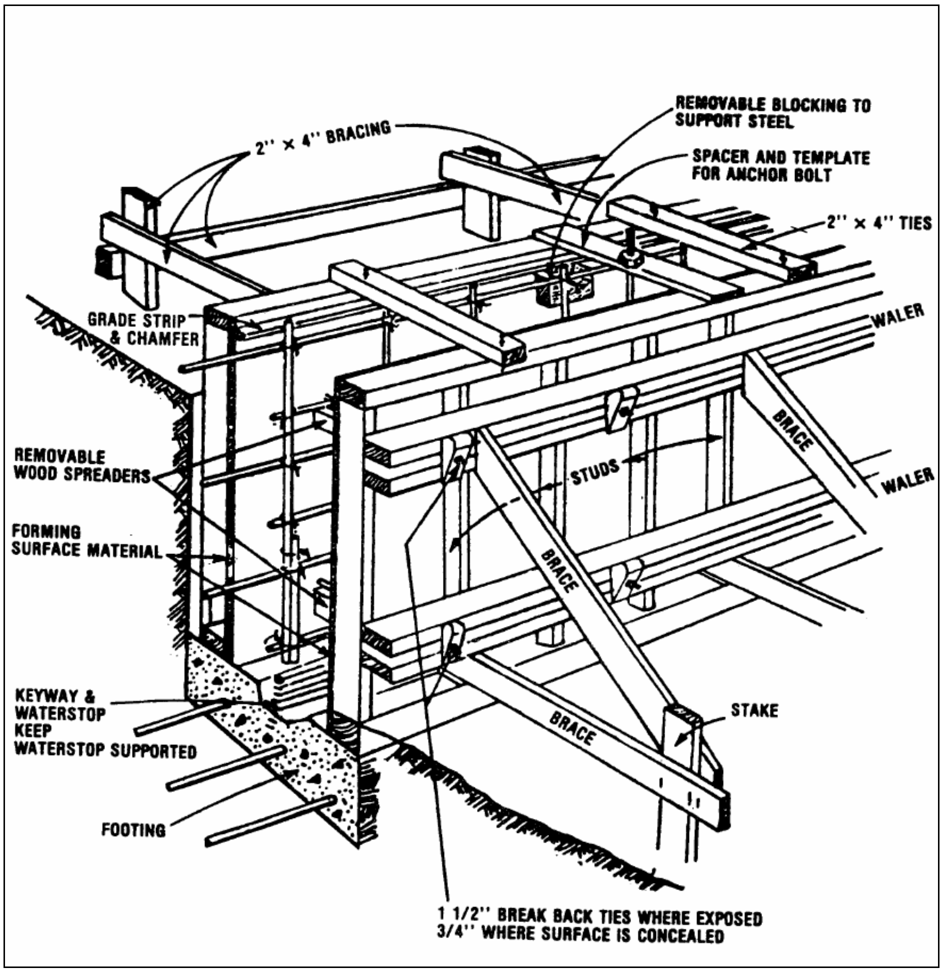
Supports and tying for reinforcing materials must conform to ACI 318. Main steel must be accurately placed and securely tied at all intersections and splices tied with 16-gauge black annealed wire. Wire tie ends must point away from the form. Temperature steel must be tied to the main reinforcing as detailed on the approved shop drawings.

Spacers, chairs, and other approved supporting devices must be positioned around the steel to maintain position and prevent displacement during concreting operations. Precast concrete blocks should be wedge-shaped, not larger than 3%-by-$3^1$2 inches, and of a thickness specified for concrete coverage over the reinforcement at the location used. A good method for preventing steel from falling off supporting blocks is for each block to have an embedded galvanized tie wire which is hooked or looped for anchorage. The free ends of the tie wire should be long enough to tie to the supported steel.

B. Formwork

Forms are molds that contain and shape the wet concrete until it has gained enough strength to support itself. The resulting appearance of the concrete surface will reflect the quality of materials used and workmanship in constructing forms.

Formwork for exposed concrete surfaces are more stringent than for concrete surfaces that are concealed. Materials most commonly used are lumber, planking, plywood, masonite, steel, plastic, and cardboard. Form supports may be either steel or lumber. Forms may be specially prefabricated for single use, prefabricated for multi-use, or job-built; this will depend on the contractor. The formwork to be used must be reviewed and approved. Figure 3.3-2 gives a typical diagram of wall form details.



Typical Wall Form Detail
Figure 3.3-2

1. General Requirements

There are some general requirements for forms. Given below are some things to check for when building and placing forms. Expand upon these items as needed.

- Form surfaces in contact with concrete must be thoroughly cleaned before each use. Holes in the form surface must be plugged or sealed to prevent mortar leakage. The sealing must be consistent with the surface smoothness required.
- Prior to concrete placement, form surfaces that are in contact with concrete must be either wetted with water (for unexposed concrete), a chemical form-release agent, or oil. When oil is used, it must be applied prior to erecting the form or prior to placing reinforcing steel. Oil eliminates bonding between the form and the concrete surface. This facilitates removal after the concrete sets. Form oil may not be used when concrete will be painted or will receive another finish that depends on bonding with the surface.
- Studs must be spaced to prevent deflection in the form skin. The edges of the form-skin material must be adequately supported to reduce waviness in the concrete surface.
- All form surfaces and joints between form-skin panels should be tight to prevent grout leakage during placement.
- Joint patterning must be arranged vertically and horizontally. They should occur at architectural lines, vertical control joints, and construction joints.
- Temporary openings (windows) should be provided in wall and column forms to allow access after erection for cleaning, inspection, and consolidation activities.
- Check the arrangement of forming in tight places at corners and angles to ensure easy removal without damaging the concrete.
- External corners of columns, girders, beams, and foundation walls projecting outside overlying masonry, and any other exposed external corners, will usually be specified to be rounded or chamfered (beveled) by moldings placed in the forms. The drawings may indicate certain corners that will not require such treatment.

2. Finishes

The specified concrete finish will be the key to the care that must be taken in building and erecting forms, and to the condition of the surfaces in contact with the concrete. Surface finishes are defined by the degree of visible exposure when the work is completed.

Concrete surfaces that will be visible and those that will be painted are specified to have a smooth finish. Since the concrete surface reflects the form surface, forms should be made of new 4 by 8 foot plywood panels. Smaller size panels may only be used as filler pieces and around openings or joint details. When less than 4 feet wide, the filler must be in one piece and accurately cut to the required dimensions. The panel joints must be smooth and free of offset. Form materials must have faces that are free of defects such as holes and scratches. This limits the reuse of forms. Inspect any panels proposed for reuse.

Concrete surfaces that will not be visible when construction is completed require less care and finished quality. Forms for these surfaces may be No. 2 common or better lumber, or other material producing an equivalent finish. The main requirement is that it be true to line and grade and be tight to prevent leakage of mortar.

3. Separators and Ties

Separators and ties for forms vary. These must not leave a hole larger than 1 inch or smaller than 'A inch in diameter in the concrete surface. Ties remaining in the concrete after the removal of exterior parts should not project beyond the surface. For concrete surfaces that will be visible, painted, dampproofed, waterproofed, or exposed continually to water, no portion of the tie remaining in the concrete may be nearer the surface than 1 inch. Bolts and rods that will be completely withdrawn must be coated with a non-staining bond breaker.

4. Joints

The area of floor slabs and length of wall formwork are limited by the specifications to control shrinking and cracking. Construction joints in concrete must be adequately formed and must incorporate the features shown on the plans. Keyways and waterstops must be adequately supported to ensure the necessary embedment, shape of joint, and prevention of flotation.

Vertical control or weakened plane joints should be placed to align with masonry control joints. Since these are continuations of masonry joints that will be calked, the forming should provide a key to form a recess for calking in the concrete surface.

5. Removal

Forms must be removed in a way to ensure complete safety to the structure. Where the structure is supported on shores, the side forms of walls, girders, beams, and columns may be removed as early as 24 hours after placement, provided the concrete is sufficiently hardened to prevent damage. The supporting forms and shoring are not removed until the structure has developed enough strength to support its own weight plus any superimposed loads. In no case shall they be removed in less than 6 days. If forms used for curing are removed before the end of the curing period, other provisions must be incorporated for the remainder of the curing period.

3.4 FINISHING AND CURING CONCRETE

A. Finishing

After forms are removed, surfaces are finished. This involves steps such as removing unwanted ties and patching holes. The final finish depends upon experienced craftsmen.

1. Patching

Formed surfaces that are visible, surfaces to be painted, and surfaces that will receive dampproofing, waterproofing, perimeter insulation, or bond adhesive or plaster application must be cleaned and imperfections patched. After removing all fins and loose material, patching is performed according to the type of imperfection.

- Honeycomb,, aggregate pockets, voids over 1/2 inch in diameter and holes left by tie rods or bolts must be cut out or removed down to solid concrete, thoroughly wetted, brush-coated with neat cement grout, and then repaired with dry patching mortar to a finish that is flush with adjacent surfaces.
- Holes that go through the wall are filled with a pressure device from the inside face to the outside face, where a stop board is held to ensure complete filling. Voids and holes left by the removal of tie rods or bolts in surfaces that will be exposed to water must be filled by one of these methods.

Patching mortar is composed of 1 part portland cement and not more than 2 parts of fine aggregate, passing a No. 16 sieve, using white portland cement for all or part of the cement.

Water in the mix is limited to just enough required for handling and placing. When dry, the mortar color should closely match the adjoining concrete color. The proper patch should be approved in the sample concrete panel. Damp cure all patchwork for a minimum of 72 hours.

2. Smooth Finishing (Visible Surfaces)

Interior and exterior surfaces that are visible or are to be painted are given a subsequent finish called a smooth finish.

This finish follows the curing and patching operations. The steps to be taken are defined in the specifications.

Smooth finishing involves thoroughly wetting the surface to which the finish is to be applied so that the dry surface will not immediately absorb the water in the cement grout. A cement grout composed of 1 part cement to not more than 2 parts fine aggregate, passing a No. 30 sieve, is mixed with enough water to form a consistency of thick paint. White portland cement is used for all or part of the cement, in proportions determined from trial batches. When dry, the color should approximate that of surrounding concrete. While the wetted surface is still moist, a heavy brush coat of the cement grout is applied.

Immediately after the grout has been applied to the surface, a cork or wood float is used to work the grout into all pits, air bubbles, and surface holes that were not filled in the patching operation. Using a trowel, all excess grout is scraped from the surface. After trowelling, the surface will be rubbed with clean, dry burlap to remove any visible grout film. Care must be taken to avoid damaging the stability and surface of the grout remaining in the small surface voids. The surface must be kept damp by means of fog spray during the setting period.

3. Floor and Roof Finishing

The degree of level and smoothness required in concrete floor and roof slab finishes depends on forms that are accurately and rigidly set to true line and grade. To keep the level uniform between forms in large areas, it will be necessary to set screed strips spaced as necessary to support the ends of drag-off equipment. Any irregularities or unevenness may be picked up in the final finish. Care must be taken with each successive step to ensure that all low spots are filled and that all high spots are eliminated while the concrete is still plastic.

Slabs must be pitched to drain. Screeds must be set from the line where slope begins to the drain. The deviation from a true plane surface must not exceed 1/8 inch when tested with a 10-foot straightedge, unless otherwise indicated. Straightedges are dragoff and floating instruments that have straight and true edges. The appropriate time to make any correction in the surface level is at this stage, not during the time of trowelling. Concrete must be screeded and floated with straightedges to bring the surface to the required finish with no coarse aggregate visible.

Screeding (strikeoff) is the process of cutting off excess concrete to bring the top surface of the slab to proper grade. Floating embeds aggregate just beneath the surface. This removes slight imperfections and compacts the mortar at the surface in preparation for additional finishing operations. Trowelling follows floating when a smooth, hard, dense surface is desired. Floating and trowelling are performed after the concrete has hardened enough so that water and fine material are not brought to the surface.

B. Curing

Design engineers depend upon controlled construction techniques to reduce the uncertainties that at one time were characteristic of concrete construction. The curing procedures specified must be carefully followed for acceptable concrete quality. Curing involves preventing loss of moisture, rapid temperature change, and damage from construction activity, rain, or flowing water, for the specified curing period. Moisture must be retained to continue the hardening process necessary to improve strength.

Forms must remain in place long enough for members to safely support their own weight plus superimposed loads. Forms may be left in place during the curing period. Where surfaces do remain under forms, the forms must be kept continually wet. Due to the normal shrinkage of the concrete during setting and the separation of the form from the concrete surface on sides, for example, curing will not be effective unless the space between the form and concrete is kept continually wet. The exposed top surface must either be under continuous water spray or covered with burlap or mats and kept continuously wet. To effectively cure formed surfaces that do not require support, the forms may be removed after 24 hours provided their removal will not damage the surface, and the curing process started immediately.

Moist-curing of surfaces using burlap, cotton, or other approved fabric mats kept continually wet is a very effective curing process, but usually difficult to enforce. Membranes, such as polyethylene and waterproof papers designed to retain the evaporated free water, are not effective curing agents for vertical surfaces containing dowels, form projections, or other features that prevent direct contact with the concrete. Membrane-forming curing compound cannot be used on surfaces that will be painted, waterproofed, or that will receive other bonding materials.

Slab surface curing is begun as soon as free water has evaporated from the surface after finishing. Several methods of curing are specified each of which will require a critical inspection peculiar to its own specific characteristics. Following are requirement for various curing methods:

- When burlap is used, it must be in direct contact with the surface and kept continually wet for the curing period or it will act as a wick, thus accelerating evaporation and defeating its purpose. On non-work days, the contractor must maintain a work force to continue the wetting process.
- Waterproof paper must be lapped at least 4 inches at edges and ends, and sealed with mastic or pressure-sensitive tape. It must be weighted to prevent displacement. Any holes or tears that develop in the membrane during the curing period must be repaired or patched immediately. Opaque polyethylene sheeting may also be similarly used.
- Membrane-forming curing compound conforming to ASTM C309 is specified as an optional curing medium. These consist of waxes, resins, chlorinated rubber, and solvents of high volatility that retard loss of moisture from evaporation. The pigmented type is for paving, curb and gutter, or surfaces that will not receive subsequent treatments. However, resin-base or chlorinated rubber-base curing compounds may be used on floors that are to receive adhesive applications or resilient flooring.
- Where conditions permit, the most effective curing is when the surface is under a pond of water. This is accomplished by damming around edges and openings. As a substitute, the surface may be covered with a clean sand, which will not stain, and which must be kept continually wet.

3.5 MASONRY MATERIALS AND STORAGE

A. Masonry Construction

The construction engineer should become completely familiar with the plans and specifications relating to masonry work and determine that the contractor is thoroughly familiar with his responsibilities. Approval data and sample submittals must be timely so that their installation will fit within the time frame of the overall schedule. Masonry workmanship is important for structural as well as aesthetic purposes since it is a highly visible component of the building. The structural integrity and density of masonry materials is a factor in design selection. Because of these properties and the multitude of combinations available, masonry materials can be combined to form critical structural elements or may be used as non-load bearing curtain walls.

B. Storage

Materials must be handled, stored, and protected to avoid chipping, breaking, contamination from contact with soil or other such material, and weather exposure. Anchors, ties, and joint reinforcements must be kept free of rust. Steel reinforcement bars or rods must be kept free of loose scale and rust. Prefabricated lintels should be marked on top sides to show either the lintel schedule number or the number and size of top and bottom bars. Cement kept on site must be stored in a weatherproof storage shed. Metal accessories should always be protected from the elements to avoid deterioration. Masonry units must be kept completely covered and free from frost, ice, and snow.

C. Metal Accessories

Metal accessories should be approved for use. Approval should not be given until evidence of compliance is furnished, including samples. Unless otherwise specified, a zinc-coating conforming to ASTM A153 must be applied to all ferrous metal accessories.

1. Wire-Mesh Ties

Wire-mesh ties that are specified as anchorage for intersecting 4 inch thick masonry partitions must be made of steel wire at least 0.0625 inch (16 gauge) in diameter, manufactured in a 1/2-inch mesh pattern. These ties must be 1 inch less than the wall width and at least 12 inches long, depending on wall thicknesses.

Wire ties consisting of lengths of joint reinforcing materials may be used in lieu of wire-mesh ties. Corrugated or crimped metal ties, as specified, must be at least 7/8 inch wide and made of steel not lighter than 0.0299 inch (22 gauge) in thickness. Ties for structural glazed tile may be 24 gauge in thickness.

2. Cavity-Wall Ties

Cavity-wall ties are rectangular-shaped, at least 4 inches wide by 8 inches long, and are made of 3/16 inch diameter zinc-coated or copper-clad steel wire. Cavity-wall ties may also be of a continuous-type conforming to joint reinforcement specifications that are covered later in this section.

3. Composite-Wall Ties

Composite-wall ties are rectangular-shaped, at least 2 inches wide by 6 inches long, and are made of 3/16 inch diameter zinc-coated or copper-clad steel wire, without drip. Composite-wall ties may also be of a continuous-type conforming to joint reinforcement specifications that are covered later in this section.

4. Dovetail Anchors

Dovetail anchors are flat or flexible, as required. A 1 inch wide flat anchor of at least 16-gauge sheet metal is used for anchoring masonry walls or partitions of square-end units to abutting concrete columns and walls, for anchoring masonry to the underside of beams and slabs, and for anchoring single-wythe concrete masonry units extending over concrete columns. (A wythe is each continuous vertical section of a wall, one masonry unit in thickness.) Flexible anchors for anchoring exterior cavity-wall wythes or composite-wall facings extending over concrete columns, must be of at least 6-gauge steel wire, triangular shaped, with one side discontinuous.

5. Rigid Steel Anchors

Rigid steel anchors are manufactured of flat bar that is galvanized after fabrication. They are 11/2 inches wide and 'A inch thick. The anchor must be at least 24 inches long and the ends turned in opposite directions a minimum of 2 inches. Rigid steel anchors are required to anchor intersecting interior walls or partitions over 4 inches thick and to anchor fire walls to exterior walls.

6. Joint Reinforcement

Joint reinforcement is factory-fabricated from steel wire conforming to ASTM A82, welded construction. Tack welding is not acceptable in reinforcement used for wall ties. Wire must have zinc-coating conforming to ASTM A116, Class 1, except that cross-wires or box-ties must have a minimum Class 3 zinc-coating when reinforcement is used for cavity-wall ties. All wires must be at least 9 gauge.

Reinforcement in single wythe concrete masonry units, walls, or partitions should be of one design throughout, either ladder or truss design, having two or more deformed or smooth longitudinal wires. Reinforcement in double wythe construction should be continuous joint reinforcement having three or more deformed longitudinal wires, either ladder or truss type. It is recommended that in cavity-wall construction only ladder-type reinforcement be used, thereby permitting differential contraction or expansion between the two wythes.

As an alternate for clay or shale, brick-faced masonry back-up, or brick-faced cavity-wall construction, continuous joint reinforcement may be of two longitudinal wires with box-ties spaced not over 16 inches on center, 4 inch nominal width, and of a length to approximately center upon the exterior facing. Longitudinal wires must be spaced 2 inches plus or minus 1/8 inch less than the nominal width of the unit or wall in which placed. The distance between contacts of cross-wires with each outermost longitudinal wire of ladder or truss design must not exceed 6 inches for smooth longitudinal wires and 16 inches for deformed longitudinal wires. Joint reinforcement for straight runs must be furnished in flat sections at least 10 feet long (roll type is not permitted). Factory-formed pieces must be provided at corners and intersections of walls and partitions.

D. Insulation

Cavity-wall insulation must be rigid board-type insulation. Choices are normally limited to polystyrene, polyurethane, or polyisocyanurate. Board-type insulation must have a waterproof facing on one side or be treated with a water repellent.

Insulation adhesive specifically prepared to adhere insulation to masonry must be nonflammable and must not adversely affect the insulation. It must have a proven performance record for the conditions under which it is to be used.

E. Masonry Units

Masonry units are so numerous that no attempt will be made to define or even identify each type. The specifications should be clear in their definition of the units required for each project. Generally, however, the specifications may include the materials described below.

1. Brick

Brick must be clay or shale conforming to ASTM C216, Type FBS, when facing brick is specified and ASTM C62 when building brick is specified. Regardless of the type of brick, the specifications should further spell out the degree of resistance to weather action. Severe weathering (SW) brick should be used on exterior facing below grade and for the first 6 inches above grade when the weathering index is 100 or more. Severe weathering or moderate weathering (MW) may be used throughout when the weathering index is less than 100. The weathering index is shown graphically in the respective ASTM specification. Grade negligible weathering (NW) should not be considered in most work. The color range should be indicated in the specifications or on the plans when facing brick is specified. Samples are required for color range approval and to check the manufacturer's accuracy.

2. Concrete Brick and Split-Block

Concrete brick and split-block that conform to ASTM C55, moisture controlled units, Type I, may be used for filling out in concrete masonry unit construction. They cannot be used for exterior facing, however, unless indicated by the specifications or plans. When permitted, Grade U-1 or P-1 units are used below grade and for all other exterior surfaces. Either Grade U-1, P-1, or G-1 units may be used as back-up or for other interior surfaces. Split-blocks are solid concrete veneer and facing units, sometimes called concrete masonry units (CMU), which are larger than brick size.

CMU are specified as hollow or solid under ASTM standards, based upon their usage. Generally, all concrete masonry must be modular in size and be furnished with all closers, jamb units, headers, and special shapes required for the project to eliminate the cutting and fitting of standard units. The specifications further identify locations where 1-inch radius bull-nose units are to be used for vertical external corners. For appearance and resistance to chipping, these block with radii are most important.

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Hollow load-bearing units must conform to ASTM C90, Moisture Controlled Units-Type I, and are to be used throughout except where solid load-bearing units are required. Units must be Grade U-1, P-1, or G-1. Grade G-1 is not to be used in foundation or basement walls or in visible, coated, exterior CMU walls, or where higher compressive strength units are required by the design. Grade G-1 units may be used in exterior walls in climates where there is no frost and where they will be painted.

Solid load-bearing units must conform to ASTM C145, Moisture Controlled Units-Type I, and may be used in any CMU construction Units must be Grade U-1, P-1, or G-1 and of the same usage as described for hollow load-bearing concrete masonry walls.

F. Mortar

Mortar for all masonry must comply with the property specification for type M or S in ASTM C270. Mortar must be mixed to laboratory-established proportions. This mix design must be furnished before any masonry work is started. The contractor submits a certified copy of the design and tests as evidence that the mortar meets the requirements of the property specification. No change is to be made in the mortar mix unless the contractor furnishes another certificate of the new design and tests. As much water as is required to produce workability without regard to initial flow, may be used in the mix.

G. Reinforcing Steel

Reinforcing steel used in masonry work has the same specification as that used in concrete. No mill reports or certificates are required with the delivery; however, insist upon compliance with ASTM A615 or A616.

H. Structural Clay Wall Tile

Structural clay wall tile is incorporated in all specifications as an optional material that the contractor may use in lieu of CMU when specified. This tile comes with a smooth face where the surface is to be exposed and/or painted and with a rough, scratched face where the surface is to be plastered. Closures, jambs, and other required shapes will be furnished with this tile. The structural requirements for the tile determine the governing specification.

I. Control Joint Key

The key used in control joints of CMU must be factory prefabricated of natural or synthetic rubber or some other rubber-like material. The key is fabricated so that it will fit without being forced into the sash grooves of standard CMU. The shear section must be at least 5/8 inch thick. CMU, concrete brick, and split-block should have representative samples selected from stockpiles to be tested for air-dry condition.

3.6 PREPARATION FOR MASONRY WORK

A. Sample Panel

Before any masonry work begins, there should be a complete understanding between the contractor and the construction engineer of the requirements regarding workmanship, patterning, placement of metal accessories, bonding, and any other feature that needs special emphasis. A sample panel was devised for this purpose because there is no better way to display knowledge of an operation than by demonstration. It is at this stage that all phases of the masonry installation should be discussed and acceptable procedures agreed upon. The sample panel or panels should be built in a position on the job site where it can be protected and maintained until all masonry work represented has been completed and accepted. This panel should show color range, texture, bond mortar joints (including tooling), anchors, anchorage of meeting masonry walls of different thicknesses, joint reinforcing, wall ties, wall reinforcement, grouting, flashings, insulation when required, parging (backplastering) when required, weep holes, and the pointing and cleaning.

B. Preparation for Masonry Construction

At the beginning of masonry construction operations, the construction engineer should become familiar with the contractor's procedure in making the necessary layout. At this stage, the contractor must provide such a layout that a minimum of cutting will be necessary to provide the maximum size of units adjacent to door and window openings and other such features. The location of expansion joints and control joints must be included in this planning. The contract drawings are often merely schematics that do not give complete dimensions. Even when dimensions are shown, some freedom is allowed to permit a convenient layout maximizing the use of standard units, except when dimensions are critical.

In the process of making the horizontal layout, the contractor must use the latest architectural plan layouts with all change orders posted, the setting drawings that are approved for use with glazed structural units, and other materials requiring setting plans.

In addition to the horizontal layout, the construction engineer must check the accuracy of the contractor's vertical layout. The coursing of masonry units must be accurate and so arranged that different masonry materials used in a wall will bond at regular intervals. Coursing with whole units must provide for placement of doors, windows, built-in cabinets, and other features. If it is impossible to work standard coursing to door and window heads, the base unit should be sized to accommodate the height required. The accuracy of this coursing should be maintained through the use of story poles.

