AIR FORCE TACTICS, TECHNIQUES, AND PROCEDURES 3-32.33 VOLUME 3

26 September 2023

EXPEDIENT STRUCTURAL AND UTILITIES REPAIR

DEPARTMENT OF THE AIR FORCE

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BY ORDER OF THE SECRETARY OF THE AIR FORCE

AIR FORCE TACTICS, TECHNIQUES, AND PROCEDURES 3-32.33V3

26 September 2023

Tactical Doctrine

EXPEDIENT STRUCTURAL AND UTILITIES REPAIR

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RELEASABILITY: There are no releasability restrictions on this publication.

OPR: AF/A4CX

Certified by: AF/A4C (Brig Gen Brian S. Hartless)

Pages: 269

This Air Force Tactics, Techniques, and Procedures (AFTTP) describe expedient repair concepts and methods employed by Civil Engineer (CE) personnel in support of Air Force Instruction (AFI) 10-210, *Prime Base Engineer Emergency Force (BEEF) Program*, and AFI 10-209, *RED HORSE Program*. It previews basic ideas, options, and procedures for accomplishing expedient repairs to damaged structures and utility systems during contingency operations when standard equipment and materials are not available or when necessary for minimum-essential restoration of base facilities and services. This publication applies to all DAF civilian employees and uniformed members of the Regular Air Force, the Air Force Reserve, and the Air National Guard. This publication does not apply to the United States Space Force. Refer recommended changes and questions about this publication to the Office of Primary Responsibility using the Department of the Air Force (DAF) Form 847, *Recommendation for Change of Publication*; route DAF Forms 847 from the field through the appropriate functional chain of command and Major Command publications/forms managers. Ensure all records generated as a result of processes prescribed in this publication adhere to Air Force Instruction 33-322, *Records Management and Information Governance Program*, and are disposed in accordance with the Air Force Records Disposition Schedule, which is located in the Air Force Records Information

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APPLICATION: This AFTTP is nondirective and does not replace technical orders and manuals, or other applicable mandatory procedures or instructions. Personnel should adhere to applicable technical, safety, and policy requirements when performing tasks addressed in this publication.

SCOPE: For this document, "expedient" is considered as "a means devised or employed in a time and place where prompt action is essential." During contingencies, expedient repairs may be a consideration for minimum-essential restoration of base facilities and services. Normal engineer repair practices should be used when time, materials, and conditions allow.

Chapter 1

INTRODUCTION

1.1. Overview. Air Force civil engineers often make expedient repairs to base facilities and infrastructure damaged from the effects of natural disasters, major accidents, or hostile acts. The goal of expedient repairs is to sustain or ensure continued mission operations, prevent significant additional damage to facilities and infrastructure, and protect the safety and security of the installation, mission, or personnel. Expedient repairs should be improved as time and supplies permit. This AFTTP provides examples of expedient repair methods for structures and utility systems when immediate action is necessary and standard resources are unavailable. While mostly applicable during wartime and overseas contingency operations, some procedures may be options during disaster recovery and humanitarian assistance operations. The material applications and expedient repair methods illustrated herein are compiled from multiple sources, including data from Department of Defense (DOD), Joint, and Service publications as well as Best Practices and Lessons Learned from AF Civil Engineers and the US Army Corps of Engineers (USACE). Any data and procedures presented are general in nature and does not constitute mandatory guidance. Personnel should adhere to directive AF guidance for related equipment, systems, and procedures.

1.2. Environmental Considerations. The Department of the Air Force (DAF) is committed to maintaining environmental quality to ensure long-term access to the air, land, and water needed to protect United States interests abroad. Although a high level of environmental quality can be difficult to achieve during contingency operations overseas, the health and safety of personnel are critical in any military operation. Safe food, water, air, and a means of properly disposing of waste is essential. The intention of environmental goals during contingencies is to minimize risks to human health and safety and prevent unnecessary damage to the environment while maximizing the natural resources available to support readiness and operational effectiveness. Further information on integrating environmentally responsible practices during contingency operations is located in Department of Defense Instruction 4715.22, *Environmental Management Policy* *for Contingency Locations*, and Air Force Handbook 10-222V4, *Environmental Considerations for Overseas Contingency Operations*.

1.3. General Safety Practices. During CE expedient construction or repairs, it is important to be both flexible and safe, especially if employing nonstandard methods and materials. You should not compromise safety, because it could result in personnel injuries or disabled equipment, and negatively affect the mission. Below are some general safety considerations for CE construction and repair activities. See detail safety procedures and requirements in subsequent chapters.

1.3.1. Construction and repair work often involves activities that are hazardous to personnel. Workers and supervisors should be vigilant; adhere to technical data warnings and cautions and wear protective clothing and equipment in accordance with safety information and standards.