3.7 MASONRY INSTALLATION

A. Cold Weather Installation

Before erecting masonry during temperatures below 40°F, discuss with the contractor methods proposed to heat the masonry materials and protect the masonry from freezing. Masonry units must be kept completely covered and free from frost, ice, and snow at all times and must have a minimum temperature of 20°F when laid. Temperature of mortar and grout (if used) must be between 40°-120°F. The air temperature on both sides of the masonry must be maintained above 32°F for 24-48 hours (check specifications), but may be reduced if high-early-strength cement is used instead of portland cement or masonry cement in the mortar. Frozen work may not be built upon.

B. Installation of Flashings

Flashings installed in masonry joints are placed in the center of the joint with mortar above and below the flashing materials. This type of installation both cushions the flashings and provides a tight joint for good support. Certain flashings and metal embedments in masonry joints are specified to be cut to a width allowing a setback from the edge, while others may extend completely through the wall. The specification and plans should be closely followed in this respect.

C. Expansion Joints

All building structures are subjected to expansion and contraction in the materials due to temperature and moisture changes. Expansion joint locations and details for their construction should be shown on the plans. Filler used in expansion joints should be a compressible-type material and firmly installed.

A building expansion joint is sometimes called a seismic expansion joint. This joint virtually cuts the structure in two and extends completely through the walls, roof, floor, and structural steel. It should extend completely through the wall and should contain an expandable-type water-stop and a filler material. The outside of the joint will usually be caulked and the inside covered with a metal cover plate.

Since clay and shale brick expands when wetted, expansion joints are installed through brick wythes at regular intervals. These joints should contain a compressible-type filler and be caulked. They need not line up with contraction joints in back-up wythes of cavity wall systems. Locate them as shown on the drawings. If not shown, check with the designer. A good rule of thumb is to locate them about 10 feet from corners of long walls and at intervals of 43 feet (for a % inch wide joint).

D. Control (or Contraction) Joints

Concrete masonry units shrink as they dry or cure. Because of this, it is necessary to install control joints in CMU wythes at regular intervals. They are to be located as shown on the drawings. Again, if not shown, check with the designer. In walls with joint reinforcement at 16 inches on center vertically, a good rule of thumb is to locate control joints at 24-foot intervals in exterior walls and 30-foot intervals in interior walls.

E. Partitions

Interior partitions that abut continuous partitions or walls, both exterior and interior, must be tied together when CMU and common clay building tile are used. The tie between abutting walls will be made with metal ties. In load-bearing walls, this tie will be rigid steel anchors with ends embedded in mortar-filled cells. Four-inch partitions may be anchored with a wire-mesh tie or segments of joint reinforcing. Other partitions and walls will be anchored with rigid steel anchors. Walls or partitions (including walls abutting concrete columns) must be anchored with metal anchors or ties spaced not more than 16 inches on center vertically.

Check the plans and specifications closely for anchorage of masonry walls to steel columns and to the structure above the wall.

A masonry bond is used at external corners of walls in order to maintain the bond pattern. The shape and size of units required at these corners will vary according to the thickness of the wall. Standard units are available and should be furnished for this requirement.

F. Masonry Construction at Door Frames and Windows

The spaces or voids between the end of masonry and door frames, window frames, and similar built-in items must be filled solidly with mortar. This becomes difficult unless such spaces are filled as the work progresses. The tendency among masons is to delay this operation until they have either built up to the next door frame anchor or to the head of the door frame. This delay in the filling operation should be discouraged because inadequate efforts are exerted to properly consolidate the mortar. Door frames are specified to be furnished with at least 3 anchors per jamb spaced 24 inches on center with the first approximately 24 inches above the floor. These will be installed in the mortar joints as the masonry work progresses.

G. Concrete Fills

Where reinforcing is specified to be placed in the masonry for lintels, bond beams, pilasters, etc., the units containing the reinforcement must be filled solidly. Just as is required in the placement of concrete, care should be exercised to ensure complete coverage of reinforcing steel in order to develop a bond. The concrete must be puddled well or otherwise vibrated to ensure adequate consolidation around the reinforcement.

H. Joints

Bed and head joints must be full and well-compacted to ensure good construction. The bed joint under the first course of masonry is specified to be solid under all types of units, including flush cut, in those areas to receive resilient-tile floors, and those which remain concrete finished. This joint should be consolidated and struck flush when the mortar becomes thumbprint hard. When it is allowed to set and become hard before it is finished, the surface will be irregular and lumpy. The mortar should be placed on the bed after the end of the unit being laid is buttered solid and then shoved into its final position, allowing the mortar to extrude from the joint. The practice of buttering two edges of the units before shoving it into position should not be allowed. The head joints with this method of laying will never be solidly filled.

Except for the first course and special applications such as piers, pilasters, columns, at anchors, and grout barriers, CMU will be fully bedded under both face shells, but mortar should not extend through the unit on web edges. Head joints must be filled solidly with mortar for a distance in from the face of the unit not less than the face shell thickness.

For brick masonry, both head and bed joints should be completely filled with mortar when laid. Face-shell buttering, such as is allowed for CMU, is not permitted for brick masonry installation.

All visible joints and joints occurring in painted walls must be tooled slightly concave, thoroughly compacting and pressing the mortar against the edges of the masonry units. The tool used for this operation must be as long as practical to ensure uniform jointing. (For horizontal jointing, it should be at least 24 inches long and for vertical jointing, 6 to 8 inches long). The size of the tool should be slightly larger than the joint space to permit uniform compaction and to press against the edges of the joint. The mortar in these joints should have developed its initial set and be thumbprint hard before tooling. When the mortar is tooled while it is too green it will not retain its shape and it will have a rough texture. When the mortar is too hard, the amount of compaction is irregular and because of the inability to compress the mortar, it will not be dense, therefore, not watertight.

Around all frames in exterior doors and windows, a caulking groove must be provided to ensure proper sealing. This groove is best made with a strip of wood lath or plywood held against the frame while masonry is being laid to it. This acts as a space and leaves a uniform joint for caulking. Other joints specified to receive caulking must be cut out to a 3/4 inch depth. This operation should be done while the mortar can be easily removed. Once the mortar has become hard, it is very difficult to cut it to the specified depth. Devices can be easily made that will uniformly cut out a joint while the mortar is still partially plastic.

3.8 REINFORCED MASONRY AND SEISMIC REQUIREMENTS

A. Reinforced Masonry

Reinforced masonry is used for two primary reasons: to reinforce the masonry walls against naturally occurring forces such as hurricane and earthquake damage and for security or antiterrorist purposes. For purposes of seismic design and construction, the country is divided into four seismic hazard zones. The contract drawings should include reinforcement details and information concerning the seismic zone. It is important that such special requirements be discussed with the contractor prior to beginning the masonry work to ensure agreement with and complete understanding of the reinforcing details.

B. Characteristics

All three types of masonry construction - single wythe, double wythe cavity, and double wythe composite - may be used in reinforced masonry construction. Depending upon the severity of the seismic or security exposure, the designer may specify every core to be grout-filled and may require vertical and/or horizontal reinforcing bars. On the other hand, it may only be required to reinforce and grout select cores. Construction requirements are basically the same as for unreinforced masonry, but there are several important differences, which are discussed in the following sections.

C. General Construction Requirements

1. Grout Types

The reinforced masonry specification will list a 28 day compressive strength requirement. Following the approved laboratory mix proportions is important. Fine grout consists of cement, lime, and fine aggregate mixed with sufficient water to obtain a pouring consistency (slump between 9 and 11 inches). Low-lift grout consists of cement, lime, and fine and coarse aggregates mixed with sufficient water to obtain a pouring consistency (slump between 9 and 11 inches). High-lift grout is the same as low-lift grout except that the coarse aggregate may be somewhat larger and a grout admixture is added. The admixture helps make the grout fluid and also produces an expansive action in the plastic grout to offset water-loss shrinkage and to promote bonding to all interior faces of the masonry units.

2. Wall Construction

It is important to take care in aligning cores of hollow units to preserve the vertical continuity of the cells for grouting. Minimum clear horizontal dimensions of vertical cores should be 2 by 3 inches.

Provide cleanout holes (minimum 3 by 4 inches) at the bottom of every pour in cores containing vertical reinforcement when the height of the pour exceeds 48 inches. A grout pour is the entire height of grout fill placed in one day, while a grout lift is the layer of grout placed in one continuous operation. A pour is normally composed of a number of successively placed lifts. If all cells are to be grouted, provide cleanout courses using inverted open-bottom bond beam units to permit cleaning of all cells by flushing. Cleanouts should be plugged only after all masonry work, reinforcement, and final cell cleaning is complete.

In cases where not all cells are to be grouted (i.e., only those containing reinforcement), then the cells to be grouted must be sealed by spreading mortar on the webs around those cells when erecting the walls. If all cells are to be grouted, provide vertical grout barriers at intervals not exceeding 85 feet horizontally. Spread cross-webs with mortar at these grout barriers to limit the horizontal flow of grout. It is also important to avoid fins of mortar that protrude into cells to be grouted. Fins protruding more than % inch into these cells must be removed.

Structural bond beams at floor and roof levels should be continuous through control joints. All other bond beams should be discontinuous at control joints. All bond beams should be discontinuous at seismic and expansion joints. When the structural bond beams pass through control joints, a dummy control joint should be formed at that location.

Vertical reinforcement bars may only be spliced where indicated on the drawings. Splices in adjacent bars should be staggered. The length of lap splices should be specified, but a good rule of thumb is 40 bar diameters or 24 inches, whichever is greater. The minimum clearance between bar and masonry is ½ inch and between parallel bars is one bar diameter. Vertical reinforcing must be supported accurately in place at ends of each bar and at specified intervals using centering clips, spacers, ties, etc. Column and pilaster ties must be wired around the vertical steel, not simply layed in the mortar joint.

3. Grouting

The low-lift method is the process of grouting masonry in 8 to 24 inch lifts as the wall is being laid. Grout should be placed at a rate that will not cause wall displacement from hydrostatic pressure. If the mortar has been allowed to set prior to grouting, remove fins protruding more than ½ inch into the grout space. Rod or puddle grout during placement using a 1 by 2 inch wooden stick or mechanical vibrator. Do not insert vibrators into lower pours that have semi-solidified.

The high-lift method is the process of grouting masonry in 3 to 4 foot lifts after the wall has been laid to its full height. Mortar fins protruding more than 1/2 inch into the grout space must be removed as the work progresses, using a rod or stick. The grout space is cleaned before grouting. Cleaning by high-pressure water is not recommended because wetting the block cells will reduce the effectiveness of the block and grout bond. Grouting should not proceed until mortar joints have set for 24 hours in single wythe construction, and 3-5 days in double wythe construction, depending upon weather conditions. Grout is placed in maximum 48 inch lifts with a waiting period between lifts. It is recommended that water absorbtion by the masonry and grout be allowed to take place for 5 minutes or so before vibrating. This will help improve the masonry and grout bond. Consolidate the first lift with mechanical vibrators. After the lift becomes plastic, but before reaching its initial set, the second lift will be placed. Again, consolidate the new lift extending 12 to 18 inches into the preceeding lift. Continue the process until after the top lift is placed. Following the waiting period for the last lift to become plastic, consolidate it a second time.

Grouting a section of wall between lateral flow barriers must be completed to the top of a pour in one day unless a new series of cleanouts is established and the new horizontal construction joint is cleaned.

If blowouts, misalignment, or cracking of face shells occurs during construction, that section of wall must be rejected and rebuilt.

4. Pointing and Cleaning

The nature of masonry construction makes cleaning a problem. The process of applying plastic mortar mix in excess of the quantity actually needed to a unit while in one position, then moving it into its final position, generates an extrusion of the excess mortar. With experience, knowledge of the materials being used, and pride in workmanship, a mason can lay an extremely clean masonry wall. Because of the manufacturing processes on clay units, the resistance of the finished product to cleaning solutions is much greater than other masonry materials, including the mortar joint. In the process of cleaning masonry surfaces, care must be exercised to avoid damage to those surfaces that are less dense.

With CMU, the materials are entirely different from clay products and, consequently, the cleaning operations must be considered in a different light. Acid solutions must never be used with CMU. All masonry work must be checked continuously for conformance with the specifications. Defective units, excessively chipped units, irregular joints, poorly tooled joints, and partially filled joints are to be removed and replaced. In the process of repointing masonry for what-ever reason, the replaced joint must be tooled and colored to match adjacent joints.

The cleaning of CMU can be minimized if care is exercised while laying them to avoid excessive smearing of the mortar on the face of the units. Mortar smears and droppings on concrete masonry should be removed either immediately or preferrably after a brief period to allow partial setting. After a partial set, these droppings can be easily removed with a trowel. After the droppings and smears are removed, a wire brush may be used with care so as not to damage the mortar joint.
At the conclusion of the masonry work, the walls are reinspected and cleaned of any accumulations of mortar that may remain. In the cleaning operation, every precaution should be taken not to impair or otherwise alter the textured surface of the units. All dust and foreign matter should be brushed from the surface.

4. STRUCTURAL STEEL AND WELDING

This section will acquaint project engineers and construction management personnel with many aspects of structural steel fabrication and erection procedures. Special steel-related quality problem areas are also noted. welding is the joining of metals by applying heat, sometimes with pressure and sometimes with a filler metal having a high melting point. It involves many technical fields such as metallurgy, physics, electricity, and chemistry. The welding sections are designed to acquaint the project engineers and construction management personnel with basic welding processes and procedures and to provide quality verification of welding operations.

4.1 Structural Steel

A. Materials

1. Structural Steel

Contract specifications indicate the type of steel required. The American Society for Testing and Materials (ASTM) Standard A36 is generally used for bolted, welded, or riveted structures. To verify that the materials furnished are those specified, mill reports and heat number identification of each piece of steel are required. Many other types of steel, such as high-strength and weathering steels, are available but are not as common as A36.

a. Shapes

Structural steel comes in various shapes. Construction manaement personnel should have access to the American Institute of Steel Construction (AISC) Manual of Steel Construction, which gives the different shapes and physical and design properties of structural steel. Following are descriptions of various steel members:

- The "W" shape is a new term for the old wide-flange section. The "W" has essentially parallel flange surfaces.
- The "S" shape is a new designation for the old "I" beam. The flanges are narrower than those on the "W." Also, the flanges are tapered on the inside, compared to the parallel flanges on the "W."
- "HP" designates a shape that has essentially parallel flange surfaces and equal web and

flange thickness, that is, the flange is more square in shape.

- "M" shapes are miscellaneous shapes, those that do not fall under the "W, S, or HP" classifications. They have various slopes on their inner flange surfaces.
- American Standard and miscellaneous channels, along with various sized and shaped angles, are lighter than full beams. Structural tees are made by splitting an "M" shape. These may be combined to produce structural members for special applications.

b. Tolerance

There are three types of tolerance: rolling, fabricated, and erection. The first two types, rolling and fabricated, are aspects of steel manufacturing. Manufacturing flaws are usually obvious, for example, a bent flange or excessive camber. Steel members with such flaws should be rejected. Erection tolerance is measured using a transit and plumb line to ensure that the structure is within permissible tolerance ratios. The AISC Steel Construction Manual gives these ratios. Be aware, however, that the contract may have more stringent standards and may override normally recommended tolerance ratios.

c. Storage

Materials should be examined for damage when they arrive on the jobsite. Proper storage is important, especially since space is usually limited. When planning for materials storage, keep in mind that projects are built from the ground up. Place stacks so that those materials needed first are most accessible. For example, reinforcement bars should be at the front, while roof decking should be placed at the rear of the storage area. Timber or steel skids are used beneath stacks to keep materials clean and dry. Timber blocking is used between beams of different shapes and sizes when stacked.

Three commonly found delivery and storage deficiencies are listed below:

- Structural steel members carelessly handled during delivery to the site. They are often thrown off the truck or train and piled in such a manner as to cause distortion in the members.
- Structural steel piled in direct contact with the ground.
- Coated steel decking, siding, and roofing improperly stored, allowing moisture between sheets, causing white rust.

2. Bolts

A structure is assembled from individual structural members by means of connections. Design and installation of connections is crucial, as this is the point at which structural failure may occur. Loads are applied through bolts, welds, or rivets, or a combination of these, and are concentrated on small portions of the joints. Distribution of stresses usually is highly irregular, as it is affected by the deformation of the fasteners and the connected material. There is a great deal of data concerning connection performance under various loads. The engineer takes this into account when designing the structure.

Project engineers and construction management personnel should become acquainted with the materials and installation procedures for high-strength bolting now commonly used. (Installation procedures are covered in section 4.2.) The AISC Specification for Structural Joints Using ASTM A325 or A490 Bolts, gives the allowable stress design for strength and slip resistance of structural joints using ASTM A325 high-strength bolts, ASTM A490 heat treated high-strength bolts or equivalent fasteners, and for the installation of such bolts when connecting structural steel members. (Further references to this document will be by the title AISC Specification.) Generally speaking, unfinished bolts/nuts are no problem. Refer to ASTM Standard 307 for conformity.

ASTM A325 and A490 provide for three types of high-strength bolts. The designer specifies the type bolt to be used. The three types of bolts are as follows:

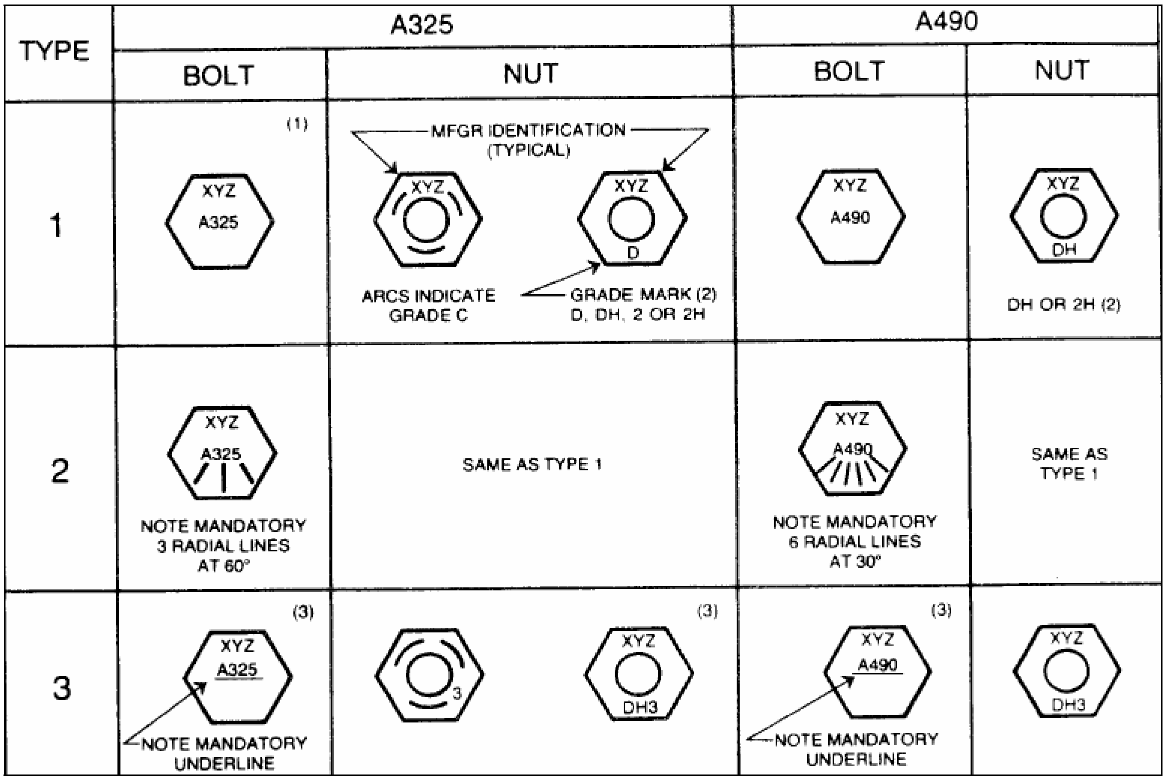
Type 1. Medium carbon steel for A325; alloy steel for A490.
Type 2. Low-carbon steel (not to be hot-dipped galvanized).
Type 3. Improved atmospheric corrosion resistance and weathering characteristics.

The length of bolts should be such that the end of the bolt will be flush with or outside the face of the nut when properly installed. The AISC Specification gives the method to determine required bolt length.

Various ASTM standards regulate the manufacturer of high-strength steel bolts. There are many counterfeit bolts coming into the country that are made of mild steel, which is unsuitable for construction use. It is mandatory that the contractor verify, through quality verification, that the bolts are made in accordance with the ASTM standards. Before work begins, the contractor shall provide the manufacturer's certificate (preferably the original). If in doubt, bolts can be laboratory tested to verify that they are American made.

ASTM A325 and A490 bear certain mandatory markings that give the place of manufacture. These easily read, distinctive markings for bolt-and-nut assemblies are shown in Figure 4.1-1. The manufacturer may apply other distinguishing markings.

Identification of high Strength Bolts



(1) ADDITIONAL OPTIONAL 3 RADIAL LINES AT 120° MAY BE ADDED.
(2) TYPE 3 ALSO ACCEPTABLE.
(3) ADDITIONAL OPTIONAL MARK INDICATING WEATHERING GRADE MAY BE ADDED.

High Strength Bolts
Figure 4.1-1

B. Shop Drawings

Structural steel shop drawings sometimes contain substitutions of sections or modifications of details that are submitted in lieu of those indicated on the contract drawings. Also, certain members and connections that were not indicated on the contract drawings will be designed by the fabricator and shown on the shop drawings. These changes and additions should be pointed out by the fabricator, then reviewed and approved by the construction engineer.

In most instances, the shop drawings will conform to the contract drawings. If there are changes, they require approval by the construction engineer. Under no circumstance should substitutions be used without approval.

Specifications usually require that the contractor submit copies of a detailed erection procedure, including sequence of erection and temporary staying and bracing. It is important that this plan be reviewed to anticipate problem areas and to schedule monitoring of the work.

Structural drawings are included as a part of the contract plans. These should be checked along with the shop drawings. Construction management personnel are not authorized to make changes without approval from the project engineer.

If, in your review, you feel that there is a design mistake, it should be brought to the architectural engineer's attention to solve before the construction phase begins.

4.2 HIGH-STRENGTH BOLT TIGHTENING CONTROL TESTING

A. Connections

The connection is the point at which cataclysmic failure may occur in a structure. Most connections are designed by the steel fabricator. There are three types of connections: bolted, welded, and riveted, or a combination of these.

High-strength bolts may be used in either bearing or friction-type connections. When high-strength bolts are required by the plans and specifications, assume these are friction-type connections. A friction connection clamps two pieces of material by a high-strength bolt and a nut tensioned in such a way that it clamps the two pieces by an equal and opposite pull on each. Bearing type connections bear on something else and may be tightened by a spud wrench or an impact wrench to snug tight, whereas friction-type connections require one of four special methods of tensioning, which will be covered in this section.

1. Bolted

The AISC Specification discontinued the designations "friction-type" and "bearing-type" connections to focus attention on the real manner of performance of bolted connections. Thus, the design of high-strength bolted connections begins by determining the strength required to prevent premature failure either by shear of the connectors or by bearing failure of the connected material.

Next, for connections that are defined as "slip-critical," the resistance to slip at the working load is checked. The AISC Specification recognizes that, in a significant number of cases, slip of the joint would be detrimental to the serviceability of the structure. Such joints are termed "slip critical" joints. This is somewhat different from the friction-type connection because it recognizes that all tensioned high-strength bolted joints resist load by friction between faying surfaces up to the slip load. Subsequently, they are able to resist even greater loads by shear and bearing.

(Additional design information can be found in the AISC Specification.) The AISC Specification also gives installation procedures for bolts that are not within the slip-critical or direct-tension category.

First, the requirement for identification of connections on the drawings may be satisfied either by identifying the slip-critical and direct-tension connections that must be fully tightened and inspected or by identifying the connections that need to be tightened only to the snug-tight condition (tightness present when the plies of the joint are in firm contact). This change is intended to improve the quality of bolted steel construction and to reduce the frequency of costly controversies. It also focuses attention, during the installation and tensioning phase and during inspection, on the true slip-critical connections. This change will reduce the requirement for costly tensioning and tension testing of the many connections that are not slip-critical.

High-strength bolts designated as slip-critical or in direct tension must be tightened to a tension that is equal to or greater than their proof load, regardless of the bolting method used. Figure 4.2-1 is a table from the AISC Specification. This gives the fastener tension required for slip-critical connections and connections subject to direct tension. This tension produces the high clamping force that enables surfaces to carry loads by friction, provided the bolted surfaces are free of paint, oil, or other lubricants.

Any type of paint may be used on faying surfaces that are not slip-critical. In slip-critical areas, either paint qualified by prior testing must be used or there must be no paint on the contact surfaces approximately one inch, but not less than the bolt diameter, away from the edge of the hole.

Specifications call for a heavy hexagonal-head structural bolt, a hexagonal nut, and either one washer or no washers, depending on the tightening method used and the type of bolt. Bolt holes are slightly oversized to allow entry of the bolt. Washers provide a hardened surface under the element turned in tightening for all installation procedures.

Four methods are approved for use in obtaining the proper bolt tension. They are:

- Turn-of-Nut.
- Calibrated Wrench.
- Alternate Design Fasteners.
- Direct Tension Indicators.

Fastener Tension Required for Slip-critical Connections and Connections Subject to Direct Tension

Nominal Bolt Size, Inches	Minimum Tension* in 1000's of Pounds (kips)	
	A325 Bolts	A490 Bolts
1/2	12	15
5/8	19	24
3/4	28	35
7/8	39	49
1	51	64
1 1/8	56	80
1 1/4	71	102
1 3/8	85	121
1 1/2	103	148

**Equal to 70 percent of specified minimum tensile strengths of bolts (as specified in ASTM Specifications for tests of full size A325 and a490 bolts with UNC threads loaded in axial tension) rounded to the nearest kip*

Fastener Tension Chart
Figure 4.2-1

These methods are designed to provide a minimum bolt tension that is equal to the minimum tension given in the AISC Specification for A325 and A490 bolts (see Figure 4.2-1). In all cases, tightening should begin at the most rigidly fixed or stiffest point and progress toward the free edges, both in the initial snugging-up and in the final tightening stages.

a. Turn-of-Nut

When the turn-of-nut tightening method is used, obtain a representative sample of at least three bolts/nuts of each diameter, length, and grade to be used. Check these at the start of work using a tension-indicating device, such as the Skidmore-Wilhelm gauge. The test confirms that the method of estimating the snug-tight condition and controlling turns from snug tight, to be used by the bolting crews, develops a tension not less than 5% greater than the tension requirements noted in Figure 4.2-1.

Bolts are installed in all holes of the connection and brought to a snug-tight condition. "Snug-tight" is defined as the tightness present when the plies of the joint are in firm contact. This may be attained by a few impacts of an impact wrench or by the full effort of a worker using an ordinary spud wrench. Snug tightening progresses systematically from the most rigid part of the connection to the free edges, and then the bolts of the connection are retightened until all bolts are simultaneously snug-tight and the connection is fully compacted.

Following this initial operation, all bolts in the connection are tightened further by the applicable amount of rotation specified in the AISC Specification. Figure 4.2-2 is an extract that gives the required nut rotation from the snug-tight condition. During the tightening operation, there should be no rotation of the part not turned by the wrench. Remember that A325 fasteners may be installed without hardened washers when tightened by this method as long as the yield point of the steel is less than 40 ksi (i.e., A36 steel). However, a washer improves the accuracy and makes turning the nut easier. Where the outer face of the bolted parts has a slope greater than 1:20, a smooth beveled washer should be used to compensate for the lack of parallelism between the nut and the steel. Refer to Figure 4.2-2 for the required additional rotation from snug-tight when one or two beveled washers are required.

Bolt tension has an important effect on the load-slip characteristics of the joint. Figure 4.2-3 shows a comparison of load turns data for A325 and A490 bolts from snug tight. When the high-strength bolt is tightened past the snug-tight position, the bolt is loaded with tension. This stretches the steel. Steel is elastic and tries to return to its original dimension, but cannot because the steel work is in the way, so the bolt clamps the connection together. Tensioning up to a point is necessary and efficient; past this point, the effectiveness of the connection is diminished, as illustrated in this figure.

It may be necessary to retighten bolts loosened by subsequent tightening of other bolts. This retightening does not constitute re-use of bolts. To assist in the inspection of bolts installed by the turn-of-nut method, the bolt point and outer face of the nut may be match-marked with a dab of paint or crayon after the assembly has been snug-fitted. The amount of rotation can then be easily read. When using an impact wrench, the edges of the bolt heads and nuts will be peened over when using A325 bolts. The edges of an A490 bolt will appear slightly peened.

b. Calibrated Wrench

The second approved method to tighten bolts to the required tension is the calibrated wrench method, which may be used only when installation procedures are calibrated on a daily basis and when a hardened washer is used under the turned element. Calibration of the wrench is required at least daily for each bolt diameter, length, and grade of fastener. This is accomplished in a device capable of indicating actual bolt tension by tightening three typical bolts of each diameter, length, and grade. Wrenches must be recalibrated any time significant differences are noted in temperature, surface conditions of bolt threads, nuts, or washers, or any time the wrench is dropped. When calibrated wrenches are used, they must be set to provide a tension not less than 5% in excess of the minimum tension given in the AISC Specification (refer to Figure 4.2-1). All bolts must be installed and brought to a snug-tight condition. Again, tightening should progress systematically from the most rigid part of the joint to its free edges.

c. Alternate Design Fasteners

The third approved tightening method is for alternate design fasteners. This involves an irreversible mechanism such as yield or twist-off of an element. The bolts used have a splined end extending beyond the threaded portion of the bolt, which is gripped by a special design wrench chuck that turns the nut relative to the bolt until the splined end is sheared off. Bolts must be installed in all holes and all fasteners first tightened to a snug-tight condition in which all materials are in contact. Next, the fasteners must be fully tensioned in a systematic manner and the splined end sheared off. If the fasteners are installed and tensioned in a single continuous operation, they will give a misleading indication to the inspector that the bolts are properly tightened. Therefore, the correct way to inspect these fasteners is to observe the jobsite testing of the fasteners and the installation procedure. Then monitor the work while in progress to assure that the specified procedure is routinely followed.

d. Direct Tension Indicators

The last approved tightening method is by direct tension indicators. A direct tension indicator is a hardened washer incorporating several small formed arches that are designed to deform in a controlled manner when subjected to a load. Because the washers depend upon an irreversible mechanism, inelastic deformation of the formed arches, bolts, together with the load-indicating washer plus any other washers required by the AISC Specification, should be installed in all holes of the connection and the bolts brought to a snug-tight condition. Only after this initial tightening operation should the bolts be fully tensioned in a systematic manner.

Load-indicating washers delivered for use in a specific application should be tested at the jobsite to demonstrate that they provide a proper indication of bolt tension and that they are properly used by the bolting crew. To determine if load-indicating washers are properly installed, use an ordinary feeler gauge to measure the gap between the washer and the bolt head. To check for a 0.015 inch or less gap, insert the gauge into three different locations until the feeler gauge will not go into any of the three points checked. If for some reason the load indicating washer is installed at the nut end of the fastener assembly, an additional hardened washer is necessary and the gap required is then 0.005 inch or less, again only until the gap closes to the point that the feeler gauge can no longer be inserted into any of three points checked. Consult the manufacturer's data on load-indicating washers for additional information.

2. Welded

Most connections are bolted. Welded connections transfer the load from one member to another through the weld. This topic is included in the welding portion of this section.

4. Riveted

Riveting is rapidly becoming a lost art. It remains in contract specifications should a contractor elect to use it. In view of its very limited use, a discussion will not be offered in this course.

B. Contractor Responsibilities

At the preparation meeting, make sure the contractor is familiar with the high-strength bolting requirements of the AISC Specification. The contractor must also be able to tighten all bolts to the specified tension. Given below are some commonly found bolting-related deficiencies:

- A proper procedure for high-strength bolting was not used.
- Bolt tension indicating device not on site.
- Washers not used where required.
- Retightening of high-strength bolts was not accomplished after initial snugging-up.

The contractor must have adequate operational control for consistency throughout the steel erection process.

Nut Rotation From Snug Tight Condition *

Bolt length (Under side of head to end of bolt)	Disposition of Outer Face of Bolted Parts		
	Both faces normal to bolt axis	One face normal to bolt axis and other sloped not more than 1:20 (beveled washer not used)	Both faces sloped not more than 1:20 from normal to the bolt axis (beveled washer not used)
Up to and including 4 diameters	1/3 turn	1/2 turn	2/3 turn
Over 4 diameters but not exceeding 8 dia.	1/2 turn	2/3 turn	5/6 turn
Over 8 diameters but not exceeding 12 dia.**	2/3 turn	5/6 turn	1 turn

*Nut rotation is relative to bolt regardless of the element (nut or bolt) being turned. For bolts installed by 1/2 turn and less, the tolerance will be + or - 30 degrees; for bolts installed by 2/3 turn and more, the tolerance will be + or - 45 degrees. Applies only to connections in which all material in the grip of the bolt is steel.

** No research has been done by the Council to establish the turn-of-nut procedure for bolt lengths exceeding 12 diameters. Therefore, the required rotation must be determined by actual test in a suitable tension measuring device which simulates conditions of solidly fitted steel.

Required Nut Rotation
Figure 4.2-1

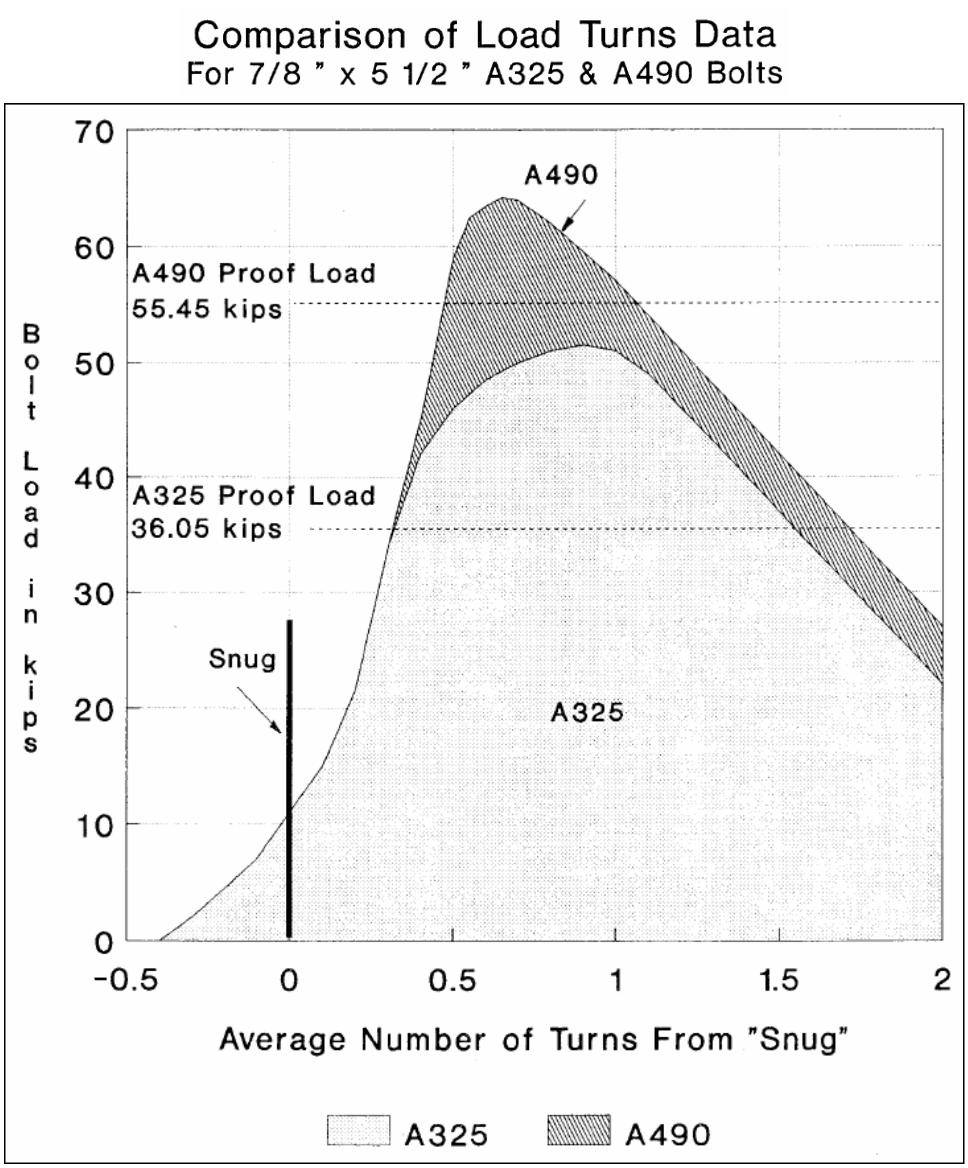

Comparison of Load Turns Data
For 7/8 " x 5 1/2 " A325 & A490 Bolts
Bolt Load in kips
70
60
50
40
30
20
10
0
-0.5
0
0.5
1
1.5
2
Average Number of Turns From "Snug"
A490
A490 Proof Load
55.45 kips
A325 Proof Load
36.05 kips
Snug
A325
A325
A490

Figure 4.2-3

4.3 COMMON WELDING PROCESSES AND PROCEDURES

A. Welding Symbols

1. Contract Drawings

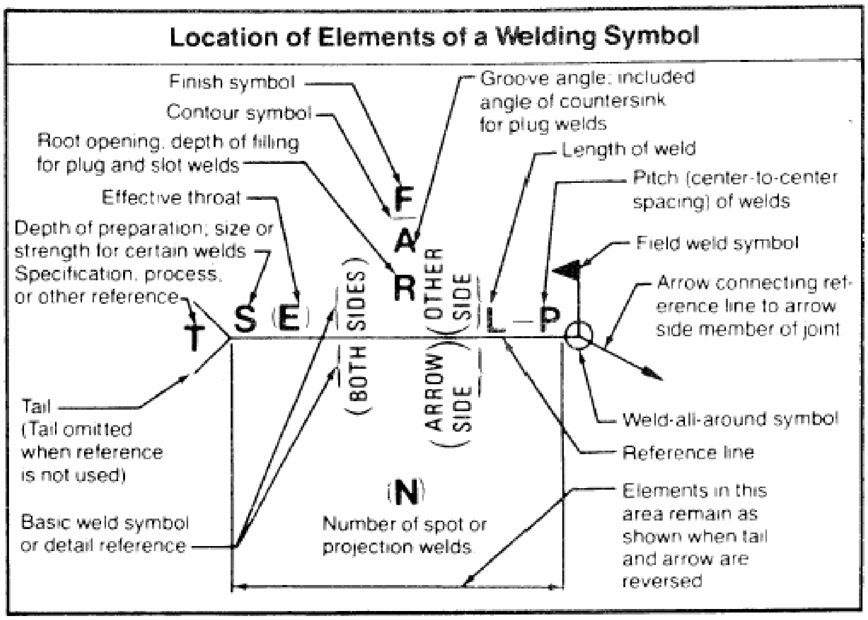
Welding symbols are shown on the contract drawings to indicate the type, size, and dimensions of the weld required at each connection. Reading welding symbols is not difficult, but there are many combinations that may be displayed on a welding symbol. For this reason, welding symbols are easily confused, as is occasionally evidenced by improper welding symbols on contract drawings. However, assume that the symbol is correct and follow it to the letter. Any symbol that appears incorrect should be referred to your supervisor. The design engineer has designed a specific weld and delineated that design through a symbol on the drawings. Improper enforcement of the requirement could result in structural failure and possible injury.

2. Standard Welding Symbols

The American Welding Society (AWS) has published standardized welding symbols. These symbols are found in a number of sources and should be available for ready reference. There are seven types of welds listed:

- Fillet.
- Plug or slot.
- Arc seam or arc spot.
- Groove.
- Seam.
- Surfacing.
- Flange.

These symbols can be found in the Hobart Pocket Welding Guide. It is unnecessary to known all the symbols; however, you should be familiar with the most frequently used ones, such as fillet and groove. Figure 4.3-1 shows the standard location of elements of a welding symbol.



Explanation of AWS classification numbers

MILD STEEL AND LOW ALLOY ELECTRODES—AWS A5.1-69 AND A5.5-69

All mild steel and low alloy electrodes are classified with a 4 or 5 digit number prefixed by "E."

Prefix "E" = Electrode

First two (or three) digits = Tensile strength (psi) (stress relieved)

Third (or fourth) digit = Position of welding
1 = All positions (flat, horizontal, vertical, overhead)
2 = Horizontal and flat positions only

Fourth (or fifth) digit = Type of coating and welding current

FOURTH DIGIT	TYPE OF COATING	WELDING CURRENT
0	cellulose sodium	DCEP
1	cellulose potassium	AC or DCEP
2	titania sodium	AC or DCEN
3	titania potassium	AC or DCEN or DCEP
4	iron powder titania	AC or DCEN or DCEP
5	low hydrogen sodium	DCEP
6	low hydrogen potassium	AC or DCEP
7	iron powder iron oxide	AC or DCEN
8	iron powder low hydrogen	AC or DCEP
E6020	iron oxide sodium	AC or DCEN or DCEP
E6022	high iron oxide	AC or DCEN or DCEP

DCEP—Direct Current Electrode Positive
DCEN—Direct Current Electrode Negative

EXAMPLE

MILD STEEL WELDING WIRES—AWS A5.18-69
Example: E70S-3

The prefix E designates an electrode as in other specifications. The number 70 refers to the required minimum as-welded tensile strength in 1,000 psi. The letter S designates a bare, solid electrode. The suffix "3" indicates a particular classification based on as-manufactured chemical composition.

MILD STEEL TUBULAR WELDING WIRES—AWS A5.20-69
Example: E70T-1

The prefix E designates an electrode as in other specifications. The number 70 refers to the required minimum as-welded tensile strength in 1,000 psi. The letter T designates a composite or powder-cored electrode (that is, a continuous tubular-type electrode with a powdered flux in the tube). The suffix "1" indicates a particular classification based on deposited weld metal chemical analysis, shielding gas used, and usability of the electrode for single or multiple pass applications.

Typical Welding Symbols
Figure 4.3-1,

B. Electrodes

The electrode carries electric current to the arc. The arc is a luminous discharge of electric current crossing a gap. The electrode is composed of a core of metal wire around which a chemical coating has been shaped and baked. The core wire melts in the arc and tiny droplets of molten metal shoot across the arc into the molten pool. The electrode provides additional filler metal for the joint to fill the groove or gap between the two pieces of the base metal. The coating also melts or burns in the arc. It has several functions: it makes the arc steadier, increases the arc force, provides a shield of smoke-like gas around the arc to keep oxygen and nitrogen in the air away from the molten metal, and provides a flux for the molten pool that picks up impurities and forms the protective slag.

Flux is material used to prevent, dissolve, or facilitate removal of oxides and other undesirable surface substances. Slag is the mass left as residue by the melting or fusing of metals.
AWS has standardized electrode classification numbers. Project engineers and construction management personnel should become familiar with the numbering system found in Figure 4.3-2. Check the electrodes used against the specified approved welding procedure. Special storage procedures are necessary for low-hydrogen electrodes. These should be kept dry at all times and, when a can is opened, stored at temperatures from 250°F to 400°F in a proper enclosure.

One of the problems in making a weld is that the molten metal in the arc stream, as well as in the moltencrater in the work piece, is exposed to the atmosphere. Metal exposed to the atmosphere oxidizes or rusts. When metal is exposed to the atmosphere in a molten state, oxidation takes place very rapidly. The oxides that form in the weld reduce its capability to be shaped and molded. Nitrogen is also picked up from the atmosphere. Nitrogen makes steel brittle, so should be excluded from the weld metal.

The arc between a bare electrode and the work is unstable. This means that the current is not easily sustained across the gap and will short out easily as droplets of electrode metal bridge the gap. The arc also tends to burn off the electrode at a comparatively low rate. These chemical and electrical properties are the reasons for coating electrodes. It is necessary to protect the molten metal from the air and to stabilize the arc and make more effective use of the arc energy.

C. Welding Processes

There are over forty different welding processes. The four most common ones will be discussed here.

1. Shielded Metal-Arc Welding (SMAW)

This is the most widely used method for general welding applications. It is also known as metallic-arc, manual metal arc, or stick-electrode welding. This process uses the intense heat of an electric arc between a coated metal electrode and the base metal. Arc shielding is obtained from the decomposition of the electrode coating. Filler metal is obtained from the electrode core. The electrode, put in a hand-held clamp, is struck against the base metal and withdrawn to create a gap. The molten portion of the electrode fuses into the molten pool of the base metal, producing the weld.

There are several advantages of using SMAW. This manually-controlled process welds practically all ferrous (iron) metals, ranging from 18 gauge to unlimited thicknesses. For plates over inch thick, a bevel edge preparation and the multipass welding technique are used. The process provides all-position welding and the arc is visible to the welder. Slag removal is required.

2. Submerged Arc Welding (SAW)

This process is used typically in dam construction and production welding. It is a high-speed process that may be either automatic or semi-automatic. welding is possible in the flat or horizontal positions. SAW is used to weld low and medium carbon steels, low alloy high-strength steels, quenched and tempered steels, and many stainless steels. It is also used for hard surfacing and build-up work.

A more descriptive name for this process would be hidden arc, since the arc is completely hidden from view (submerged) by a mound of granular flux. An arc is formed between the electrode and the work. The arc is completely covered at all times by the flux that is deposited continuously from a hopper around the wire as it is fed to the work area. The arc melts the electrode, the base metal, and a quantity of the flux. The molten flux covers the crater as it cools, solidifying into a brittle slag. The functions of the flux in welding are similar to those of the hard electrode coating. It contains the arc and concentrates its forces and heat in the joint. This containing effect also helps to eliminate spatter, even though high currents are being used. (Spatter is the metal particles expelled during fusion welding that do not form a part of the weld.) Through the composition of the flux, which can readily be varied, the chemistry of the weld metal can be controlled to produce a wide variety of weld-metal compositions. The flux also acts as a dam to form the molten bead, resulting in welds with excellent shape and appearance.

3. Gas Metal Arc Welding (GMAW) or Metal Inert Gas (MIG)

GMAW is also called MIG arc welding or CO_2 welding. It is a gas shielded metal arc welding process that uses the intense heat of an electric arc between a continuously fed, consumable electrode wire and the work to be welded. Metal is transferred through
the gas mixture. The major equipment components required for this process are:

- The shielding gas system and controls.
- The welding machine (power source).
- The wire feeding mechanism and controls.
- The electrode wire.
- The welding gun and cable assembly.

The shielding gas displaces the air surrounding the weld pool, preventing contamination of the weld metal by atmospheric oxygen and nitrogen. Argon, helium, CO2, or an argon-helium mixture is used for shielding with this process. Usually, a single gas cylinder is required. A flowmeter and pressure-reducing regulator is mounted on top of the gas cylinder.

A specially designed welding machine (power source) is used for GMAW. It is a constant voltage (CV) type of power source. It can be a direct current (DC) rectifier or a engine-driven generator. The output power of a constant voltage machine has essentially the same voltage no matter what the welding current may be. The current output is regulated by a rheostat on the welding machine. GMAW uses an arc voltage of 15 to 30 volts. Open circuit voltage (while not welding) and arc voltage (while welding) are read on the welding machine's voltmeter. There is no current control on a constant voltage type machine, and for this reason it cannot be used for manual electrode welding. The welding current output is determined by the wire feeder.

The special wire feeder and the constant voltage welding machine constitute the heart of the GMAW welding process. There is a welding current so, at a given wire feed speed rate, the welding machine will produce the current required to maintain the arc.
Thus, the electrode wire feed rate determines the welding current. Wire feed speed (welding current), is set by the wire-speed control knob on the wire reader. The current, which is read on the welding machine's ammeter while welding, ranges from 100 to 400 amperes depending upon the diameter size of the electrode wire being used. For this process, direct current with reverse polarity (DCRP) is used.

The consumable electrode wire sizes normally used are .035, .045, 1/16, 3/32, and 1/8 inch in diameter. The wire is solid and bare and must be carefully selected so that the resulting weld will have mechanical properties similar to the base metal being welded.

Since the GMAW process can be either semi-automatic or automatic, a manually controlled welding gun or a fixed welding torch is used, depending upon the method of the process being used. The primary function of both is to direct the shielding gas and the consumable electrode wire from the wire feeder into the arc area. The welding gun or torch can be either air or water cooled, depending upon the amperage being used. With the lower amperages, air cooling is used. With higher amperages, water cooling is required. The gun or torch nozzle should be cleaned regularly to assure efficient gas shielding. Special anti-spatter compounds are sometimes used to prevent spatter build-up on the nozzle.

The advantages of GMAW are:

- Its ability to weld metals that before had been hard to weld with other processes.
- It is economical.
- Welding is possible in all positions.
- The arc is visible to the welder.
- There is a minimum amount of post-weld cleanup or spatter removal.

GMAW is used primarily for welding aluminum, nickel, magnesium, copper and their alloys, titanium, and stainless steels. Metal thicknesses range from 12 gauge to 1 inch or thicker in some instances.

4. Gas Tungsten Arc Welding (GTAW) or Tungsten Inert Gas (TIG)

GTAW, or TIG arc welding, is a gas shielded arc welding process that uses the intense heat of an electric arc between a non-consumable tungsten electrode and the work to be welded. It is also known by the trade name "Hiliarc." Shielding is obtained from an inert gas or from a mixture of inert gases. Filler metal may or may not be used; however, it is usually employed, except when welding thin metals. When a filler rod is used, it is usually manually fed into the weld pool. GTAW is the most popular method for welding aluminum, stainless steel, and nickel-base alloys. It provides more precise control of the weld than any other welding method because the arc heat and filler metal are independently controlled.

The shielding gas displaces the air surrounding the arc and the weld pool, preventing contamination of the weld-metal oxygen and nitrogen in the atmosphere. Since GTAW requires an inert shielding gas, either argon or helium, or a mixture of both, is used. Argon is more widely used since it is more readily available and because it is a heavier gas that provides better shielding at a flow rate. A gas flow rate of 15 to 30 cubic foot per hour (cfh) is normally used, with a somewhat higher rate for overhead position welding.

A specially designed welding machine (power source) is used with the GTAW process. It may be an alternating current/direct current (AC/DC) rectifier, or a DC generator, which can be either motor or engine driven. AC or DC may be used, and either straight or reverse polarity can be used with DC. A high-frequency stabilizer may be used for TIG welding, a high frequency current superimposed on the welding current aids arc starting. It is more commonly used with AC welding. The selection of AC or DC, the selection of polarity, and the use of high-frequency current depends on the material being welded. AC is recommended for welding aluminum and magnesium; DC is recommended for welding stainless steels, cast iron, mild steels, copper, nickel and alloys, and silver. GTAW welding machines operate with a range of 1 to 500 amperes at 40 volts with a 60% duty cycle.

Electrodes used with the GTAW process are made of tungsten and tungsten alloys. They have a high melting point and are practically nonconsumable. The electrode does not come into contact with the molten weld puddle. Properly positioned, it hovers over the work and the intense heat from the arc keeps the puddle fluid. Electrode tips contaminated by contact with the weld puddle must be cleaned or they cause a sputtering arc. Cleaning is usually done by grinding off the contaminated surface.

Electrodes are either pure tungsten, 1% or 2% thoriated tungsten, or zirconiated tungsten. They are supplied either in a cleaned or ground finish, and in 3 inch to 24 inch lengths. The use of proper electrodes provides easier arc starting and arc stability. When filler-metal rods are used, they should be matched to the base metal.

The advantages of GTAW are:

- It produces the highest quality welds in nonferrous metals.
- Almost no post-weld cleaning is required.

- The arc and weld pool are clearly visible to the welder.
- Metal does not transfer through the arc.
- Welding is possible in all positions.

GTAW is used primarily for welding nonferrous metals such as aluminum, magnesium, stainless steels, silicon bronze, silver, copper and alloys, nickel and alloys, cast iron, and mild steels. It is also used to make a root pass on carbon steel pipe. A wide range of metal thicknesses are weldable with GTAW. The process may either be manual or automatic, with the manual method being more widely used.

4.4 QUALIFICATION REQUIREMENTS/WELDING PROCEDURES

A. Qualification Requirements

Qualification tests assure that welders and welding operators meet a certain minimum skill level. Welding procedures are qualified to assure that they meet the criteria of a particular specification or code. Qualification requirements presented here are based on AWS D1.1, Structural Welding Code. When a specific code is referenced for use in a contract, the provisions of that code govern the job.

1. Welding Personnel Qualification

A welder is able to perform a manual or semiautomatic welding operation. To become qualified to work on a job covered by a welding code or specification, the welder must perform certain qualification tests that are specially designed to determine ability to produce sound welds. The welder performs specified welds using qualified welding procedures. Certification under one code does not necessarily qualify the welder under other codes. The contractor must maintain records of welder certification. Figure 4.4-1 shows a sample welder qualification testing certificate.

The contractor usually conducts qualification tests prior to beginning work. Production personnel who have been working under a similar welding procedure within the last 90 days may not be required to be retested. The project engineer should be notified at least 24 hours in advance as to time and place of testing. A list of names and symbols used to identify production personnel's work should be provided for the project engineers records.

2. Welding Operator Qualification

A welding operator is one who operates machines or automatic welding equipment. All welding operators must be qualified by taking the tests prescribed in the code.

3. Weld Procedure Qualification

The welding procedure is a detailed written explanation of the welding standards to be followed by the contractor on the job. Figures 4.4-2 and 4.4-3 give a sample of the suggested format for welding procedure specifications using Section IX of the ASME code. This information is essential for project engineers and construction management personnel to check the various aspects of the welding operation. In addition to giving the welding procedure specification number, it gives the process to be used, sketches of joints to be welded, base metal and filler metal (electrode) specifications, and other information such as the welding positions, preheating requirements, and technique details.

There are six basic welding positions. These positions are classified based on two factors: whether the welding is done flat (1), horizontally (2), vertically (3), overhead (4), or in a fixed position; and whether the weld is a fillet (F) or groove (G) weld. For example, two of the most commonly used welding positions are 2F, which denotes a fillet weld in a horizontal plane, and 3G, which is a groove weld in a vertical plane. Positions 1 through 4 can be used for both fillet and groove welds. Positions 5 and 6 apply only to groove welds. A welder qualified for position 2 can weld in both positions 1 and 2 and so forth. Thus, the larger the position number for which a welder is qualified the better his welding ability and expertise.

The welding procedure is established and recorded by the contractor as a procedure specification. An investigation to qualify this procedure follows, using the procedure specification. Tests are required to determine the tensile strength, ductility, and degree of soundness of the welded joints made under a given procedure specification. The number of tests, base metal and its preparation, and position of the welds are all specified within the welding procedure.

4. Prequalified Welds

There are a number of welds that have been used in the past and have been tested according to established procedures, thus are considered prequalified. By following these well defined variables, the user does not have to qualify the procedure. If any of these variables is changed beyond specified limits, qualification of the procedure is required. AWS D1.1 gives a list of prequalified welds.

4.5 NONDESTRUCTIVE TEST METHODS

A. Nondestructive Tests

There are a number of tests that may be used which assure, to a degree, the quality of a weld. Construction manaement personnel usually will not have the elaborate equipment with which to test welds; therefore, they should become familiar with routine testing techniques. Several tests will be covered here, but the emphasis will be on the visual inspection.

There are many benefits of nondestructive testing. It provides reasonable assurance of sound welds without destroying the work tested. It also eliminates further labor and machine costs, so is relatively inexpensive. Specific nondestructive tests are
commonly used to ensure uniformity and continuity in the inspection process.

B. Test Methods

1. Penetrant Inspection

Liquid dye penetrants are a sensitive, low cost way to detect minute surface flaws such as cracks, pores, and leaks. They can generally be used with any nonporous metallic or nonmetallic material. Entire surfaces of complex shapes can be tested in one sequence of operations. The area to be tested must be clean and dry. The penetrant is applied by painting, brushing, or aerosol spray and allowed to seep into surface imperfections. Excess penetrant is cleaned from the surface and a developer applied. The developer acts like a blotter, drawing penetrant out of the defect up to the surface where it can be seen by the naked eye or under a black light when using fluorescent dyes. The use of rilliant dyes and penetrating oils, together with fluorescent dyes, have improved this technique.

2. Magnetic Particle Inspection

The basic theory behind magnetic particle testing is that defects in metal interrupt the continuity of the solid mass. In a magnetized mass of material, they will cut across the lines of force. When these cuts occur, polarity is produced at the interruption, creating magnetic poles on each side of the defect. The newly created magnetic field will draw and hold the fine magnetic particles that form a bridge across the discontinuity. The result is an accumulation of particles along the outline of the imperfection indicating size, shape, and extent of the defect. This method should not be used to detect cracks or flaws more than 1/4 inch into the weld. Though useful only for detecting defects near the surfaces of ferromagnetic materials, such as steels, this method of nondestructive testing is widely used.

3. Ultrasonic and Radiography Inspections

Ultrasonic and radiography are two viable options for nondestructive testing. Ultrasonic sound waves and gamma or X-ray radiation may be used to detect internal defects. These testing methods require special equipment and a high level of technical expertise to correctly perform these tests and to interpret the results. For these reasons, such services are usually contracted out.

4. Visual Inspection

visual inspection begins when the steel comes on the job site, and continues with observing preparation work through to the inspection for visible surface defects. This is the most widely used inspection technique for several reasons given below:

- It is usually inexpensive.
- Very little equipment is needed.
- No external power source is needed.
- It can be instrumental in avoiding defects and repairs.
- It is usually fast.

However, it is not foolproof. Internal defects cannot be found by this method. Certain equipment should be available to the project engineer with which to perform a visual inspection. Some of the equipment that might be used includes a flashlight, a magnifying glass (10X or less), a protective lens, weld and bevel gauges, a hammer and chisel, and a magnet.

There are several checks that should be made prior to executing the weld, such as joint fit-up, edge preparation, accuracy of beveling, pre-heat procedures, root opening, tacking, jigs, distortion control, electrode selection, machine settings (amperage), terminals on cable equipment, and so forth. A number of these items are specified in the welding procedure.

A visual inspection of the weld itself can be a substantial guideline in evaluating its soundness. Given below are nine points to check:

- Size: Check leg size of fillets, as well as throat thickness.
- Geometry: Check the dimensions and angles of jointed pieces and those of the weld.
- Undercut: A groove melted into the base metal adjacent to the weld caused by poor technique on the part of the welder and high current.
- Craters: When these appear, look for radiating cracks within the crater and re-evaluate the ability of the welder.
- Overlap: Piling the weld up causes stress concentration in these areas and should be avoided.
- Convex (outward bulge) and Concave (inward curve) Surfaces: Should not exceed the values specified.
- First and Last Pass: Check for surface slag and any other irregularities on the root (first) and last passes in particular. These are the key to a sound weld.
- Cracks: Check for cracks lengthwise, across, over, and through the weld.

C. Contractor Construction Management

The extent of nondestructive testing which involves laboratory work will be indicated in the special or technical provisions of the welding procedure. Quality construction of the rest of the work must be by visual inspection. Proper surveillance of activity prior to performing the weld is essential. Items such as welding procedures, welder qualifications, joint preparation, and dimensional tolerance should be thoroughly examined prior to the contractor's preparation and initial inspections.

Given below are some of the contractor's preparation functions:

- Receive and review shop drawings.
- Coordinate any embedded items with other trades.
- Verify that copies of the specified code or codes are available.
- Check welder certifications and identification numbers.
- Check the quality of the fabricated base material.
- Check approved weld procedures to be used against welding equipment and equipment

settings, electrodes, joint preparation, fit-up, and so forth.
- Check for welding sequence procedure. Review the safety of all operations.
- Check for cleaning and painting requirements.
- Assign someone other than the welder to make on-going visual inspections.
- Check for nondestructive test requirements and certifications that may be required for nondestructive test operators.

These contractor construction management requirements should be reviewed at the preparation inspection.

In addition to preparation functions, the construction management personnel should watch for these possible problem areas:

- The welder is not qualified, has an outdated certificate, or is not qualified for the position.
- The welder's symbol is not being used to identify welds, as required by the contract or applicable code.
- Welders not being retested and requalified when the quality of their work is questionable.
- Welding equipment is set at a higher amperage than is included in the approved procedure.
- The joints are not properly fitted up (wide gaps).
- Ragged-cut joint preparation (torch used).
- Weld size is not closely controlled: legs of weld not equal in size (oversized or undersized).
- Filler rods used to fill wide joints.
- Welding rods approved for use, or used on the job, are not the same size, strength, flux, or coating and position as specified or required by the approved welding procedures.Base metal is not preheated, when required.
- Full joint penetration groove welds not being obtained.
- Welding is incomplete at the ends of the joints.
- Surfaces to be welded are inadequately cleaned.
- Temporary tack welds being used for finished work.

The safety of welding personnel must be considered. Exposure to intense light and heat are primary concerns. Personnel monitoring welding work must use safety glasses and avoid looking at the arc while welding is in progress. Refer to OSHA for health and safety standards for welding. Fire hazards must also be guarded against. These concerns should be addressed at a pre-construction conference and routinely monitored when work begins.

5. CARPENTRY, INSULATION, HARDWARE, AND TILE

This section will acquaint project engineers and construction management personnel with materials, storage, and installation of carpentry, insulation, hardware, and tile, techniques and guidance for quality verification in carpentry construction and the proper insulation, hardware, and tile installation.

5.1 CARPENTRY: MATERIALS, STORAGE, and INSTALLATION

A. Materials

1. Moisture Content

Moisture content requirements most projects are as follows:

- Not to exceed 25% for material over 2 inches thick.
- 19% maximum for material 2 inches thick or less.
- 15% maximum for roof decking.
- 12% maximum for finish lumber, including treated material.

Moisture is checked with a moisture meter when lumber arrives at the jobsite and again when it is being installed.

The dryness of all lumber should be indicated with an "S-dry" stamp, The "S-dry" stamp indicates seasoned wood.

2. Lumber Grade

Lumber grade stamps are required on each piece of lumber. Only trained wood-graders can determine the grade of a piece of wood. There are several types of grade stamps. The stamp gives the grade of the wood and the grading organization, such as "WWP" for Western Wood Products Association or "SPIB" for Southern Pine Inspection Bureau. Check for the specified grade of lumber delivered to the jobsite by a visual inspection of the grade stamp. The stamp will appear only on one side of the material. Plywood also carries a grade stamp. It is always on the back side, or lowest-grade side, of the plywood. The only exception to this requirement is on plywood used for cabinets and fine-finish work. On such materials, the stamp is on the edge of the plywood.

3. Preservative Treatment

Preservative treatment of lumber is also recognized by a stamped mark similar to a grade stamp. Each piece of treated wood must have a preservative stamp on it. Most projects require that the preservative treatment meet American Wood Preservers Bureau (AWPB) requirements. The treatment of wood materials helps prevent rotting and insect damage.

4. Fasteners

Fasteners can be nails, screws, or bolts. Most commonly used fasteners are 16-penny and 8-penny nails. A 16-penny nail is 3 1/2 inches long and an 8-penny nail is 2 1/2 inches long. The 16-penny nails are used when fastening two 2x4 boards together. When toe-nailing, an 8-penny nail is used at these locations. Toe-nailing is a method of fastening two boards together as in a "T" by driving nails into the board that forms the stem of the "T" at an angle so they enter the other board and cross each other. There must be at least a 1-inch protrusion into the second piece of material.

B. Storage

When the material arrives on the jobsite, it should be stored off the ground either inside a building or under a protective cover. Dunnage should be placed between each layer of loose material and between bundles if in large mill bundles. The use of dunnage between the layers of material is to provide space for air to get into the stack and around the material to prevent sweating.

Carpentry materials should be stored in an area that does not have extreme temperature changes or high humidity. If stored outside, it must have a protective cover over it. This cover should be canvas, never plastic. Plastic causes lumber to sweat and raises the moisture content of the material.

Wood soaks up moisture like a sponge and swells. Then it dries out to between 10 and 12% moisture content when it is placed in the structure and, subsequently, warps and bows out of shape. This results in walls that crack and creak. If there is a great variation in temperature between the storage area and the installation area, allow some resting time for the lumber to adjust to the new temperature before installing.

C. Installation

1. Spacing

Proper spacing of construction members is important to ensure that finish materials fit properly with a minimum of waste.

Wall studs are spaced at 16 inches on center with three studs at all corners and double studs at all framed openings. Lap joints for wall top-plates are a minimum of 24 inches and should actually join over a stud. When one wall intersects with another wall, the top-plate is notched into the other wall. Header plates for door and window openings are required to be double members set on edge to give proper strength to the opening.

2. Nailing

Nails are utilized to fasten the members together. A minimum of two 16-penny nails are used at each nail point. Eight-penny nails are used to toenail one member to another; there must be a minimum of four nails, with two on each side. Toenailing should never be done on the edge side of the members, as this may hinder the placement of wallboard.

3. Preservative-Treated Lumber

Preservative-treated material is placed in damp, moldy, or high fire-risk conditions. Treated material is also placed in contact with concrete, CMU blocks, and as nailers in roofing areas that are in contact with the ground or within 2 inches of soil. The most commonly missed framing member is the one within 24 inches of soil. When treated material is cut or bored, it must be retreated with the same type of preservative. This is usually accomplished by brush-coating the cut or bored area. Visually inspect such lumber. Look for a slightly darker color than the rest of the material. This retreatment should be done immediately following cuting or boring to reduce the risk of untreated lumber being installed.

4. Plywood

Plywood is used for roof sheeting, subflooring, and underlayment. The plywood lumber stamp gives information based on the product standards of the American Plywood Association (APA). This stamp gives the permissible span rating. When plywood is utilized in any of the installations mentioned, it must be layed with expansion spaces. For roof sheeting, the spacing is a 1/8 inch side gap and a 1/16 inch end gap. On subflooring, a 1/4 inch side gap and a 1/8 inch end gap. On underlayment, expansion spacing should include a 1/32 inch side gap and a 1/32 inch end gap. The nail spacings are 6 inches on center for supported edge nailings (over floor joists) and 6 to 12 inches on center for unsupported edge nailings. Plywood clips are available and should be utilized for proper spacing of roof sheeting.

5.2 INSULATION: MATERIALS, STORAGE, and INSTALLATION

A. Materials

Insulation is used to resist heat flow. This means increased fuel efficiency. Properly-installed insulation offers the greatest return on investment of any building material, as well as increased user comfort.

Insulation materials usually consist of mineral-fiber insulation, loose-fill insulation, or high-density insulated sheeting board. In some cases, a vapor barrier will be required.

Mineral fiber insulation normally comes in the following types:

- Type I - Blankets or batts with no membrane covering (unfaced), wich require a 4-mil polyethylene vapor barrier.
- Type II - Blankets or batts with a non-reflective membrane covering one side (Kraft-paper

faced).

- Type III - Blankets or batts with a reflective membrane covering one side (foil faced).

These are used primarily for wood-frame construction.

Loose-fill (granular) insulation normally consists of perlite, vermiculite, rock or slag, glass, or macerated paper. This insulation is blown or poured in place.

Insulated sheeting is high-density board which is sometimes used around utilities in walls. For example, 1-inch expanded polyurethane board may be used because it is not permissible to crush a 3 1/2 inch fiberglass batt to fit in a 1 inch space.

A vapor barrier is used for condensation control. Insulation with a factory-applied vapor barrier gives the best protection. However, when Type I blankets with no facing are used, a vapor barrier must be installed.

Insulation value is stated in terms of "R" value and "U" value. "R" value is resistance to heat flow, while "U" value measures heat transfer. These values will be specified in the contract.

B. Storage

Insulation must be kept dry at all times. The air spaces in insulation are what gives insulation its ability to prevent heat loss or gain. It is most important that insulation be properly stored. If any insulation inadvertently gets wet, it must not be used in the construction. The insulation value of the material varies with the density, therefore, the wetter the material, the less insulation value it has. It is virtually impossible to reduce moisture content in insulation after installation.

Not only must insulation be kept dry, it must be kept from getting crushed. Insulation must be stored on the ends of the rolls in a low-humidity, dry area. By storing on the ends of the rolls, it is not likely to be crushed by other materials being placed on top of it. To keep insulation dry, it should be stored in a closed compartment. This will keep water from getting onto and into the rolls or blankets of insulation. If a storage trailer is used, it should be checked for holes to ensure that it does not leak. Additionally, insulation should never be stored in contact with the ground, as it will absorb moisture from the soil. Some type of dunnage should be utilized.

C. Installation

Insulation should be installed only when construction has advanced to the point that remaining construction operations will not damage the insulation. Even when this is done, electricians and pipefitters often have work left to do after insulation has been installed and cause some type of damage. Any torn spots or areas that are not fully sealed must be repaired to prevent heat loss or gain. Such repairs may be made using duct tape extending 2 inches beyond the edge of the tear.

When installing wall insulation between wall studs, the ears on each side of the wall insulation should be stapled to the 3 1/2 inch face of the stud. The ears should lap to form a proper seal between two adjacent areas. Specifications refer to the manufacturer's approved instructions, so it is imperative that these instructions be available before the initial inspection is made.

When pipes, heating/cooling ducts, electrical conduits, or wires are in a wall, the requirements are to meet a certain "U" value. A different type of insulation to use in this situation is insulated sheeting with a "U" value to meet specification requirements. When placing insulation around utilities, the insulation is placed on the cold, or weather, side of the utility.

Proper installation of the vapor barrier is crucial. Whether faced or unfaced insulation is utilized, the vapor barrier must face the warm--in-winter side. This will prevent moisture from entering the insulation from the inside of the building.

5.3 HARDWARE: MATERIALS, SCHEDULE, AND INSTALLATION

A. Materials

Fire doors and fire-exit hardware are specially designed doors and equipment. All fire doors and exit devices must meet the requirements in NFPA 80, Standard for Fire Doors and Windows, to assure that they comply with specifications. NFPA 80 requires that all items in a fire-rated opening be labeled by the manufacturer. The door schedule on construction drawings gives each opening's fire rating.

Construction management personnel are not qualified to determine whether the doors, closers, hinges, closer coordinators, and lock sets are properly sized. This work is subcontracted to a member of the Door and Hardware Institute (DHI) who, in turn, makes the hardware schedule, which will be discussed later in this section. The hardware schedule is used by project engineer to verify that the material used is of the proper size, is properly labeled (if necessary), and complies with contract specifications. All hardware items must arrive on the jobsite in the original manufacturer's packaging since these bear identifying numbers and markings that must be checked against the hardware schedule. If hardware does not arrive in the original packagings, it must be rejected since the manufacturer is the only one who can assure that such hardware complies with specifications.

Keying systems are complex mechanisms. It takes special training to understand keying systems. The customer determines the keying system to be installed. Engineers must know what type system is to install, whether it is a master-key system, where one key unlocks all doors, or a simple-keying system, where each door has only its own key.

B. Hardware Schedule

The most important inspection tool for hardware materials is the hardware schedule. This document gives an outline of the hardware to be installed in the door for each particular opening. The opening number is given, along with the door, lock set, closers, latches, kick plate, pull handle, exit devices, and any other material along this line.

The hardware schedule is used in the field to identify hardware materials as they arrive on the jobsite. Quality verification cannot be accomplished without this schedule. The specification does not give the manufacturer's identification numbers, which are found on the original packagings and correspond to the hardware schedule.

C. Installation

It must be stressed that builder's and architectural hardware must arrive at the jobsite in the original manufacturer's packaging. In these packages are the instructions for proper installation. Examples of items that will be covered are proper positioning of the lock set, hinges, and clearance requirements. All keyways must have the blade (thin edge) of the key pointing up. Hinges must be properly aligned to prevent hinge-bind. All screws must be fully seated. Doors must have reinforcement points to which the hardware is attached. Metal doors require clearances of 1/8 inch (+1/32 inch) between top and sides, 1/4 inch (+1/16 inch) between meeting stiles, 3/8 inch (+1/32 inch) between bottom and threshold, and 3/4 inch (+1/32 inch) between bottom and floor. Wood doors require clearances of 1/8 inch (+1/32 inch) top and side, 1/4 inch (+1/16 inch) at meeting stiles, 1/4 inch (+1/32 inch) between bottom and threshold, and 1/2 inch (+1/32 inch) between bottom and floor.

Fire doors and fire-exit hardware must be installed in accordance with the manufacturer's recommendations and NFPA 80. These two items must be used when performing an initial inspection. If the fire-exit hardware is not installed properly, it may not function correctly when it is needed to prevent the movement of fire for a rated period; incorrect installation may be life-threatening.

Approved keying systems are installed according to the keying schedule. The correct function of a locking system is matched to the correct door for proper operation. The keying schedule, hardware schedule, and manufacturer's instructions and recommendations must be followed very closely.

Doors are like windows in that they have to be plumb, level, and true to plane for proper operation. A carpenter's four-foot level is used to plumb and level doors and windows. After the doors and windows have been plumbed and leveled, they should be caulked to prevent moisture from entering and to help prevent heat loss or gain.

Glazing is applied according to manufacturer's recommendations; these recommendations must be followed explicitly. A check of contract specifications and the material being used will show if the proper type of glazing is being utilized. If incorrect glazing is used, it must be removed and proper glazing installed.

5.4 TILE: MATERIALS, TOLERANCES AND FINISHES, AND INSTALLATION

A. Materials

Request that a master-grade certificate be issued by the manufacturer to the contractor and use this to certify shipments. Tile grades and the master-grade certificate must match the grade of tile required. Whatever type of tile is used, it must be delivered in the manufacturer's original, unopened containers. The packaging seals must be unbroken and the hallmarks and labels intact. This is important, as the seals must correspond with the master-grade certificate.

Grade seals are placed over the lap flaps of each box of tile. Tiles are shipped in sealed packages marked with color-coded grade seals: blue for standard grade and yellow for seconds. A visual check of the cases of tiles will show whether the material is standard grade or seconds. Tile is typically specified as standard grade. This means as near perfect as possible.

Ceramic tile and trim (4 1/4 by 4 1/4 by 1/4 inches) is a clay material formed and furnace-fired, with a decorative glaze. Ceramic-mosaic tile and trim (1 by 1 inch, 1 by 2 inches, 2 by 2 inches) are also furnace-fired clay material, but without any decorative glaze. They are supplied in sheets held together with glued paper-backing or glued joints that bond one tile to another. Mosaic tiles (unglued ceramics) have similar grades of standard and seconds.

All unglazed mosaics fall into one of these classes:

- Impervious: 0. 0 - 0.5% water absorption.
- Vitreous: 0.5 - 3% water absorption.
- Semi-vitreous: 4 - 7% water absorption.

Quarry tile and trim (6 by 6 by 1/2 inches) is a natural, unglazed stone with either a smooth or abrasive surface. This tile also comes in standard grade and seconds.

B. Tolerances and Finishes

The foundations for tile must meet the tolerance requirement of the specification. If the dry-set method is used over masonry or concrete, specifications should require the following conditions:

- Steel trowel and fine-broom finished concrete floors free of curing compounds and waxes.
- Masonry surfaces that-are level and plumb, with struck joints and square openings.
- No variations in the surfaces exceeding 1/8 inch in 10 feet and no abrupt irregularities exceeding 1/16 inch.

These tolerances must be checked because the finish is only as good as its foundation.

In addition to the mentioned tolerance, be aware of temperature. The temperature in the work area must be at least 50°F and rising before ceramic tile can be placed. This is to keep the curing operation moving so that bonding develops between the tile and the grout or adhesive before it sets.
Cleanliness in the area where tile is installed is very important in order for the tile to set properly. If any dirt, dust, mud, oil, or grease is on the surface to which tile is applied, it will prevent the grout or adhesive from bonding to that area. Grit is very harmful to ceramic and quarry tile installed on floors; for example, if a piece of grit gets under a rigid tile, the tile may split under load.

C. Installation

When installing floor or wall tiles, it is required that jointing and symmetry be met, if at all possible. Jointing in tile work must be straight, true, uniform in width, and solidly filled with grout. There should be no hollow or void areas, loose, cracked, or defective tiles. If any of these are present, they must be replaced. Ceramic-mosaic tile joint width is set by glued-paper backing. Ceramic and quarry tiles are set one tile at a time. The range of width of quarry tile can be between 1/4 inch and 3/8 inch; but once set, it should not vary between that range, it must be uniform.

Not only must the joints be correct, symmetry must also be met. Symmetry is a requirement of the specifications. Tile must be laid out so that tiles of less than a half-tile width do not occur. When laying out the tile area, if one border is less than a half-tile, then go back to the center of the layout and move the center tile to split the center of the room. This will move all tiles one-half tile and leave the edge tile with at least one-half or greater at the borders.

Control joints are placed:

- To match building joints.
- Where backing materials change.
- Where tile floors abut rigid walls.
- At intervals of 24-36 feet in large floor areas.
- There are three methods of tile installation on walls. They are:
- Plastic or cured mortar method, for prolonged wet areas.
- Dry-set mortar method, for wet or dry masonry.
- Organic adhesive method, for dry areas only.
- The plastic or cured mortar method of installation is as follows:
- Build up a solid foundation of 4-mil polyethylene, metal lath, and a scratch coat of mortar.
- Cure in a minimum of 24 hours.
- Evenly saturate the surface.
- Add a ¾ inch maximum thickness mortar bed.
- Contractor option:

* Set the wet tile and a thin bonding coat in the plastic mortar, grout the joints, and damp cure for 72 hours.

* Damp cure the mortar, then install the tile according to thin set installation in ANSI A03.2.1.

The dry-set method of installation is as follows:

- Begin with a solid foundation.
- Mix the dry-set mortar, allow it to stand for 15 minutes, and remix it.
- Cover foundation with mortar bed about 1/8 to 5/32 inch thick.
- Comb mortar with notched trowel within 10 minutes of applying tile.
- Beat-in unsoaked tile to achieve 80 to 100% coverage on back of tile and finished mortar bed thickness of 3/32 inch to 1/8 inch.
- Fill the joints with grout and damp cure a minimum of 72 hours.

The organic adhesive method of installation is as follows:

- Begin with a solid foundation in a dry area only.
- Inspect the preparation of the area, which varies for gypsum board and openings.
- Spread adhesive with a notched trowel.
- Press dry tile onto the adhesive.
- Beat in tile so the average contact area on the back of the tile is 75%.
- Allow at least 24 hours for evaporation of the solvent.
- Grout the joints and damp cure for at least 72 hours.

The methods for placing tiles on floors are generally the same as for walls, with one exception. That exception is if the bed is placed over a waterproofing membrane in areas with floor drains, wire reinforcing is also required in the setting bed.

Proper curing is specified by the manufacturer. Normally, 72 hours must elapse before traffic is allowed on tile flooring. If the curing time is not met, the tiles may shift and leave an uneven floor. As soon as possible after the curing time has been met, the tile floor must to be covered for protection. Normally, plywood or heavy cardboard is used. This covering will prevent the tile from being broken if something is dropped on it and will prevent the tile from being scratched when heavy objects are moved over the floor.

Glazed tile must be cleaned after setting and grouting is complete. Thoroughly sponge and wash the tile, then polish it with clean, dry cloths. *Do not use acid to clean glazed tile!* Acid will remove the glaze from the tile. Epoxied tile must be cleaned immediately. This cleaning is covered in ANSI A108.6.

Unglazed tile cleaning is not started until at least 10 days after setting. It is cleaned with a solution of one pound sulfonic acid to five gallons of water that is at room temperature. Remember that acid will damage metal and enamel surfaces, so they must be protected.

6. ROOFING

This section will acquaint project engineers and construction management personnel with the component materials, storage requirements, and installation procedures for roofing systems, including sheet metal. There are many technological innovations in the roofing industry, however, past experience shows that failures often occur due to products and installation methods that are not adequately tested before release on the market. Consequently, the engineer should take a conservative approach to roof design. Techniques and guidance are provided for quality verification of roof construction for buildings.

A. Introduction to Roofing Systems

Engineer personnel must become familiar with these and should read supplemental publications, such as manufacturer's literature, to keep abreast of changes and developments in the roofing industry, including new products and installation methods. Proper coordination of trades and planning for roofing operations depends on the contractor's timely submittal of shop drawings, and product samples.

Attention to proper materials and installation methods is crucial for many reasons. Roof construction is often done hurriedly by semi-skilled laborers. Interior-finishing (gypsum wallboard, painting, etc.) should not start until the building is watertight. The source of roof problems is often hard to locate. Roof failure is usually detected by interior damage (sagging and discolored ceiling tiles, peeling paint, etc.), leading to costly repairs. Materials and workmanship quality must be carefully observed, verified, and documented.

B. Roofing System Components

The two most widely used roofing systems are built-up and single ply. Basic requirements for these systems are covered in this section. Listed below are components that are common to roof systems:

- Structural decking is the foundation of the roofing system.
- Drainage system channels water off the roof of the building.
- Vapor retarder guards against moisture-related problems within the roof insulation in cold climates.
- Insulation results in user comfort and energy savings.
- Roofing membrane is the water proofing.

1. Structural Decking

The deck is the substrate (surface) over which the roof is placed. It must be properly sloped for good drainage, and strong enough to support thick insulation and increased weight from loads such as ice and snow. Factory Mutual, a major insurance underwriter, has developed roofing requirements that are accepted throughout the construction industry. According to their recommendations, structural decking may be constructed from steel or from concrete, including cast-in-place, pre-cast planks, prestressed sections, gypsum insulating concrete, or lightweight insulating concrete.

2. Drainage System

Proper roof drainage guards against many possible problems. Ponding is the accumulation of rainwater and/or water from refrigeration units. This may be caused by improper roof slope, or by clogged drains. Roofs must have a minimum slope of 1/4 inch per foot to drain properly and to prevent deterioration of the membrane. There are two kinds of drainage systems: interior and exterior.

Interior drainage systems provide for water drainage into drains in the roof and leaders (piping), that channel flow to the building collection system. Such systems aren't as easily affected by problems such as icy weather since they are warmed by heat from inside the building. Overflow scuppers, which are openings through the parapet walls at the top of the cant, provide alternate water run-off paths in case of drain clogging.

Exterior systems consist of gutters or scuppers at the edge of the building. Leaders or downspouts channel water to flow down the outside of the building. Although they are able to drain large amounts of water faster, they are affected by icy weather and unusually heavy rainfall.

3. Vapor Retarders

Vapor retarders are barriers that retard water vapor from entering the roofing insulation from inside the building. During winter months in cold climates, the temperature within the insulation may reach the dew point of the warm moist air rising from within the building, causing condensation to occur, thus reducing the insulation's overall R-value and durability. Vapor barriers should be continuous with no penetrations through which water vapor might seep, causing damage to insulation.

4. Insulation

Insulation is a thermal barrier that provides increased heating and cooling efficiency, which results in energy cost savings and increased user comfort.

Four basic types of insulation for roofing are:

- Rigid insulation.
- Insulating concrete roof decks.
- Polyurethane foam.
- Extruded polystyrene.

Rigid insulation comes in prefabricated panels made of either, foam plastic, organic, or inorganic materials or of a composite of the two. It is installed on top of the deck under the membrane.

Insulating concrete fills consist of perlite or vermiculite bound with portland cement or of perlite mixed with asphalt. This is cast in place to form a roof deck.

Polyurethane foam is mixed with a Freon additive and then sprayed in place.

Extruded polystyrene boards are installed above the roofing membrane in a protected roofing membrane systems and under single-ply membranes.

5. Roofing Membrane

The membrane is the component that provides the actual waterproofing for the roof system. It consists of four plies of glass fiber felt with interply bitumen for built up roofs and EPDM or PVC for single ply roofs,

C. Built-Up Roofing System

The components of the built-up roofing system include vapor retarder (if applicable), insulation, glass fiber roofing felt membrane, bitumen, bitumen stops, bituminous flashing, and surfacing. (See Figure 5-1.)

1. Vapor Retarder

Vapor retarder is applied directly on the completed roof deck, except for metal decks. Its composition varies depending on the roof decking. Vapor retarders on concrete decks and over the first layer of insulation for metal decks are composed of two plies of 15 pound roofing felt (organic or glass fiber) with interply bitumen. Vapor retarders on gypsum or lightweight concrete decks are composed of one ply of venting inorganic base sheet covered with two plies of 15 pound roofing felt (organic or glass fiber) with interply bitumen. Envelopes help prevent bitumen seepage. They are required at the termination of vapor retarders at walls, eaves, and rakes. Envelopes consist of two plies of 15 pound organic roofing felt that are 18-inches wide.

2. Insulation

The contractor is allowed optional materials for roof insulation. This material is a board with adequate density to support the loads imposed during the roof membrane and surfacing application. Optional materials are specified to result in the most economical roofing system for all areas and climates.

The optional materials are:

- Cellular glass.
- Expanded perlite.
- Urethane.
- Fiberboard.
- Mineral fiber (glass fiber).
- Isocyanate.Phenolic foam.
- Polystyrene.
- Composite board.

Polystyrene insulation board may be used only with single-ply membrane roofing systems. Composite board insulation consists of one component of plastic insulation, such as urethane or isocyanate, bonded to a component of fiberboard or perlite. The thickness of the insulation board must provide the resistance to heat flow (R-value) indicated in the contract documents. R-value is determined by the designer based on energy analysis and construction elements of the building. The R-value per inch of each material is provided by the manufacturer. The selected thickness of insulation must result in an R-value which equals or exceeds that required.

3. Membrane

The built-up roofing membrane consists of four plies of 15 pound glass fiber felts with interply bitumen. This component of the roofing system provides waterproofing for the building. Membrane applied on gypsum and concrete or lightweight concrete decks must consist of one ply of venting inorganic base sheet, three plies of 15 pound glass fiber felt.

Membrane applied near aircraft hangars or run-up areas must consist of three plies of 15 pound glass fiber felt, and one ply of mineral-surfaced cap sheet. The cap sheet provides the finished surface and does not require surfacing aggregate which may damage aircraft engines.

4. Bitumen

Bitumen is applied as a hot liquid to adhere felts, between felts as waterproofing material, and as a flood-coat to embed surfacing aggregate.

There are two types of bitumens used for roofing:

- Asphalt bitumen, a crude oil product.
- Coal-tar pitch, a coal product.

Bitumen is delivered to the jobsite in a solid form. It is heated to a liquid form for application.

Bitumen Stops

Bitumen stops consist of two plies of 15 pound organic felts that are 18-inches wide. Bitumen stops are installed at the terminations of the membrane roofing felts at eaves, rakes, openings, and vertical projections. They prevent the interply bitumen from seeping out from between the membrane plies and running down the side of the building when the sun heats the roof surface.

Bituminous Flashing

Bituminous flashing is utilized at parapets and vertical projections. It consists of a three-ply system, two plies of woven-glass fabric with mineral-surfaced roll roofing as the outer ply.

Surfacing

The surfacing for built-up roofs is installed after completion of the installation of the four-ply membrane. The surfacing consists of aggregate embedded into a flood coat of hot bitumen. The aggregate may be crushed stone, gravel, or crushed slag (contractor's option). The aggregate should be light-colored, clean, and comply with the specified gradation.

D. Single-Ply Roofing System

The single-ply roofing system components are similar to the built-up roofing system for the vapor retarder and insulation. However, the single-ply membrane is quite different. (See Figure 5-2.) At this time, there are three types of single-ply roofing systems typically used:

- Elastomeric roofing (EPDM).
- Polyvinyl chloride (PVC).
- Elastomeric roofing, fluid applied.

There are many more available in the industry.

1. EPDM Membrane

This membrane consists of a rubber-like material which is 0.060 inch thick. The laps are sealed with adhesive. If loose-laid, this membrane must be held in place by ballast or it may be fully adhered with adhesive. The ballast used for loose-laid application must be round water-washed aggregate.

2. PVC Membrane

This membrane consists of a vinyl-type material that contains fibers or fabric and may be 45 or 60 mils thick. The laps are sealed with solvent welding or hot-air welding. This membrane must be held in place by ballast if loose-laid, or fully adhered with adhesive, or mechanically fastened, as specified. The ballast used for loose-laid application must be round water-washed aggregate. Slip sheets for isolation from other materials are used if applicable.

3. Elastomeric Roofing, Fluid Applied

This type of single-ply system consists of sprayed-on urethane foam insulation coated with an elastomeric protective coating 30 mils thick. The coating is a three-coat application of silicone rubber or a two-component chemically-cured polyurethane. Granules may be applied over the top coat.

E. Shingle Roofing

Shingle roofing is used for roof slopes that exceed 3-inches per foot. Shingles may be organic-mat type, inorganic-mat type, or glass-felt type. Organic mat shingles must conform to UL997. Inorganic mat shingles must conform to ASTM D3018 and UL997 and weigh not less than 210 or 255 pounds per square. Glass-felt shingles must conform to ASTM D3018 and UL997 and weigh not less than 190 or 225 pounds per square. Underlayment consists of 15 pound asphalt-saturated felt and is applied to the roof deck in single or double layers, as specified, before applying shingles. Shingles must be approximately 12-by-36 inches in dimension with a two-tab, three-tab, four-tab, or no-cut design.

F. Metal Roofing

Metal roofing is recommended for roof slopes that exceed 1/2 inch per foot. The metal is fastened to the roof structure with exposed or concealed fasteners.

There are two commonly used metals for roofing:

- Galvanized (zinc coated) steel.
- Aluminum sheets.

Galvanized (zinc coated) steel sheets are a minimum of 0.024-inch thick. Aluminum sheets are a minimum of 0.032-inches thick. Metal roofs are manufactured in various styles, including standing seam and corrugated.

G. Sheet Metal

Sheet metal is used in roofing systems to divert water from the roof and to provide watertight termination of roofing membranes.

1. Materials

There are six optional materials allowed for sheet metal:

- Aluminum alloy sheet.
- Copper.
- Copper-clad stainless steel.
- Lead-coated copper.

- Lead sheets.
- Stainless steel.

2. Shapes

There are numerous sheet metal shapes used for roofing systems, depending on where used. The most common uses are:

- Building expansion joints.
- Cleats.
- Downspouts.
- Cap flashing.
- Gravel stops.
- Gutters.
- Scupper lining.
- Splash pans.
- Copings.
- Pitch pockets.

3. Fasteners

The fasteners used to attach sheet metal to supports must be manufactured from material compatible with sheet metal material.

4. Thickness of Sheet Metal

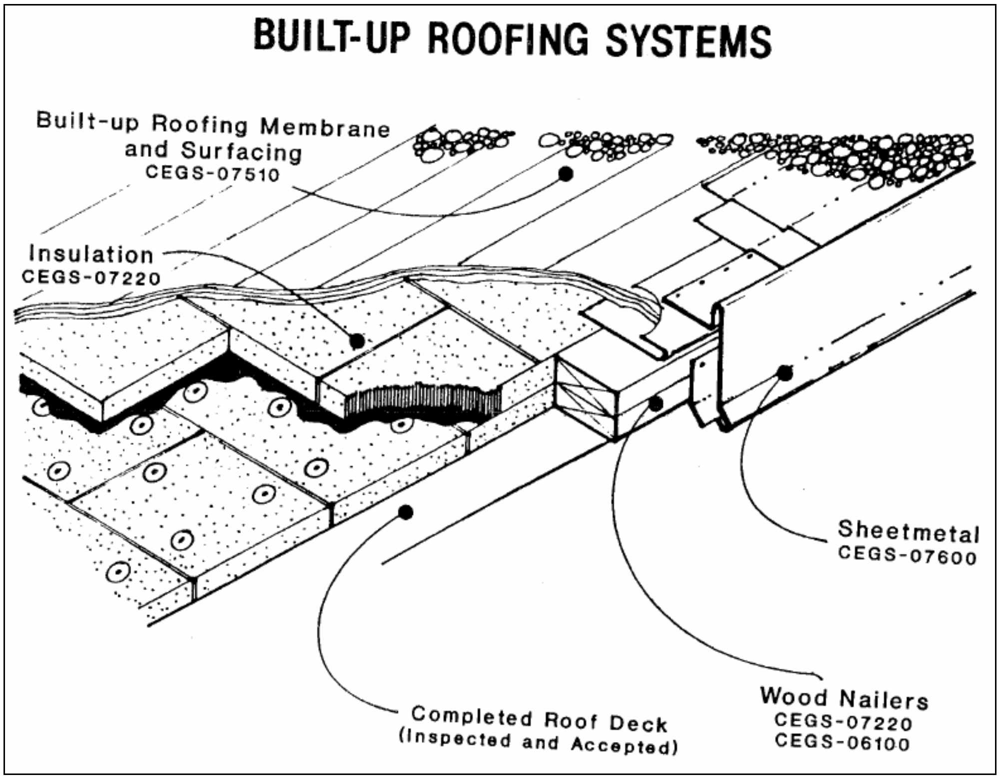
The thickness of sheet metal depends on the type of material and shape.

5. Joints

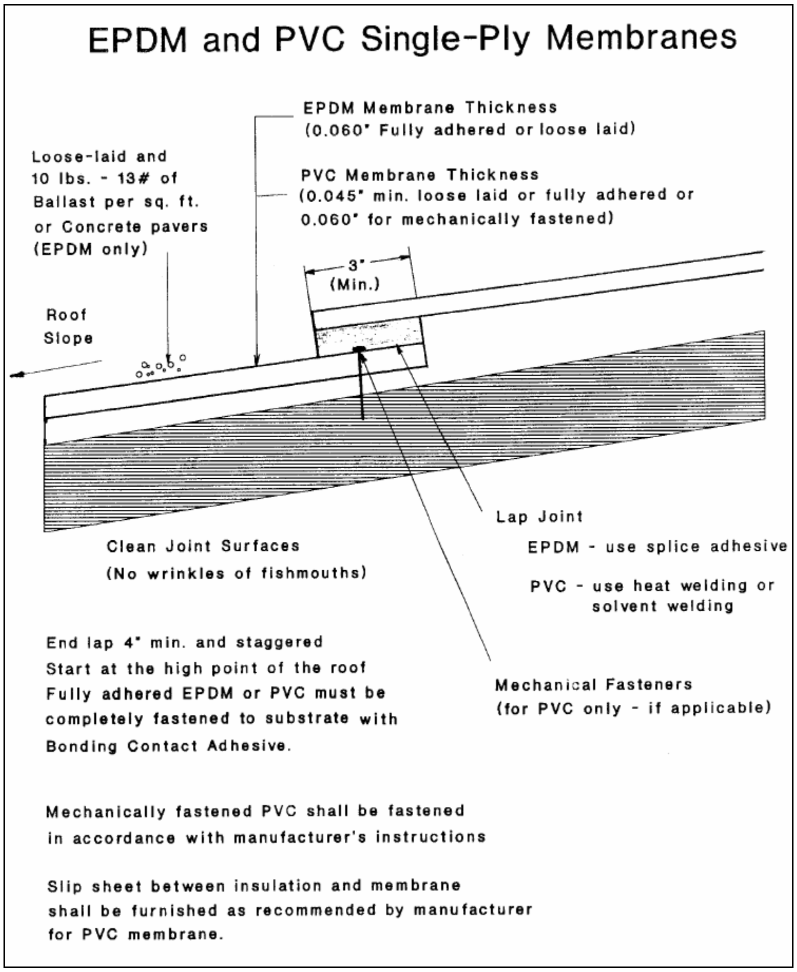
Sheet metal items must be joined together to provide a continuous, watertight installation. The types of joints used for joining sheet metal are:

- Solder-lap.
- Flat lock.
- Unsoldered, plain lap.
- Butt.
- Standing seam.

The type of joint used depends on the type of material and shape.



Built-Up Roofing System
Figure 6.1



Single Ply-Members
Figure 6.2

7. INTERIOR FINISHES

Interior finishes (walls, ceilings, and floors) are highly visible building components. Close attention to quality will help ensure quality verification and customer satisfaction. This section will acquaint construction engineers with the usage and application of interior finishes and with aspects of fire ratings.

7.1 LATH AND PLASTER

A. Materials

Plaster

The two most commonly used types of plaster are portland cement and gypsum. These materials are similar in that they each contain water, aggregate, and some lime for workability. The only difference is that portland cement plaster has a portland cement binder, while gypsum plaster has a gypsum binder. Portland cement plaster is normally used in areas that are subjected to grease, moisture, and vapors, such as kitchens and laundry areas.

Lath

Lath used in plaster operations is normally either gypsum lath or metal lath. Gypsum lath has a gypsum core similar to regular gypsum wallboard; however, the face paper is multi-layered to control absorption and to resist plaster slide. Gypsum lath is most commonly used in the 3/8 inch or 1/2 inch thicknesses with either a solid or perforated face paper. Metal lath is manufactured from galvanized or cold-rolled sheet steel that has been slit and expanded to form small mesh openings. This lath comes in four types:

- Diamond mesh-lath for normal applications to wood or metal studs.
- Paper-backed metal lath for application to wood or metal studs in areas where moisture penetration is a concern.
- Rib-lath for use in partitions where stud spacing is wider than the normal 16 inches on center.
- Self-furring lath for application of plaster to hard, smooth surfaces, such as masonry or existing plaster.

Accessories

Accessories used in plaster work include metal or wood studs, 1 1/2 inch channel main runners, 3/4 inch channel furring runners, 8 gauge wire hangers, corner beads, control joints, and floor and ceiling plates or runners. The sizes and gauges of these accessories are determined by the design engineer.

B. Storage

All materials must be delivered to the jobsite in their original packages, containers, etc., bearing the brand name and manufacturer's name. Gypsum products should be stored inside, since various problems can result if they become damp or are left in direct sunlight for extended periods. They must be stored off the ground, under watertight covers, and away from damp areas, such as curing concrete or masonry. All materials must be checked for compliance with approved shop-drawing submittals prior to installation.

C. Application

General

Plaster work should only be done in well-lighted areas and areas in which the temperature and humidity can be controlled during the application and curing processes. Finish coats should be as thin as possible. Gypsum is dry-cured, while portland cement plaster is wet-cured by using a fog-spray method for 48 hours after application of the finish coat.

Walls and Ceilings

Plaster can be applied to existing masonry surfaces, solid gypsum partitions, or to hollow partitions. Studs, which may be wood or metal, are placed vertically and attached to floor and ceiling runners with nails or screws. The gypsum or metal lath backing is placed with the long dimension perpendicular to the studs and secured to the studs at specified intervals.

Plastered ceilings are normally classified as contact, furred, or suspended. In construction, the most common type is the suspended ceiling, which consists of a structural framework made up of 8-gauge wire or steel-strap hangers, 1%-inch channel main runners, 3/4-inch channel furring runners, and in some cases, metal studs. Lath is attached the same as in walls. Control joints must be used in both ceilings and walls to control movement and prevent cracking. Plaster can be applied in either a two-coat or three-coat application.

7.2 DRYWALL

A. Materials

Drywall

Drywall includes various types of wallboard made up of wood, wood products, and gypsum products. In construction, the type of wallboard most commonly used is gypsum wallboard, which is manufactured in three basic types: regular, water-resistant, and fire-resistant. Gypsum wallboard sheets are made in 4-foot widths but with differing lengths, thicknesses, face papers, and core textures, all depending on the specific purpose for which the material is to be used.

Accessories

Accessories used in drywall installations normally include wood and/or metal studs, floor and ceiling runners, corner beads, control joints, 1 1/2 inch channel main runners, 9 gauge wire hangers, and steel strap hangers. Specific gauges and widths of items, such as suspended ceiling supports and wall studs, are determined by the designer.

B. Storage

All materials must be delivered to the jobsite in original packages, containers, and bundles bearing the brand name and manufacturer's name. Gypsum wallboard must be stored flat within a completely enclosed structure, off the ground, and enclosed in a watertight covering. Upon their delivery to the jobsite, all materials should be checked against approved shop drawing submittals for compliance with contract requirements.

C. Installation.

General

Drywall work should be started only after the building is completely enclosed to the extent that a minimum temperature of 50°F can be maintained for at least 48 hours prior to start of work, during, and after work is completed.

Walls and Ceilings

Wood or metal studs are placed vertically and attached at the top and bottom to floor and ceiling runners. Drywall is installed horizontally, with the long dimension perpendicular to the studs, and attached with either nails or screws at specified intervals. Joints between individual sheets should be staggered so that they do not occur on common studs, and should be finished with joint compound and tape. Care must be taken to avoid damaging the face paper when finishing or sanding treated joints.

Ceilings are installed before the walls. Ceilings are either furred or suspended, with the most common being the suspended ceiling. The suspended ceiling framework consists of 1 1/2 inch channel main runners and hat-channel furring runners supported by either 9 gauge or steel-strap hangers. The drywall is attached with the long dimension perpendicular to the furring runners by using Type-S bugle-head screws. Control joints must be utilized in walls and ceilings to control movement and prevent cracking. Control joints must be supported on each side with an individual support and should be located to match building expansion joints.

7.3 ACOUSTICAL TREATMENTS

A. Materials

Acoustical

Acoustical materials are lightweight, sound absorbent, and fire resistant. The most commonly used materials are 12” by 12” tile, 2’ by 2’ board, and 2’ by 4’ board. Acoustical tile is normally used in a concealed-grid system, while acoustical board is used in a semi-exposed or exposed-grid system.

Accessories

Accessories include 12 gauge wire or steel-strap hangers, main runners, cross runners, wall angles, and inside and outside wall-angle corner clips.

B. Storage

Acoustical materials must be delivered to the jobsite in their original packages, containers, or bundles bearing the brand name and manufacturer's name. Materials must be checked against approved shop drawing submittals for compliance with contract requirements. Because of its brittleness and almost total absence of moisture, this material must be handled carefully to prevent breakage and must be stored in an enclosed area where temperature and humidity can be controlled.

C. Application

General

Installation of acoustical materials must not begin until the work area is completely enclosed, all wet work completed, and the HVAC system is operating in order to maintain a temperature of between 60°F and 80°F and a relative humidity of not more than 75%. Acoustical materials should not be used where moisture is a problem, such as food preparation areas or shower rooms.

Installation

Acoustical ceiling systems normally consist of a structural frame-work made up of main-runners and cross-runners supported by 12 gauge wire or metal strap hangers. The system is further supported by a perimeter wall angle. Hangers should hang vertically from the building structure above; they should never be supported by electrical conduit or piping. However, hangers can be splayed to avoid obstructions as long as the lateral forces caused by the splaying are equal in all directions.

The proper method for laying out a ceiling is to begin at the center of the room and end with no less than one-half of a ceiling tile or board around the perimeter. Also, close attention should be given to seismic requirements in areas subject to earthquakes, such as attaching the ceiling grid to two adjacent walls, leaving it free at two adjacent walls, and providing four splayed hangers at connection points. Look for such differences in the contract specifications.

7.4 PAINT

A. Materials

There are many paints and protective coatings used in construction, for example, epoxy, vinyl, latex-based, oil-based, and water-based latex. Paint requirements vary according to geographic location and climatic conditions. Commonly used surface preparations are metal primers and CMU fillers. Paint type is chosen by the designer and the user and is specified in the contract.

B. Storage

Paint must arrive at the jobsite in sealed containers bearing labels that show, among other things, the paint name, formula, specification number, batch number, date of manufacture, and any warnings associated with its use. The paint should be stored in a dry, well-ventilated enclosure where temperatures can be maintained between 65°F to 85°F. Paints that are subjected to freezing or excessively high temperatures may be damaged and should not be used.

C. Application

Testing

Before any painting begins, require samples be taken from the paint to be used and tested for compliance with contract requirements. The testing must be performed by an approved commercial laboratory on all paints, except for proprietary brands of one color in quantities of less than 50 gallons. Approximately 30 days should be allowed to complete the testing. A representative of the contracting officer must witness the taking of all samples to be tested.

Surface Preparation

Poor surface preparation is the single greatest reason for paint failure. Specific requirements, such as checking wood or masonry to see if the maximum moisture content is within the allowable limits, removing rust, grease, or other foreign matter from steel, conditioning CMU surfaces to remove free moisture or efflorescense, and assuring that follow-on coats of paint are compatible with the base coat, are just a few of the things to be done which will provide a long-lasting protective coating.

Painting

Paint can be applied using brushes, rollers, or spraying equipment; however, some paints are applied using only one method. Paint must be applied in a manner that prevents runs, drips, ridges, brush marks, and variations in color, texture, and finish. Each coat should result in uniform thickness over the total surface, including items such as welds, corners, edges, and particularly those areas exposed to weather. Coverage must be complete, with no voids. Items not scheduled to be painted must be protected. Painters should wear protective clothing at all times and respirators must be worn when painting in enclosed areas or when using spraying equipment.

7.5 RESILIENT FLOORING

A. Materials

Flooring materials are selected primarily based on the conditions and use to which they will be subjected. For example, the advantage of vinyl composition tile is that it is scuff-resistant; seamless PVC is used in areas where maximum cleanliness is a requirement; conductive type flooring resists static electricity, so is often used in hospitals and in munitions plants; and rubber flooring may be used where sound reduction is desired.

B. Storage

All flooring materials must be delivered to the jobsite in their original packages, containers, or bundles bearing the brand name and manufacturer's name. Materials must be stored in an enclosed area where temperature and humidity can be controlled. Most resilient flooring materials must be stored at a minimum of 70°F for at least 48 hours prior to installation.

C. Installation

General

Installation of resilient flooring should not start until all other work has been completed and the environmental conditions and access to the work area can be controlled. After installation, flooring must be protected from damage by using recommended protective coverings. Only the flooring manufacturer's recommended adhesive and wax should be used.

Subfloor Preparation

In order to install an attractive, long-lasting floor covering, some very important preparation work must be performed on the subfloor. Included in this preparation work is removing all foreign matter, such as dirt, grease, and mortar droppings, and leveling the surface to the tolerances required by the contract specifications. Joints in wood subfloors must be securely nailed down, filled with wood filler, and sanded smooth. Concrete subfloors must be dry, clean, and the curing process finished. Concrete subfloors should be tested for excessive alkalinity to prevent linoleum or vinyl tile from becoming stained.

Application

Only the flooring manufacturer's recommended adhesive should be used. The adhesive should be spread evenly on a smooth, clean subfloor with a notched trowel and then allowed to set properly. The flooring is installed, cleaned, polished, and protected according to the contract specifications. Vinyl wall-base and edge strips are applied after the flooring installation is complete. As in acoustical ceiling installations, floor layouts should begin at the center of the floor so as to leave no less than one-half tile width around the perimeter of the room.

8. CENTRAL REFRIGERATION AND MECHANICAL INSULATION

This section will acquaint the construction engineer with many aspects of refrigeration equipment and thermal insulation installation. Proper installation and operation of air-conditioning equipment is an important energy and comfort consideration. The refrigeration cycle is the means by which air-conditioning equipment operates. Mechanical insulation includes a thermal barrier that helps minimize heat loss or gain and a vapor barrier to prevent condensation from forming on the insulated surface. Proper thermal insulation enhances system performance in terms of both comfort and economy.

8.1 COMPONENTS AND STORAGE REQUIREMENTS FOR REFRIGERATION

A. General

Refrigeration is the mechanical process of heat removal known as "cooling." This process lowers the temperature of a space below that of the surrounding atmosphere. The capacity of a refrigeration system is expressed in tons. Tons is a unit of measurement that refers to the heat removal capacity of a machine. One ton equals 12,000 BTU per hour. (BTU stands for British thermal unit, which is the heat required to raise the temperature of a pound of water by one degree.)

Air conditioning is the process of treating air to control its temperature, humidity, cleanliness, and distribution. Air-conditioning systems include the equipment necessary to add heat or to remove heat. (The heating process is covered in the next section.)

B. Systems

There are two main refrigeration systems: direct expansion (DX) and chilled water. Water piping is less expensive than refrigerant, therefore, chilled water systems are an economic preference when extensive piping for cooling is involved.

In the direct expansion system, the evaporator is a direct expansion-type coil that is located in the air handling unit (AHU). Air is circulated across the face of the coil, a process by which it is cooled and dehumidified. This conditioned" air is moved by the AHU fan into the ductwork and is then distributed into the building spaces. Condensate formed by dehumidification is carried away by a drain line to prevent overflow and flooding of the area around the air handling unit.

The evaporator of the chilled water system is a heat exchanger and is located in the chiller unit. Flowing water is cooled as it flows through the unit and is then circulated by a pump from the chiller to either an air handling unit or to fan coil units. Each of these units has a chilled water cooling coil. The air is moved through the face of the coil by a fan. Air is cooled and dehumidified by the release of its heat to the chilled water inside the coil. The resultant warm water is recirculated to the chiller unit where it is again cooled by the refrigeration process and the cycle repeated.

C. Components

Components making up a refrigeration cycle are: (a) compressor, (b) condenser, (c) expansion valve, (d) evaporator, (e) piping, and (f) .refrigerant. Components properly installed in a refrigerant cycle will be installed in a series arrangement. Correct sequencing will be compressor to condenser, condenser to expansion valve, expansion valve to evaporator, and finally evaporator to compressor.

Compressors (Pumps)

A multiple selection of commercial compressors are available for competitively bid. Each compressor unit must conform to and consist of the equipment listed in American Refrigeration Institute (ARI) standards. Compressor types allowed by specification are as follows:

- Open compressor.
- Semi-hermetic.
- Hermetic.
- Screw.
- Centrifugal.

Open compressors are manufactured as individual components. They must be connected to a power drive by means of a mechanical coupling.

Semi-hermetic compressors are manufactured with an electric motor and a compressor enclosed in the same casting. The heads and end plates can be removed for field maintenance.
Hermetic compressors are manufactured integral with an electric motor in a totally enclosed shell that cannot be mechanically disassembled.

Screw compressors do not have pistons and cylinders. Instead, they have a screw and housing arrangement. As the screw rotates, the refrigerant is forced through and between the threads.
Centrifugal compressors are identified by their large-diameter single wheel compressing arrangement.

Condensers (Heat Rejectors)

Specifications should outline at least three types of condensers:

- Air cooled.
- Water cooled.
- Evaporative condensers.

Air-cooled condensers are identified by the refrigerant-to-air heat exchange method.
Water-cooled condensers are recognized by the refrigerant to water, water to cooling tower heat exchange method.

Evaporative condensers are recognized by their use of the refrigerant-to-water, then water-to-air heat exchange method.

Expansion Valves

Expansion valves are identified by their manufactured configuration which uses the combination of a plug-valve body and a pressure-operated diaphragm.

Evaporators (Heat Absorbers)

The expansion valve will be located immediately before the evaporator. The direct expansion system evaporator is a fin and-tube coil. It is normally factory-installed and located within the air handling unit. The chilled water system evaporator is a shell-and-tube heat exchanger. It is normally factory-mounted as an integral part of the chiller unit.

Refrigerant Piping

Refrigerant piping can be identified by the locations from which the refrigerant flows into or from the individual component. The refrigerant piping connects all components in a series configuration. Correct refrigerant piping is made of copper tubing and will have the letters "ACR" painted or stamped on it. ACR stands for "air conditioning and refrigeration."

Refrigerant

The type of refrigerant that is to be charged into the piping system can be identified from factory nameplates on the equipment. The refrigerant to be used is determined by the temperature desired in the cooled space. Today refrigerants are non CFC's.

D. Storage of Material on Jobsite

Refrigerant components are shipped with factory finishes. Frame-mounted components must be protected by factory packaging from weather and from physical damage. This protection, if physically intact, will suffice for a brief period in a storage yard. It is sufficient to ensure that factory packaging is intact until the components are to be placed into the construction.

Refrigerant piping is to be stored off the ground in a dry storage area. The refrigerant piping is cleaned at the factory. The tubing is factory-sealed to prevent the entrance of foreign matter, as well as to preserve the factory charge of nitrogen. In order to minimize the possibility of dislodging the piping end-plugs, the storage location should also prevent physical contact with other equipment.

8.2 INSTALLATION AND OPERATION OF REFRIGERATION SYSTEMS

A. General

An initial inspection assures that equipment matches that described in the approved submittals. Contract plans show only a general arrangement of equipment. Further verification is needed to ensure that the specified layout drawings for the mechanical rooms have been submitted, approved, and are available at the jobsite. Correctly dimensioned layout drawings are necessary to assure that equipment will fit into the space allocated. Clearance should be adequate for both installation and maintenance.

B. Refrigerant Component Installation

Many of the systems installed on projects are factory-assembled. Field work is limited to connecting the outdoor condenser section to the indoor package equipment. Factory installation procedures must be consulted to ensure that proper procedures are followed.

Components designed for fluid flow have factory-designed inlets and outlets. Each field-installed component must be inspected to be sure that it is piped in accordance with factory design. Direct expansion system field piping to the coil connection should be checked for conformance to manufacturer's recommendations. Chilled water system field piping should be examined to determine that the correct water piping connections have been made (labeled "in and out" or "supply and return"). Flexible connections are usually found on water piping connections since the chiller equipment vibrates.

Refrigerant piping is designed for the specific system and is sized by its outside diameter. It is made of copper and stamped with the letters ACR, indicating that the tubing has been factory cleaned, dehydrated, and sealed at both ends. The contractor provides a piping diagram showing pipe size, routing, and valve location. Joints, fittings, and valves are secured with Grade III silver solder. During the brazing process, the tubing must be continuously purged with nitrogen. The purging displaces the natural oxygen-enriched atmosphere and thus prevents any copper oxide from forming on the inside of the tubing.

The circuit components are installed in a series fashion. The compressor discharges hot refrigerant vapor into the condenser. The condenser then discharges liquid into the expansion valve, which passes refrigerant liquid into the evaporator. After leaving the evaporator, refrigerant vapor passes into the suction side of the compressor. The compressor is to be mounted on manufacturer's rated vibration isolators installed either by the manufacturer or the mechanical subcontractor.

Be sure that air-cooled condensers are placed in an area where the intake air and the discharge air flow is unrestricted; it should not be placed in an area where discharged air may be re-circulated into the system inlet.

Water-cooled condensers must be provided with an air vent to ensure full circulation of water. A cooling tower is a water-saving device used in conjunction with water-cooled condensers. It transfers the heat absorbed by the condenser water to the air. The cooling tower must be placed to allow for adequate air circulation. Water treatment is required to prevent algae growth. Once the system is energized, it should be free from obvious loud noises and vibration. Pressure and temperature-indicating gauges can be evaluated to ensure that safe operating pressures are present. Normally, floor-mounted equipment will sit on a 6-inch concrete slab. Verify that any vibration isolators required are rated by the manufacturer for the specific equipment and that they are properly installed.

C. Pipe Testing

After all components of the refrigerant system have been installed and the piping connected, the piping system is subjected to quality testing.

Joint-leak testing is done with dry nitrogen. The high and low sides of the refrigerant system must be tested using the test pressure specified in the American Society of Heating, Refrigeration, and Air-Conditioning Engineers' ASHRAE 15 for the refrigerant employed in the system.

The refrigerant piping must be proven tight under pneumatic test pressure by checking each joint with a soap solution. Should a leak be detected, the joint must be taken apart, thoroughly cleaned, and remade as a new joint.

The initial leak-test pressure is to remain on the system for 24 hours with no drop in pressure. If the surrounding air temperature increases, a correction of +0.3 psi will be allowed for each degree of change in the initial and final temperature. If the surrounding air temperature decreases, a -0.3 psi correction is allowed.

Following the pressure test and the joint inspection, the entire system is evacuated to an absolute pressure of 300 microns and held at this pressure for one hour. (A micron is a unit of length equal to one millionth of a meter.) During evacuation of the system, the ambient (surrounding) temperature must be higher than 35°F. After this period, the absolute pressure should not exceed 500 microns. The test pressure is recorded by a thermocouple-type, electronic-type, or a calibrated micron-type gauge.

Following the system piping tests, the refrigerant charge is placed in the piping system. Prior to system operation, each joint is subjected to inspection with a halide torch or an electronic leak detector. If a leak does occur, the joint must be cleaned and completely remade.
The refrigerant charge is transferred from refrigerant drums to the piping system only after pneumatic pressure testing, soaping each joint, vacuum testing, and testing with a halide torch or an electronic leak detector has been performed.

D. System Charging

Placing a refrigerant charge into a properly tested and dehydrated refrigeration system should be undertaken by well-trained and experienced service professionals. Refrigerant drums are pressurized, thus safety concerns must underlie the handling of this product.

A proper refrigerant charge is determined by evaluating the pressure in the evaporator and condenser. The refrigerant drum is connected to the charging valves in the refrigeration system. The difference in pressure causes the refrigerant to flow from the drum to the dehydrated refrigeration system. When the pressure has equalized, the system is put into operation and refrigerant is again fed into the system until satisfactory operating pressures are obtained.
Some service professionals use the superheat method for determining satisfactory refrigerant charges. This is an advanced technique whereby the temperature increase in the refrigeration gas is measured after evaporation has been completed.

Specifications should require that the following steps be taken before refrigerant is placed into the piping:

- Pressure-test piping with nitrogen.
- Inspect joints with soap and halide torch.
- Pull 300 micron vacuum in refrigeration circuit.
- Begin refrigeration charge after above has been successfully accomplished.

E. Operation

The specifications require that the contractor notify the contracting officer when the performance and acceptance tests are to be conducted. Since satisfactory operation can only be determined by highly specialized, skilled professionals, the most important quality verification role is to ensure that factory-trained professionals are conducting the performance and acceptance tests.

Service professionals are trained to analyze the behavior of the refrigerant as it courses through the piping system. The specifications, for example, require that air-cooled condensers with a system capacity over 60,000 BTU/hour, have a saturated refrigerant condensing temperature of not more than 130°F. This saturation temperature corresponds to a pressure of 299 psi for the refrigerant R-22, and is expected to occur with the fully occupied building during the hottest times of the year.

As the quality verification role is being performed, it is expected and required that the contractor conform to the specifications and submit performance test reports. These test reports can then be evaluated by district or division experts. The performance test reports will include motor amperage, correct rotation of motors, operating pressures, and system capacities.

8.3 MECHANICAL: THERMAL INSULATION, MATERIALS & INSTALLATION

A. Materials

Materials to be used in guide specification construction are to be submitted for approval. The submittal, as required by specification, is to illustrate type of material, installation method, manufacturer, and its outer covering. Materials evaluation approval is the first step in quality verification. Submittal specifics will be found under the heading "Display Sample" in the specifications.

Thermal insulating materials to be incorporated into a construction project will range from calcium silicate, cellular glass, mineral fiber, unicellular plastic foam, vapor barrier jackets, adhesive bedding compounds, glass cloth, and PVC fittings.

Insulating materials are applied for two reasons: (a) they reduce the rate of heat transfer, and (b) they prevent condensation from occurring on the cold surfaces. Types, densities, thermal conductance, and thicknesses are stated in the specifications.

Very common to the thermal insulating business is the misapplication of the two products: adhesives and vapor-barrier coating compounds. It is quite common to see the adhesive substituted for the more expensive vapor barrier coating.

Surfaces to be insulated are identified as hot or cold surfaces. Insulating techniques will depend upon which surface is to be insulated. Surfaces may be boiler breechings, air-conditioning ductwork, hot water piping, chilled water piping, or roof drains.

Each surface of the system being insulated and the proper method of insulation must be shown on the display sample. It is required that quality verification start with a knowledge of the mechanical systems to be insulated. An evaluation of the display sample can then be made to assure that all insulating requirements are covered.

B. Installation

Thermal insulation installation techniques are identified by the physical characteristics of the insulation to be installed. Insulation materials fall into two broad categories: rigid or flexible. Rigid insulation may be flat or preformed to fit the contour of the system in which it is to be installed.

The guide specification divides installation techniques by hot or cold systems and, then again, by piping or duct work systems.

Piping insulation is primarily composed of preformed segments of insulation. These segments may be for a run of pipe, valves, tees, or other specialty items installed in a piping system. Insulation installed on cold pipe lines must be sealed with a vapor-barrier compound every 15 feet.

All insulation ends that are within 6 inches of flanges, unions, anchors, or other fittings typically found in piping systems are to be sealed with vapor-barrier coating.

Insulation to be secured to ductwork is attached by use of stick pins and adhesive.

Stick pin and adhesive spacing will be stated in the specifications.

The outer jacket to be installed on insulation may be one of four types:

- Fibrous glass cloth secured with adhesive.
- Aluminum metal jacketing.
- Galvanized metal jacketing.
- PVC.

To protect pipe insulation from being crushed at the point of support, a high-density insulation insert is required on piping systems 2 inches and larger. If preformed insulation is used at elbows in piping systems, 3-segment sections must be used.

9. HEATING AND AIR DISTRIBUTION

This section will acquaint the project engineer and construction manager with many aspects of heating and air distribution systems, whose proper functioning is an important energy and comfort consideration. Such systems are designed by professional engineers and are installed and tested by a mechanical subcontractor. These systems require "fine-tuning" to ensure that they perform as the design intended. Therefore, checking and adjusting/balancing is a crucial part of the system installation process and quality verification.

9.1 STORAGE OF EQUIPMENT AND MATERIALS

A. General Storage Requirements

Construction materials and equipment, including that for mechanical systems, must be stored properly. Storage requirements for heating and air distribution systems include the following:

- Provide protection from the weather and elements (rain, sun, wind, sand, etc.).
- Store on raised supports off the ground.
- All openings sealed closed (openings to coils, pumps, etc.).
- If material is stacked, provide supports so that material at the bottom is not crushed.
- Store equipment according to recommendations for positioning (correct side up).
- Provide security.
- Store equipment at a safe distance from the construction work.
- Provide protection from accidental damage while in storage.
- Provide protection, as required, for special conditions. The aluminum fins on heating coils require special protection to prevent accidental damage.

As required in the contract specifications, it is the contractor who is responsible for providing on-site and off-site storage protection for all equipment and materials.

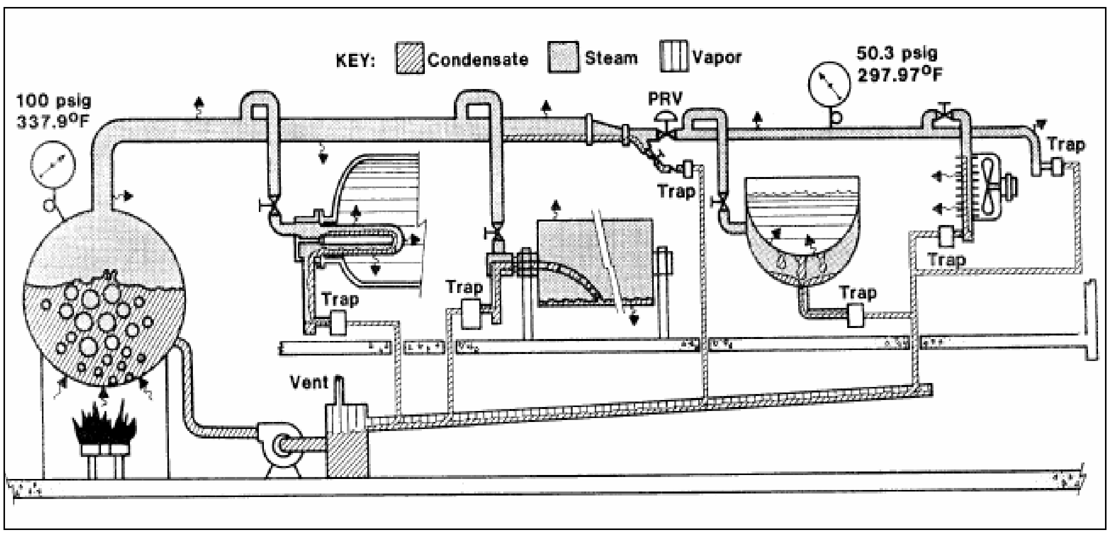
9.2 Heating

A. Heating Equipment and Materials

Heating is the transfer of energy to a gas, liquid, or solid, thereby causing a temperature increase or change of state. Sources of heat include boilers, furnaces, heat pumps, solar collectors, and geothermal. Boilers, which are the most common source of heat, derive heat through the combustion process involving fuel, oxygen, and ignition. Types of fuel include natural gas, heating oil, coal, or liquid petroleum gas. Openings to the boiler room, such as wall and door louvers, are required for combustion air supply. Air circulation for combustion air can be enhanced by providing an exhaust-air fan or a supply-air fan in the boiler room. High-point and low-point combustion air openings are required by the Fuel Gas Safety Code, NFPA 54.

Fuel combustion produces gas by-products that must be ventilated to the atmosphere by means of a flue vent through the boiler room roof. The flue vent must have proper clearance, height, and a rain hood. Natural-gas boilers may use a double-wall steel Type B flue. The flue must be rated to meet the boiler output rating. Fuel-oil boilers or natural-gas boilers that can be converted to fuel oil must use a 10 gauge steel flue. Proper and safe operation of the combustion process is regulated by law. The contract specifications should reference NFPA 54 for natural gas and NFPA 31 for fuel oil. Boiler emission testing, which indicates if the fuel is burned in a clean and proper ratio, requires the flue gas temperature and percentage of carbon dioxide (CO2) to be measured and listed in the test report submittals.

Hot water heating systems will use a circulating pump which delivers hot water through piping and control valves to heating coils located either in the space to be heated or in the air distribution ductwork. Heat is exchanged as air passes through the coils and warm water is then returned to the boiler through piping and control valves. To maintain a constant system pressure, expansion tanks are essential to allow water to expand as it is heated. Air, which is present in the water supply, must be removed. A centrifugal air separator or air scoop in the supply piping or an air eliminator fitting at the boiler is required. (Refer to Figure 9.2-1.)



Centrifugal Air Separator
Figure 9.2-1

In regions where water quality requires treatment, a chemical pot feeder is provided so that properly measured chemicals can be applied to the water. Chemical pot feeders are normally installed with piping that connects to the suction and discharge sides of the hot water circulating pump to provide a pressure differential through the chemical tank.

By-pass piping, which includes three-way mixing valves controlled automatically by temperature, may be provided at the boiler and heating coils for efficiency and proper system balancing.

In steam heating systems, the steam produced at the boiler is forced by its own pressure through piping and control valves to heating coils. (Refer to Figure 9.2-2.) Heat is exchanged to the air as it passes through the coils. As the steam loses heat, it converts to condensate (water) and is returned to the boiler through piping, control valves, and a condensate pump. Steam-traps must be used in the piping system. A steam-trap will permit condensate to flow through it, allow air to escape, and will hold back steam so that all heat is given up or exchanged to the air. A steam-trap is required after each steam heating coil. Whenever steam piping changes direction from horizontal to vertical, steam-traps are also required.

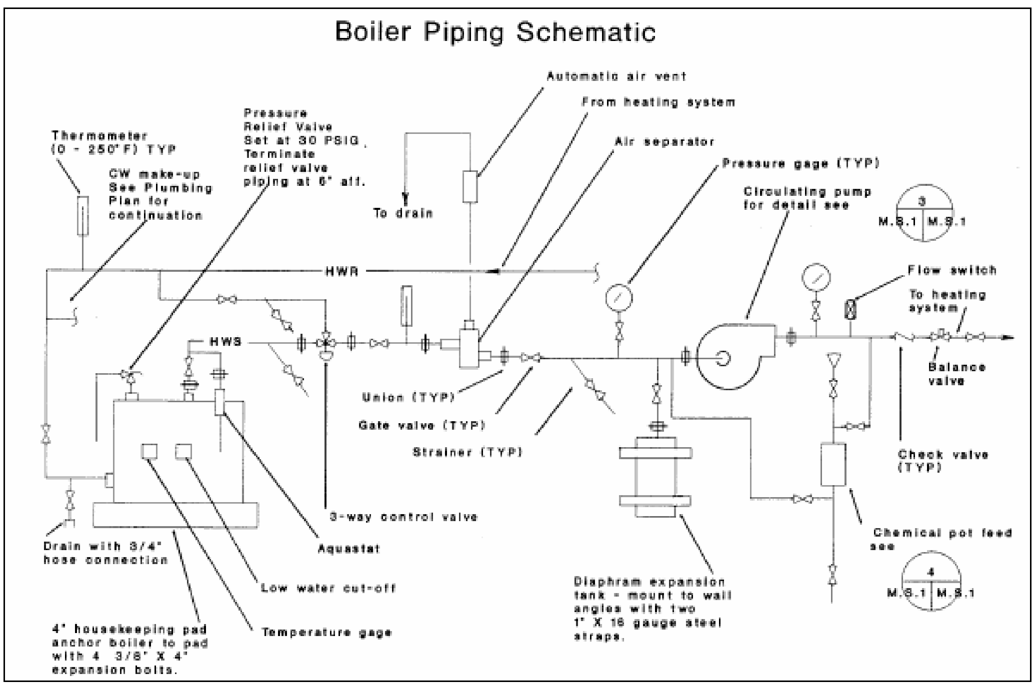


Figure 9.2-2

All hot water and steam boilers are required by law to have safety controls. These controls include low-water control, high-pressure relief, high-temperature relief, and fuel shut-off controls. Any unsafe condition must cause these safety features to operate, that is, shut off the boiler, sound an alarm, and require manual resetting. The pressure-relief valve must be sized equal to the heat output of the boiler and must be installed as close as possible to the boiler. The discharge piping from the pressure relief valve must be open and may not include any shut-off valves.

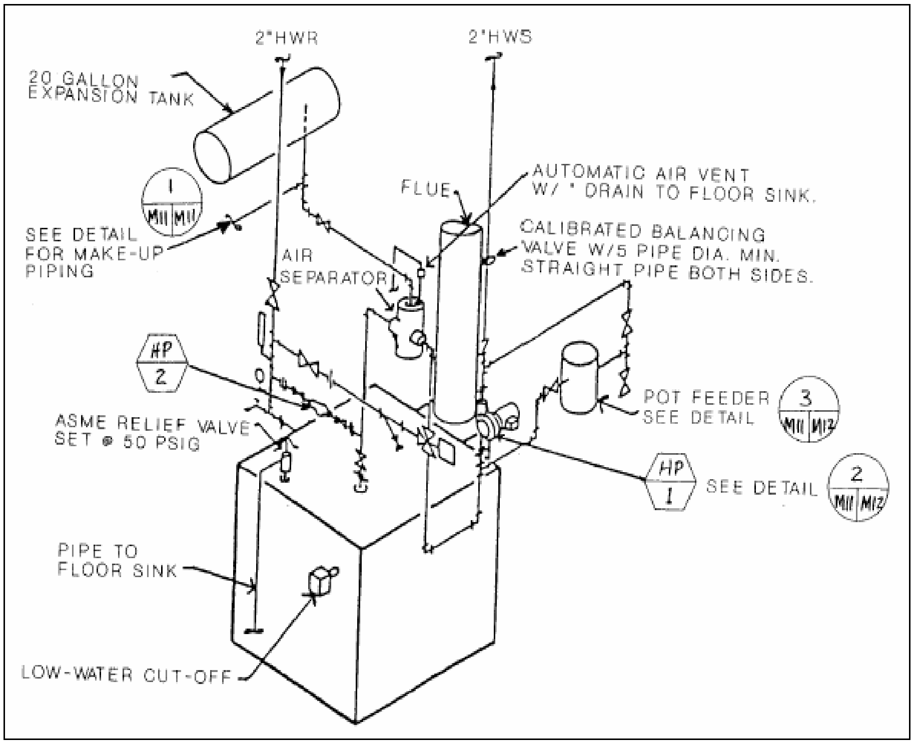
The heating equipment and materials installed must be in accordance with approved submittals and contract requirements to verify quality construction. To accomplish this task, contract drawings and shop drawings require verification with jobsite installation. Skills in blueprint reading must be developed by onsite project personnel in order to verify that heating detail drawings for boilers, pumps, and coils reflect the materials and equipment required by the contract. Project engineers and construction management personnel must be familiar with the standard symbols used in the piping drawings for heating systems. Due to variations in piping arrangements from the "schematic only" contract drawings, become familiar with options in heating equipment to assure quality piping installation by the contractor.

B. Installation of Heating Equipment and Materials

The following section gives inspection points for quality verification of heating equipment and materials.

1. Boiler (Refer to Figure 9.2-3.)

a. Coordinate its location with other mechanical equipment.
b. Locate it to allow for proper maintenance and cleaning.
c. Provide a correctly sized housekeeping pad under the boiler.
d. Provide seismic protection, as required.
e. Relief valves and drain valves should be piped to drain.



Hot Water Boiler
Figure 9.2-3

2. Pump

a. Provide an isolated-type floor pad, if floor mounted.
b. Provide a flexible pipe connector in the suction and discharge piping of the pump.
c. On the suction piping, provide a long radius elbow and straight pipe length at least five times the pipe diameter or, when space is a problem, provide a suction diffuser in the suction piping.
d. Provide pressure gauges in the suction and discharge piping.
e. Provide shut-off valves in the suction and discharge piping.
f. Provide a strainer, with drain valve, in the suction piping.
g. Pipe size changes should be made at the pump so that all other items in the suction and discharge piping are full-line size.
h. Provide seismic protection, as required.
i. Install the pump in the supply-piping side of the system.
j. Provide a non-slam check-valve in the discharge piping.
k. Provide eccentric reducing fittings on pump suction and concentric increase fittings on pump discharge.

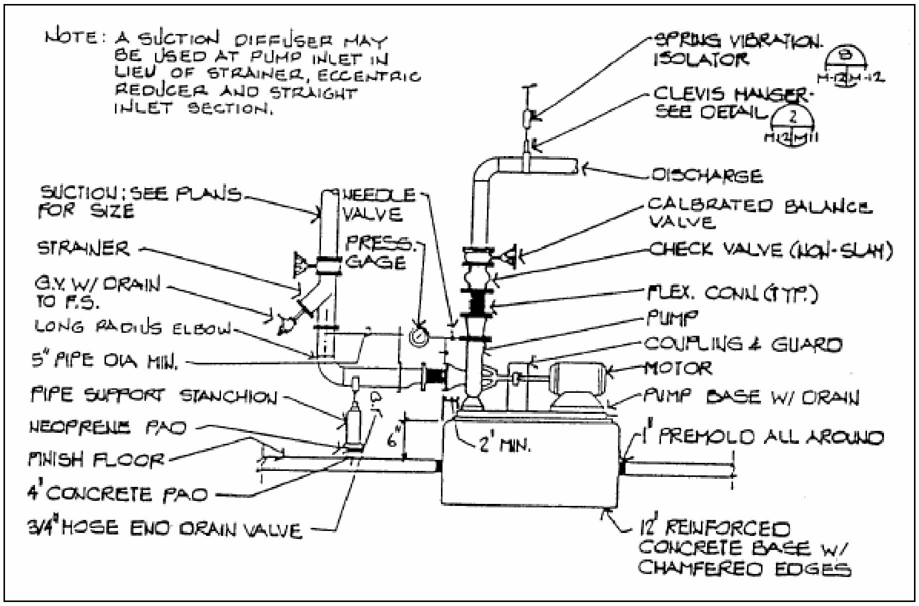


Figure 9.1-4 Base Mounted Pump Detail

3. Coils

a. Provide high-point air vent and pipe it to drain.
b. Provide low-point drain.
c. Slope coil for drainage.
d. Pipe coil in counterflow, which requires the input and output to be piped correctly.
e. Provide connections for pressure and temperature readings. Provide gauges, if specified.
f. Provide shut-off valves in the supply and return piping.
g. Provide a strainer in the supply piping.
h. Provide unions or flanges in the supply and return piping for coil removal.
i. Provide a calibrated balancing valve or automatic flow-control valve in the return piping for proper balancing of the heating system.

If a by-pass pipeline with three-way mixing valve on the return side is provided, verify that the three valve ports are piped correctly and sized correctly.

4. Air Separator (Refer to Figure 9.2-3.)

a. Air separators should be located in the supply piping from the boiler, as air separates better at higher temperatures.
b. Check for proper input and output piping connections. Water should flow out of the air separator through the low-port opening.

4. Expansion Tank (Refer to Figure 9.2-3.)

a. Atmospheric-type tanks require a sight gauge, drain, and airtrol fittings. Atmospheric tanks are commonly piped to the top of the air separator.
b. Diaphragm-type tanks should be connected downstream of the air separator and off the supply piping. Provide this type with a drain valve. The diaphragm type will not fill with air and is preferred over the atmospheric type.

5. Piping for Hot Water (Refer to Figure 9.2-3.)

a. Pitch down in direction of flow (1 inch per 40 feet).
b. Provide air vent at all high points.
c. Provide drainage at all low points.
d. Branch connections should be made below horizontal to avoid high-point air pockets.
e. Slope short branch piping (1 inch per 10 feet).
f. Use eccentric reducers, installed flat side up, in horizontal position.
g. Provide expansion loops, as required.

6. Piping for Steam

a. Pitch down in direction of flow (1 inch per 40 feet).
b. Branch connections must be at an angle of 45° above the horizontal.
c. Pitch branch piping (1 inch per 10 feet).
d. Provide a steam-trap at each change from horizontal to vertical piping.
e. Use eccentric reducers, installed flat side down, in horizontal position.
f. Provide expansion loops, as required.

7. Pipe Supports

a. Pipe supports should be in accordance with American National Standard MSS-SP-58 and MSS-SP-69, which provide standardized guidelines for hangers, rods, and clamps.
b. Due to rigidity, hanger spacing will increase as pipe diameter increases.
c. Additional supports should be within one foot of each direction of pipe change.
d. Additional load-calculated supports are required near pieces of equipment.
e. Pipe supports should be larger than pipe size to allow continuous insulation through the support.
f. Heating pipe in sizes of 4 inches and larger require roller supports and saddles welded to the pipe.

8. Common Valve Types

a. Check-valves permit flow in one direction only.
b. Non-slam check valves.
c. Gate valves for "on-off" operations.

d. Globe valve for modulating flow control.
e. Ball valve for modulating flow control.
f. Butterfly valve for "on-off" and for modulating flow control.
g. Plug valve for flow control.
h. Reducing valve to lower pressure.
i. Relief valve to relieve high pressure.

C. Testing and System Operation Verification

There are a number of steps required to test and verify system operation. The following section gives broad guidelines to follow to ensure proper testing and system operation verification. Prior to testing, the contractor submits a test plan for approval. The test plan covers scheduling and procedures.

Pressure and leak test all piping. Perform this test prior to installing insulation or concealing piping in walls or above ceiling. The test pressure is normally one-and-one-half times the system working pressure. Retest after correction of leaks.
Clean the boiler and piping with caustic solution heated to 150°F and circulated. Flush and drain the boiler and all piping. Clean all strainers. Balance the hot water flow which includes:

- Pump direction, amperage (amps), revolutions per minute (RPMs), and gallons per minutes (GPMs).
- Set flow valves at each coil (GPM).
- Pressure readings.
- Vent all manual air vents and check all automatic air vents.

Manufacturer's representative should start up the boiler and check-out controls.
Test the flue gas temperature and percentage of CO_2. Test all safety controls, including:

- High pressure and temperature control.
- Low water control.
- Flame failure lockout.
- Alarm bell.
- Flow switch.

Perform a system operational test and check-out controls, including:

- Test boiler sequencing and shutdown, as required in the contract. The hot water pump must be on when the boiler is fired up. Space-temperature sensors and outdoor-temperature sensors will control the boiler firing in coordination with the water temperature.
- Check that control valves open and close as required to provide flow according to demand.
- Check temperature differential across the boiler and heating coils under a load condition.
- Perform the operational test over the specified period of time, ensuring that the required

temperature set-points are maintained and that no problems occur. Record data readings at periodic intervals, as required.

- Submit test reports.

Submit operations and maintenance (O&M) manuals, warranty, and as-built drawings. Provide training instruction, as required.

9.3 AIR DISTRIBUTION

A. Air Distribution Equipment and Materials

The air distribution system must move a volume of air to a given space, with controlled temperature, humidity, and quality, in a quiet and efficient manner. A complete air distribution system requires that supply air, return air, relief air, exhaust air, and outside fresh make-up air be totally balanced. Air quality is improved through filtering of dust particles and exhausting of odors. An air handling unit, which includes a fan, filters, and temperature control coils, forces air through a ductwork system to a given space. The ductwork and air-handling equipment must be in accordance with the contract and the manuals compiled by SMACNA. Construction Engineers must develop skills in using the SMACNA standards to verify proper air distribution.

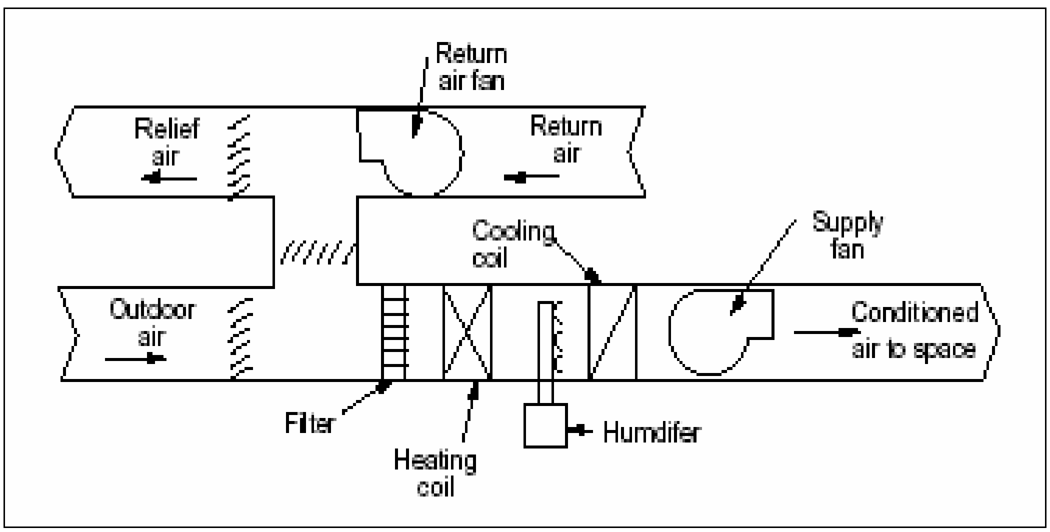


Figure 9.3-1 Typical Air-handler

1. Fans

Fans forces air movement which produces a pressure throughout the system and building. This total air pressure is a combination of velocity pressure and static pressure. Static pressure is caused by friction of the air against the sides of the ductwork and the force required to move air through filters and coils. This pressure is measured in inches of water and is commonly referred to as inches-of-static pressure. The SMACNA HVAC Duct Construction Standards contain charts according to static pressure ratings that the contractor will use to select metal duct gauge thickness and reinforcement requirements for specific duct sizes.

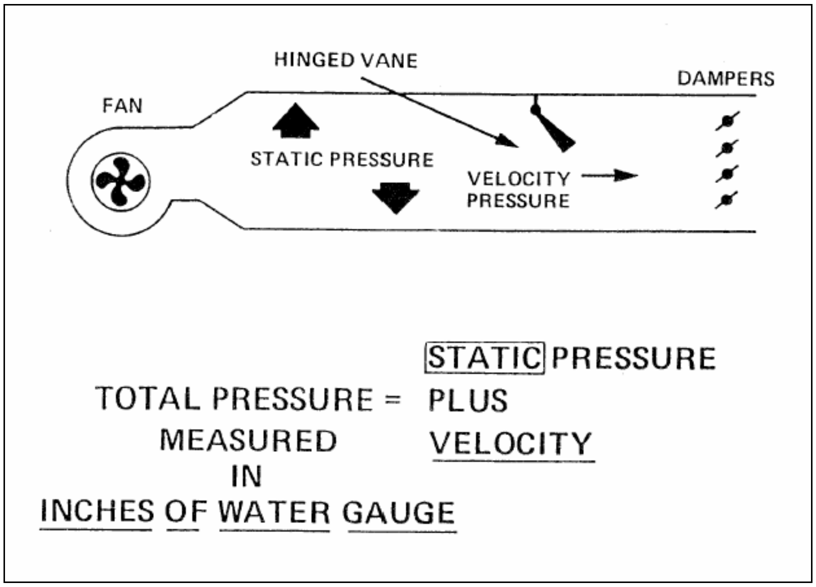


Figure 9.3-2 Static Pressure

2. Control Dampers

At the air handling unit, temperature control dampers will modulate the mixing of return air with fresh make-up air, which is then filtered and supplied to the given space at the required temperature. The volume of air moving in the system is measured in cubic-feet-per-minute (CFM). It is controlled and balanced through the use of volume control dampers located throughout the ductwork. Air enters and leaves a space through devices called diffusers, registers, and grills.

3. Ductwork

The most commonly used ductwork is made of galvanized sheets of steel. A flexible, pre-insulated duct material is used to connect the metal duct to diffusers and registers. The contract will specify the maximum length of the flexible duct material.

To control noise and vibration, the ductwork will require acoustical duct lining, normally near the fan in the supply and return duct. The duct size indicated on the drawings must be increased accordingly when acoustical duct lining is installed. The supply and return ducts must also be connected to the fan unit with a duct flex connection, normally six inches in length, using a material specified by the contract. The fan unit must be installed with vibration isolators, as required.

Fire dampers are installed in ductwork at the locations specified, such as in fire walls or fire partitions designed to stop the spread of fire throughout the building. The SMACNA Fire Damper Guide or the contract drawings provide details for proper installation and operation. Fire dampers are not required for normal air distribution control. An access door must be provided in the ductwork at each fire damper. Access through the ceiling must also be provided.

In addition to SMACNA standards, become familiar with blueprint symbols. The contract drawings and SMACNA include a list of standard symbols used in ductwork installation. Quality verification requires that contract drawing symbols be compared to ductwork installation. Remember that contract drawings are schematic in nature and that proper variations during the construction phase should be submitted, approved, and verified during installation.

C. Installation of Air Distribution Equipment and Materials

Quality verification of the air distribution system requires review and familiarization with contract drawings, approved submittals, and SMACNA standards. Each piece of equipment and material must be verified to assure quality installation. Following are the major system components, along with a check list of requirements for quality verification.

3. Air Handling Unit

a. Install air handling units on housekeeping pads, if they are floor mounted.
b. Provide vibration isolation on the fan section of the unit. Isolators must be rated (color-coded) according to the load.
c. Provide flexible connectors, normally six inches in length, between the air handling unit and the ductwork.
d. Provide pressure gauges and thermometers, as required. Locate the gauges so that they are easily readable and provide stand-off brackets for proper insulation application.
e. Provide seismic protection, as required.
f. Locate the air handling unit with coordination to all mechanical equipment and provide space for maintenance so that coils and filters can be changed.
g. Provide access doors for repairing fans, coils, and filters.
h. If the fan motor is external to the unit, provide guards over the drive belts.
i. If the fan motor is internal to the unit, provide a light, with control and power inside the air handling unit, for observation and maintenance.
j. Verify that the contractor designs the return air and the outside air-mixing section of the air handling unit with proper air flow characteristics.

4. Filters

a. Verify that the filter is of correct size, thickness, and type.
b. Verify that the filter is installed for correct air flow direction.
c. Filters must be replaced at final job acceptance.

5. Temperature Control Dampers (located near air-handling unit)

a. Must be the opposed-blade type for air flow modulation.
b. Should be a low-leakage type with replaceable neoprene edge seals and blade seals.
c. Automatic damper control actuators should include positive positioning devices and a control indicating device at the controller.
d. Damper size should be in accordance with air flow requirements and not necessarily duct size.

4. Volume Control Dampers (located at each branch duct)

a. Normally, these are manual control dampers with accessible locking-type quadrant operators, which must be set, marked for proper balance, and locked in place.
b. Provide damper operators with stand-off brackets for proper insulation application.
c. Locate dampers close to the duct branch takeoff.
d. Damper blade material should be two gauges heavier than the duct material.
e. Volume dampers should be the opposed-blade type. For ductwork 12 inches and less, single-blade dampers are normally used.

5. Barometric Dampers

a. Locate at exhaust and supply air fans.
b. Locate as required to relieve high static air pressure.
c. Verify that the damper will open to permit the required air flow without vibration.
d. Barometric dampers are the parallel-blade type for open-closed operation.

6. Diffusers, Registers, and Grills

a. Diffusers and registers should be provided with an opposed blade volume damper, which are used to fine-tune final balancing only.
b. Verify that diffusers and registers are of the four-way, three-way, or two-way throw, as required.
c. Verify that supply and return openings are located far enough apart to allow adequate air mixing throughout the space.

7. Air Deflectors

a. Air splitters, a single adjustable blade, should be installed at splits in the main air supply duct.
b. Turning vanes are required at all square elbows in ductwork. Verify that turning vanes are of the airfoil type or single-skin type, as required.
c. Air extractors may be used with a single air opening off a main duct run. They should not be used at duct branch takeoffs.

8. Fire Dampers

a. Install fire damper sleeves with breakaway connections to the duct.

b. Verify the sleeve gauge, which is normally required to be 14 gauge.
c. Verify that a minimum inch-and-a-half angle iron support is provided on each side of the wall of each fire damper installation.
d. Verify that an access door is provided for each fire damper.
e. Verify the temperature rating of the fire damper.
f. Check operation of the fire/smoke damper if it is automatically controlled.
g. Fire dampers will be Type A (in the air stream) for low velocity systems and Type B (out of the air stream) for high velocity systems.
h. Fire damper installation details must be according to contract drawings or the SMACNA fire damper guide.

9. Ductwork

In recent years, construction specifications have evolved to the point of relying almost entirely on the manuals for construction details. Most specifications elaborate on certain items, such as elbows, joints, transformations, pressure classes, etc., but, in general, they agree with the SMACNA manuals.

This section will familiarize you with some of the terminology used in duct construction and how to relate the SMACNA manuals to construction jobs. SMACNA is continuously upgrading their manuals to improve quality and economy. Examine each job specification to ensure that the referenced manual is used. The SMACNA manual used for this discussion is the HVAC Duct Construction Standards.

a. Duct material may be galvanized steel, aluminum, or fibrous glass duct. If the fibrous glass duct material is used, it must be in accordance with the SMACNA Fibrous Glass Duct Standards, which are not covered in this course.
b. Branch runouts are flexible duct sections, normally 6 to 10 feet in length, that connect the metal ductwork to the air diffuser registers. Verify for proper length, support, and approved material. SMACNA provides information for proper connection methods.
c. Flexible-duct connections at the diffusers must either be installed with a smooth, non-restricting radius or with a hard elbow to allow for proper air flow.
d. Duct sleeves are required when round duct of 15-inch diameter or less passes through walls.
e. Framed, prepared openings are required for all rectangular or round duct over 15-inches in diameter. Provide a one-inch clearance all around the duct.
f. Exposed duct passing through walls may require a four-inch wide galvanized collar closure. Duct insulation is continuous through the wall.
g. Round duct requires all fittings to be continuous-weld construction.

10. Noise Control

In addition to acoustical duct lining, as discussed above, other noise control methods include:

- Install sound attenuation equipment in the ductwork as required by contract.
- Use fan units, diffusers, registers, and dampers with rated sound decibles according to recommended sound measurements as listed in Associated Air Balancing Council (AABC), Chapter 12.

The sound testing normally required by contract is incomplete if the required sound measurement ratings are not listed on the drawings. Sound testing is normally performed at off times, such as evenings or weekends. Reference readings (no equipment operating) are measured in each space prior to starting the air distribution system for operational noise testing.

D. Testing and System Operation Verification

Testing and operation verification are crucial steps to ensure that the overall system functions properly. This is when possible problems are identified and adjustments made accordingly. All test plans and procedures should be submitted for approval and scheduling. The manufacturer's representative should startup the air handling unit to verify proper electrical and piping connections and control operation.

1. Ductwork Testing

Pressure- and leak-test all ductwork. Some contracts may allow sealing all duct joints in lieu of leak-testing for low static pressure ratings, such as two-inches-of-water gauge and less. Duct leakage tests must be performed prior to installing insulation or concealing in walls or above ceilings.

2. System Air Balancing

System air balancing should be performed by a separate certified organization. Approved, certified organizations are the AABC and the National Environmental Balancing Bureau (NEBB). Balanced test data should include:

a. Fan CFM measured by a duct traverse.
b. Fan motor amps and RPMs.
c. Measured CFM at terminal control units and all air inlet and outlet devices.
d. Static air pressure drop at coils, filters, dampers, and terminal units
e. All final, balanced damper settings must be locked in place and marked.

The total air supply to a given space must be within -5% to +10% of design. The percentage of accuracy at each inlet or outlet will vary according to design (AABC, Chapter 17). Proper air balancing may require the adjustment of fan RPMs, temperature control damper actuation, volume control damper, and splitter damper settings. For fine-tuning, the setting of opposed blade dampers at all diffusers and registers may be required. The dampers at diffusers and registers will add noise to the space if not properly balanced.

3. System Operation and Control Verification

a. Verify that all dampers operate as required by temperature demand.
b. Verify that the fan starts and stops as required, according to the sequence of operation.
c. Verify total system sequence of operation in coordination with the heating and cooling systems. The sequence can be verified in any season, however, capacity testing of the heating/cooling systems needs to be performed under the load of the appropriate season. This test is performed by the contractor over a period of time, as required, with data collected at specified time intervals.
d. Submit test reports for air balancing and system operation.

After these steps are performed, the contractor submits operation and maintenance manuals, warranties, and as-built drawings and provides instructional training, as required.

10. ELECTRICAL

The dependence on electrical power is often taken for granted. Electrical installation accounts for approximately 5-10% of building costs. Electrical hook-up begins outside with aerial or underground construction. It is then distributed to the building interior where it powers lighting, fire alarms, HVAC systems, and office equipment such as computers. Quality verification is vital in the installation and operation of all electrical equipment.

10.1 AERIAL CONSTRUCTION, INCLUDING GROUNDING

A. General

Although the subject of electricity and electrical service may seem mysterious, the logic behind harnessing the flow of electrons from one point to another is absolutely predictable. Electric current flows in a continuous path, or circuit, from a power station, across either overhead or underground conducting wires, through transformers, into a service entrance, past a meter, and into a service panel which supplies power to the various switches, lights, and outlets.

Electricity is potentially dangerous. To guard against the threat of lightning and shock, the electrical system's integrity must follow certain strict safety codes and building standards. Shop drawings and contract submittals provide diagrams, details, and product samples.

B. Materials

Aerial construction is the distribution of electric power aboveground using wood, steel, or concrete poles and metal structures to support electrical conductors. Materials should be checked for compliance with the plans and specifications when they arrive on the jobsite, before they are installed.

Poles

Poles are classified according to strength. The contract plans indicate the pole classification, as well as the length necessary for each location. The class, length, and other information is stamped or otherwise marked in a standard manner on each pole. American National Standard Institute's ANSI 5.1, Specifications and Dimensions for Wood Poles, gives information on checking the pole markings.

Wood poles must be turned smooth for their full length, roofed, gained, and bored prior to pressure treatment to assure that preservative penetrates the wood. A gain is a factory-cut flat surface where the crossarm is mounted. Sweeps and short crooks of poles in line must not exceed 50% of the maximum permitted by ANSI 5.1. Examine poles to assure that they are of good quality (no excessive crooks, cracks, or knots). Poles held in storage for more than 2 weeks must be stored in accordance with ANSI 5.1 to minimize deformation and damage to poles. Poles must be stored off the ground and flat.

Handling of wood poles shall be in accordance with ANSI 5.1, except that pointed tools capable of producing indentations more than 1-inch in depth shall not be used. Metal poles shall be handled and stored in accordance with the manufacturer's instructions.

Crossarms

Crossarms should be solid wood, distribution type, except for a cross-sectional area with pressure treatment conforming to AWPA C25, and a %-inch 45 degree chamfer on all top edges. Cross-sectional area minimum dimensions should be 4V4 inches high by 3% inches deep, in accordance with ANSI C2 for Grade B construction.

Vertical construction is also seen on projects. Pole mounting brackets for line-post insulators and eye bolts for suspension insulators must be as shown on contract drawings and be installed so as to provide not less than the required climbing space. Brackets must be attached to poles with a minimum of two bolts. The bracket mounting surface must be suitable for the shape of the pole. Brackets for wood poles must have wood gripping members. Horizontal offset brackets must have a 5 degree uplift angle, but in no case less than a 2800 pound cantilever strength.

Insulators

Insulators support a conductor physically and separate it electrically from another conductor or object. Since insulators come in many sizes and shapes and in various voltage classifications, it is very important that the correct ones are installed. To ensure that they are correct, they must be checked against the approved descriptive material while they are still in their original cartons since the carton gives all pertinent identification information.

In addition to proper voltage classification, the insulators' physical condition must be thoroughly checked. Insulators are made of a ceramic material with a highly-glazed surface.

A crack or chip in this surface will cause noisy operation and, most probably, result in premature failure. Imperfect insulators must be rejected.

Conductors

Conductors are the wires that carry the electrical current. Line conductors are either copper or aluminum and are usually bare. Conductor size specified in the project design is based on electrical and mechanical characteristics.
There are many types of conductors available on the market. The types usually found in the field are hard-drawn, solid, or stranded, copper, and ACSR. Splices and connectors must be of the non-bolted compression type.

C. Installation

Aboveground utilities are prominent in the landscape. Proper materials and good workmanship aid in the appearance of the overall project, in addition to providing dependable electrical service. If lines pass through trees, they must be trimmed.

Given below is a summary of installation practices seen on many projects, including grounding.

Poles

Poles should be set so that crooks are in the line of poles and not crosswise to it, so they will be least noticeable. Improper alignment of poles emphasizes crooks.

Wooden poles must be properly backfilled after setting. Earth is placed in six-inch layers (maximum) and thoroughly tamped before the next layer is added. When the hole is filled, earth is placed around the base in a cone shape and packed tightly so that water drains away from the pole.

Street lighting poles designated for embedding in soil must have a minimum setting depth below the reference ground line of 5 feet.

Conductors

Care must be taken in storing, handling, and stringing conductors to guard against kinks, cuts, and scratches. Conductors should be either pulled by machine through overhead reels or payed (let out) from a reel as it is carried along the right-of-way. Conductors should never be pulled over the ground from a fixed reel.

Before tying-off the conductors to the insulators, the conductors must be properly tensioned. The approved tension table for a conductor is furnished by the manufacturer. The value of the sag is the distance the lowest point of a span is below the straight line between supports.

Occasionally, the drawings will indicate a "slack span," which means that conductors are only tensioned enough to eliminate excessive droop. Care should be taken to be sure the droop is not unsightly and is uniform for the conductors.

Guying

Guys are cables used to keep poles properly positioned. Poles are intended to be loaded vertically only. Their inherent stiffness will resist side forces resulting from normal winds that shift direction periodically. This means that whenever a pole line changes direction, such as at corners and where it terminates, all poles with side loads must be properly guyed.
The drawings indicate guy locations and required guy strengths stated in thousands-of-pounds. As an example, "5M" means a strength of 5000 pounds. Adequate guying is essential for reliability as well as for good appearance of the pole line.

The distance measured horizontally from the ground surface at the pole to the point of attachment to the guy anchor is the "lead" length. When field conditions prevent the indicated guy lead, anchors must be placed in a location approved by the contracting officer and the guy strength increased. The lead angle can never be less than 15 degrees. Moving the anchor closer to the base of the pole greatly increases the guy strain. The designated guy may have to be replaced by a stronger guy system.

Grounding

Grounding is accomplished using ground rods and ground wire. Equipment, neutral, and surge arrester ground systems must be installed at poles where indicated. A resistance of not greater than 25 ohms must be provided, unless otherwise specified. Ground resistances normally is measured in dry conditions at least 48 hours after rainfall. Resistances of systems requiring separate ground rods are measured separately before bonding below grade. The combined ground resistance of separate systems bonded together below grade may be used to meet the specified ground resistance, but the minimum number of rods indicated must still be provided.

Ground rods must be as specified in the contract requirements. Ground rods are driven into the ground until the tops of rods are approximately 1 foot below finished grade. Where the specified ground resistance cannot be met with the indicated number of ground rods, additional ground rods, longer ground rods, or deep-driven sectional rods must be installed and connected until the specified resistance is obtained, except that not more than three additional 8-foot ground rods are required at any one installation. Ground rods must be spaced as evenly as possible, at least 6 feet apart and connected 2 feet below grade. The contractor may, as an option, provide copper-coil-type grounds at wood poles in lieu of ground rods where the required ground resistance can be obtained by this method. The copper-coil-type ground shall consist of a coil of at least 12 feet of No. 6 minimum bare copper wire stapled to the butt of the pole.

Neutral conductors must be grounded where indicated on the contract drawings. Ground wire sizes not otherwise indicated must have a current-carrying capacity of at least 20% of the largest neutral conductor to which a ground wire is connected, but in no case smaller than No. 6 American Wire Gauge (AWG). Each connection to earth shall consist of a ground wire connected to a ground rod driven into the ground approximately 3 feet out from the base of the pole.

Ground wires on wood poles shall be protected by half-round wood, plastic, or fiber molding from a point 18 inches above the ground line up the length of the pole. Rigid galvanized steel, schedule 80 sunlight-resistant PVC, or intermediate steel conduit are used to protect ground wires on poles from a point 14 inches above grade to a point 6 inches below grade.

The ground wire must pass unbroken through the protective conduit. Steel protective conduit must be terminated with a grounding bushing at each end. The ground wire must be made electrically continuous with the steel protective conduit by jumpers of the same size as the ground wire from each bushing to the ground wire, with a compression-type connection at both ends. Bends greater than 45 degrees in ground wires are not permitted.

Noncurrent-carrying metal parts of equipment and conductor assemblies must be grounded, as required. Ground wire sizes not otherwise indicated should be not smaller than No. 6 AWG. Connections to earth are made in the same manner as required for secondary neutral grounding. Equipment or devices energized at less than 750 volts may be connected to secondary neutral grounds of transformers with windings connected in open-delta or grounded-wye configurations. Equipment energized at more than 750 volts shall be provided with grounds separate from secondary neutral grounds, but both grounds shall be bonded together below grade at the ground rods or to the ground counterpoise, as applicable. Metal poles shall be grounded at each pole and these grounds shall not be interconnected with any other grounds.

Lighting pole grounding is accomplished by connecting its base to an adjacent ground rod by means of a No. 8 AWG wire. A ground connection from poles back to neutral ground points must also be provided, utilizing either metal raceways or ground wires.

Surge arresters must also be grounded. Ground resistance for intermediate-class arresters must not be more than 10 ohms, and for distribution-class arresters must not be more than 25 ohms. Ground wire connections must be at least No. 4 AWG for distribution arresters and No. 1/0 AWG for intermediate arresters. Connections to earth are made in the same manner as for secondary neutral conductors and run to a ground rod separate from the secondary neutral ground rod. The aerial portion of surge arrester and secondary neutral ground conductors must be separate from and independent of each other, but both grounds shall be bonded together below grade at the ground rods, or to the ground counterpoise, as applicable.

The grounding resistance must be measured, and cannot exceed 25 ohms when measured at least 48 hours after rainfall. Additional ground rods should be added until the ground resistance is 25 ohms or less. If the specified number of ground rods does not produce low enough resistance, the contracting officer must be notified. A ground mat may be necessary to establish an adequate ground. The contractor must furnish a record of the ground resistance tests of all ground rods including location and ground condition (wet or dry) at the time of each test.

Connections above grade are made with bolted, solderless, connectors, while those below grade must be made by a fusion-welding process. In lieu of a fusion-welding process, a compression ground grid connection, using a hydraulic compression tool to provide the correct circumferential pressure, may be used. Tools and dies are recommended by the manufacturer. An embossing die-code or other standard method provides visible indication that a connector has been adequately compressed on the ground wire. Where ground wires are connected to aluminum-composition conductors, specially treated or lined copper to aluminum connectors suitable for this purpose must be utilized.

Ground-resistance measurements of each ground rod must be taken and certified by the contractor to the contracting officer. No part of the electrical distribution system shall be energized prior to the resistance testing of that system's ground rods and grounding systems and submission of test results to the contracting officer. Test reports must indicate the location of the ground rod and grounding system, and the resistance and the soil conditions at the time the test was performed.

10.2 TRANSFORMERS, UNDERGROUND CONSTRUCTION AND CABLE INSTALLATION

A. Transformers

The transformer is, simply speaking, a voltage changer. Through the transformer, a given amount of power from a high-voltage line is converted and delivered to a load at a lower voltage. A transformer may also be used to convert low voltage to a higher voltage (step-up transformer). Most transformers used in projects are step-down distribution transformers.

B. Underground Construction

Underground utilities are becoming more widespread. They are more costly, but preferred for aesthetic reasons. In many respects, underground wiring is similar to an interior wiring system utilizing conduit and junction boxes. Underground construction requires that the same care be exercised when checking materials for compliance with approved submittals.

Submittals must be in compliance with project specification. Installation must comply with NFPA 70 and ANSI C2.

Manholes and Handholes

A manhole is an enclosure large enough for workers to enter. It is used for installing, operating, and maintaining underground electrical equipment and cables. A handhole is an access opening large enough for workers to reach into. It is provided for access to underground electrical equipment and cables.

The exact location of each manhole and handhole is determined after careful consideration has been given to the location of other utilities, grading, and paving. The minimum slope of duct lines is 4 inches per 100 feet in order to drain and clear other buried utilities. This sometimes affects location and depth of manholes and handholes.

A machine-finished seat for manhole covers is required to ensure a matching joint between the frame and cover. Proper identification must be stamped into the cover, (i.e., electric or telephone).

Concrete, when required for encasement, is specified in the specifications for concrete.
Manholes, handholes, and concrete pullboxes are grounded by rods protected with a double wrapping of pressure-sensitive plastic tape. Ground wires must be neatly and firmly attached to manhole or handhole walls and the amount of exposed bare wire be kept to a minimum.

Duct Lines

Several different duct materials are permitted. NEMA TC6 Type I may be used when the duct is to be encased in concrete. Type II is Schedule 40 or 80 and must be used when there is no encasement. Check that the proper materials are used and that vertical joints are staggered.
A duct line, be it single-duct or multiple-duct construction, should be as straight as practicable, both up-and-down and side-to-side, to minimize cable-pulling friction. Either vertical or horizontal changes in direction exceeding a total of 5 degrees, either vertical or horizontal, must be accomplished by long sweeping bends having a minimum 25 foot curve radius. This requirement must be strictly observed.

To prevent damage to cable, ducts must be free of obstructions and clean. This is ensured by drawing a standard flexible mandrel, at least 12 inches long with a diameter approximately 1/4 inch less than the inside diameter (ID) of the conduit, through each completed duct from manhole to manhole. This mandrel is followed with a brush.

Markers are located near the ends of cable runs, at each cable joint or splice, at approximately every 500 feet along cable runs, and at each change in cable run direction. Markers must be constructed as indicated. Duct line markers must be provided, as indicated, at the ends of long duct line stubouts or for other ducts whose locations are indeterminate because of duct curvature or terminations at completely below-grade structures. In lieu of markers, a 5-mil brightly colored plastic tape at least 3 inches wide and suitably inscribed at least every 10 feet with a continuous metallic backing and a corrosion resistant 1-mil metallic foil core to permit easy location of the duct line, may be placed approximately 12 inches below finished grade level.

Cable in Ducts

The larger cables are sized in thousands of circular mils (KCML) system on the AWG scales. On the basis that there are 1000 mils per inch, the square of the diameter of the conducting material (copper or aluminum) in mils, will give the KCML size. For example, a conductor that has a diameter of 1/2 inch (500 mils), is a 250 KCML size.

The cable must be pulled into duct lines directly from reels set up at manholes. It must not be unreeled onto the ground and then pulled into the manhole. All splices must be at manholes or handholes. A splice must not be concealed in a duct.

Cable splices must be made by qualified cable splicers in strict accordance with the recommendations of the cable manufacturer. Certification of the qualifications of medium voltage cable installers must be submitted and approved before any work is performed.

Direct-Burial Cable

Cable handling procedures are important to avoid damage to cable through overtension and abrasion. The cable reel must be pulled along the trench, unreeling cable as it goes. Cable is then lifted into place on the trench bottom. Cable may not be pulled into a trench from a fixed position.

At terminations, the cables should have a slight slack length left in the trench to eliminate tension on terminals due to the changes in ground temperature.

Although buried cable splices are permitted in long runs of cable, the splices are not permitted at intervals of less than 1000 feet and are not permitted in any run of 1000 feet or less.

Cables must be arranged neatly on the bottom of the trench in parallel configuration. Where they leave the trench and enter conduits, the cable must be held in the center of the conduit by non-hardening mastic (paste-like cement). Backfill must be compacted without disturbing this centering. Where it is necessary to cross a primary (high-voltage) cable over others in a trench, at least 3 inches of separation must be maintained or a non-metallic conduit used.

Trenching

Trenches for direct-burial cables shall be excavated to depths required to provide the minimum necessary cable cover. Bottoms of trenches shall be smooth and free of stones and sharp objects. Where bottoms of trenches comprise materials other than sand or stone-free earth, 3-inch layers of sand or stone-free earth shall be laid first and compacted to approximate densities of surrounding firm soil.

Cable Installation

Where a buried cable warning is necessary, the requirement for a tape or approved warning indication will be provided. Where soil is known to be rocky, provide selected backfill for cable protection. Cables shall be unreeled along the sides of or in trenches and carefully placed on sand or earth bottoms. Pulling cables into direct-burial trenches from a fixed reel position will not be permitted, except as required to pull cables through conduits under paving or railroad tracks. Where cables cross, separation of at least 3 inches shall be provided, unless each cable circuit is protected by a nonmetallic conduit sleeve at the crossing. Where single-conductor cable is installed, all three phases and the neutral shall be installed in the same sleeve. Bend radius of any cable shall be not less than 10 times the diameter of the cable. In no case shall cables be Left under longitudinal tension. The first 4-inch layer of backfill shall be of sand or stone-free earth. A 5-mil, brightly colored plastic tape not less than 3 inches in width and suitably inscribed at not more than 10 feet on centers, or other approved dig-in warning indication, shall be placed approximately 12 inches below finished grade levels of trenches. Selected backfill of sand or stone-free earth shall be provided to a minimum depth of 3 inches above cables.

Fireproofing Cables

Different types of fireproofing materials are on the market. Be sure that the type used has been formally approved beforehand and that the application is in accordance with the manufacturer's recommendations.

Medium-voltage cables and conductors in manholes must be fireproofed for their entire length within a manhole on an individual cable basis. Asbestos materials are not acceptable.

Tape Method

Fireproofing must be at least 2 inches wide. To apply fireproofing tape, flexible, conformable polymeric elastomer fireproof tape shall be wrapped tightly around each cable spirally in one-half lapped wrapping or in two butt-jointed wrappings, with the second wrapping covering the joints of the first.

Sprayable Method

The manufacturer must certify that cable coatings are seismically qualified in accordance with IEEE Standard 344. When coatings are applied on bundled cables, they must have a derating factor of less than 5%, and a dielectric strength of 95 volts per mil minimum after curing.

Ground Rods

In each electric manhole, at a convenient point close to the wall, a ground rod must be driven into the earth before the floor is poured so that approximately 4 inches of the ground rod extends above the manhole floor.

When precast concrete manholes are used, the top of the ground rod may be below the floor and a No. 1/0 AWG tinned ground conductor brought into the manhole through a watertight sleeve in the manhole wall.

10.3 INTERIOR ELECTRICAL, INCLUDING GROUNDING

A. Supplementary Publications

Contract plans and specifications are the basis of the electrical system documentation. However, there are many supplemental publications that set minimum standards for the quality of electrical equipment, materials, and construction. These publications are made a part of the contract by direct reference in the "Interior Electrical" contract specifications. The most important of these for interior electrical work is the National Electrical Code (NEC).

The National Electrical Code, NFPA 70, is sponsored by the National Fire Protection Association and has been adopted by the American National Standards Institute (ANSI). It is made a part of the contract by specific reference in the "General: Rules" paragraph, which contains guidelines for the basic minimum requirements of safe electrical installation. It does not necessarily provide for the most efficient, convenient, or adequate installation for good service, nor does it allow for future expansion. Therefore, the contract specifications or plans may, and often do, include requirements beyond those found in the NEC. In case of a discrepancy, the specifications and plans govern. In no case shall the installation be less than that required by the NEC.

> Certain industrial specifications and standards are also made a part of the contract by specific reference in the "Materials and Equipment" paragraph and other paragraphs of the "Interior Electrical" contract specifications. It is important that quality assurance personnel have ready access to the publications that are mentioned in the specifications of the contract. These contain requirements that are not found elsewhere.

B. Materials

As soon as any material or equipment is received at the jobsite, it should be checked against the specifications and the approved shop drawings. The earlier a discrepancy is found, the less delay in contract completion. Place particular emphasis on getting complete and adequate wiring diagrams for all electrical equipment and electrically-driven or controlled mechanical equipment well before the equipment installation begins.

When approved shop drawings are received, check dimensions of equipment to be sure that there is adequate space, including clearances, in equipment installation areas. Obtain layout drawings from the prime contractor showing locations of all equipment in utility and equipment rooms prior to any installation in these rooms. This is required under the "Special Provisions" section of the specifications.

Look for the Underwriters' Laboratory "UL" label on electrical material. If the "UL" label is not present, the contractor must submit a statement from a nationally recognized testing agency in accordance with the contract specification paragraph on "Approval of Materials." A manufacturer's statement indicating complete compliance with the applicable standard is acceptable.

Major items of electrical equipment and major components must be permanently marked with an identification name to identify the equipment by type or function and specific unit number as indicated.

Unless otherwise specified, all identification nameplates must be made of laminated plastic, with black outer layers and a white core. Edges shall be chamfered. The equipment manufacturer's standard embossed nameplate material with black paint-filled letters may be furnished in lieu of laminated plastic. The following equipment, as a minimum, must be provided with identification nameplates:

Panelboards Starters
Safety Switches
Motor Control Centers
Transformers Equipment
Enclosures Switchgear
Switchboards

Control Power Transformers Instrument
Transformers Control Devices

Conductors in cables must be annealed copper, except that AA-8000 series aluminum conductors may be used as an equivalent for copper conductors of No. 6 AWG or larger. Intermixing of copper and aluminum conductors in these sizes is not permitted.

C. Storage and Workmanship

Insist on clean, dry storage of electrical material. Equipment must be protected from mechanical damage, dust, dirt, moisture, oil, and corrosive atmospheres. Make sure the contractor properly protects the material and equipment from the time it is received on the job until is has been turned over to the customer.

All materials and equipment must be installed in accordance with the recommendations of the manufacturer, as approved by the contracting officer, to conform with the contract documents. The installation should be accomplished by workers skilled in interior electrical work. Insist on proper planning by the electrical foreman. Prior planning is essential for good installation. Electric equipment must be installed in a "neat and workmanlike" manner. This requirement for neat and workmanlike installations has appeared in the NEC as currently worded for over half a century. It stands as a basis for pride in one's work and has emphasized the training of apprentice electricians for many years.

Many Code conflicts or violations have been cited by the authority having jurisdiction based on the authority's interpretation of neat and workmanlike manner. Many electrical inspection authorities use their own experience or precedents in their local areas, as the basis for their judgments. Any ruling, however, should be based on uniformity as intended by the National Electrical Code Committee.

Examples of installations that do not qualify as neat and workmanlike are exposed runs of cables or raceways that are improperly supported, that is, sagging between supports or the use of improper support methods; field-bent and kinked, flattened, or poorly measured raceways; or cabinets, cutout boxes, and enclosures that are not plumb or that are not properly secured.

Unused openings in boxes, raceways, auxiliary gutters, cabinets, equipment cases or housings must be effectively closed to afford protection substantially equivalent to the wall of the equipment.

Electric equipment must be firmly secured to the surface on which it is mounted. Wooden plugs driven into holes in masonry, concrete, plaster, or similar materials cannot be used. Electrical equipment that depends upon the natural circulation of air and convection principles for cooling of exposed surfaces must be installed so that room air flow over such surfaces is not prevented by walls or by adjacent installed equipment. Clearance between top surfaces and adjacent surfaces of floor-mounted equipment must be provided to dissipate rising warm air.

Electrical equipment provided with ventilating openings must be installed so that walls or other obstructions do not prevent the free circulation of air through the equipment. For example, a ventilated busway must be located where there are no walls or other objects that might interfere with the natural circulation of air and convection principles for cooling.

Some types of equipment, such as panelboards and transformers, are adversely affected if enclosure surfaces normally exposed to room air are covered or tightly enclosed. Ventilating openings in equipment are provided to allow the circulation of room air around internal components of the equipment; the blocking of such openings can cause dangerous overheating.

Because of different characteristics of copper and aluminum, devices such as pressure terminal or pressure splicing connectors and soldering lugs must be identified for the material of the conductor and be properly installed and used. Conductors of dissimilar metals must not be intermixed in a terminal or splicing connector where physical contact occurs between dissimilar conductor (such as copper and aluminum, copper and copper-clad aluminum, or aluminum and copper-clad aluminum), unless the device is identified for the purpose and conditions of use.

Materials such as solder, fluxes, inhibitors, and compounds, where employed, must be suitable for the specific use and be of a type that will not adversely affect the conductors, installation, or equipment.

Many terminations and equipment are marked with a tightening torque. This will require the installer to use a torque wrench or torque screwdriver.

Sufficient access and working space must be provided and maintained around all electrical equipment to permit ready and safe operation and maintenance of such equipment. Except as required or permitted in the NEC, the dimension of the working space in the direction of access to live parts operating at 600 volts, nominal or less to ground, and likely to require examination, adjustment, servicing, or maintenance while energized, should not be less than indicated in Table 110-16(a). Distances are measured from the live parts if they are exposed or from the enclosure front or opening if they are enclosed. Concrete, brick, or tile walls are considered as grounded.

In addition to the dimensions shown in Table 110-16(a), the work space should not be less than 30 inches (762 mm) wide in front of the electric equipment. In all cases the work space must permit at least a 90 degree opening of equipment doors or hinged panels.

Note that the 30 inch wide dimension is intended to be clear all the way to the floor. These requirements apply to equipment that is likely to require examination, adjustment, servicing, or maintenance. Examples of such equipment include panelboards, switches, circuit breakers, controllers, and controls on heating and air conditioning equipment. The equipment must not be installed so close to walls, etc., that the equipment door or hinged panel cannot open at least 90 degrees. Where the doors or hinged panels are wider than 36 inches, more than a 36 inch wide space will be needed.

The minimum working clearances of Section 110-16(a) are not required if the equipment is such that it is not likely to require examination, adjustment, servicing, or maintenance while energized. Such conditions are as follows:

(1) Where exposed live parts are on one side and no live or grounded parts on the other side of the working space, or where exposed live parts on both sides are effectively guarded by suitable wood or other insulating materials. Insulated wire or insulated busbars operating at 300 volts or less are not considered live parts.

(2) Where exposed live parts are on one side and grounded parts are on the other side.