1.3.2. Crew leaders should know assigned personnel's capabilities and limitations and monitor all work efforts accordingly. In addition, ensure activities are coordinated with all involved. For example, debris removal from inside and around facilities can be a dangerous task and vibrations from heavy equipment can cause a building to collapse on recovery workers. Not only should all worksite personnel be cognizant of this hazard, but they should also be aware and able to recognize other potential safety hazards associated with the job.

1.3.3. A key responsibility of supervisors is to ensure personnel have and wear the necessary personal protective equipment (PPE) and individual protective equipment (IPE) for the working environment. Make wear of PPE a routine practice for hazards such as dust and noise, and when handling sharp objects and construction materials. When working in a contaminated environment, be sure to wear the appropriate IPE for the hazard present. In addition, wash contaminated clothing and take a shower as soon as possible after working in a contaminated environment. Additionally, it is important to protect workers from hazards such as high-pressure subsystems and components, harmful solvents and adhesives, and infectious black and gray water products from wastewater systems. **Note:** Black water refers to latrine wastewater containing human waste. Gray water refers to wastewater from non-latrine sources such as showers, laundries, kitchen operations, and handwashing devices.

1.3.3.1. Department of the Air Force Manual (DAFMAN) 91-203, *Air Force Occupational Safety, Fire, and Health Standards*, lists PPE for selected CE activities. Although technical orders (T.O.) and other job-related publications address proper wear and use of PPE and IPE (for Chemical, Biological, Radiological, and Nuclear (CBRN) defense), workers have the ultimate responsibility to properly use, inspect, and care for protective equipment assigned to them. Be sure to contact Bioenvironmental Engineering (BE) and/or Occupational Safety personnel for assistance in selecting the appropriate PPE. **Note:** Non-disposable respirators shall not be worn unless the individual has been properly fit-tested by BE personnel.

1.3.3.2. Workers should adhere to NFPA 70, Article 250 of Grounding and bonding of electrical systems, for dangerous voltages and to the IEEE Green book for information above that is discussed in NFPA 70. PPE that provides appropriate arc flash protection is required for all personnel working on or near exposed energized electrical equipment operating at 50 volts or more. Unified Facilities Criteria (UFC) 3-560-01, *O&M: Electrical Safety* and National Fire Protection Association (NFPA) 70E, *Standard for Electric Safety in the Workplace*, address tasks that require Arc Flash PPE.

1.3.4. Every job or operation has its own safety hazards, and everyone involved must follow proper safety procedures to prevent injury or illness. This is extra critical during force beddown at austere locations and base recovery activities. Exposure to construction, power production, and heavy equipment, fuel and mechanical systems, and water or wastewater systems makes for an assortment of job related hazards—remain vigilant to stay safe.

1.4. Managing and Documenting Expedient Repairs. Equally critical to rapidly responding to contingency work requirements is the need to establish appropriate record keeping practices at the very beginning of the recovery efforts. Depending on the nature of the event, the installation may need to provide recovery cost details to higher headquarters. Aggregate costs may be useful to define and defend external installation reimbursement to aid in defraying the overall costs to the Base Civil Engineer (BCE).

1.4.1. Reporting Tools: Installations need to be aware of and use the following tools as appropriate:

1.4.1.1. Storm Damage Tracker: Installations should coordinate with their major command or Air Force Installation and Mission Support Center Detachment to determine if the IMSC O&M (3400/3410 appropriation only) Storm Damage Tracker tool should be used. Details at: **https://usaf.dps.mil/teams/10041/dashboards/pages/storm%20tracker%20dashboard.aspx**. Site also contains a standard operating procedure guide and excel template.

1.4.1.2. Utility System Operational Report Tracker (USORT): Log utility system outages into the USORT tool at: **https://usaf.dps.mil/sites/CE-DASH-Tools/USORT/Module/Home.aspx**. Site also contains a USORT user guide.

1.4.2. NexGen IT Management Conventions. AFCEC/COOM SharePoint Business Process Library (BPL) contains guidance on how to account for various situations. Details at: **https://usaf.dps.mil/sites/11252/24048/CO%20Support%20TRIRIGA%20Deploy/TRIRIGA%20Ops%20Wiki/Home.aspx**. Below are some of the common practices:

1.4.2.1. Event driven facility operations facility project (FOFP). The FOFP is an efficient way to bundle all recovery efforts under a single project that automatically rolls up total cost of effort. Details at: **https://usaf.dps.mil/sites/11252/24048/CO%20Support%20TRIRIGA%20Deploy/TRIRIGA%20Ops%20Wiki/Facility%20Operations%20Facility%20Projects%20(FOFPs).aspx**

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1.4.2.2. Off-base events. NexGen IT requires special attention to record keeping for non-USAF/USSF real property locations. Details at: **https://usaf.dps.mil/sitehttps://usaf.dps.mil/sites/11252/24048/CO%20Support%20TRIRIGA%20Deploy/TRIRIGA%20Ops%20Wiki/Pseudo%20Real%20Property%20Records.aspx**.

1.4.2.3. Work Resolution Descriptions. Guidance on how to log USORT or maintenance/outage reporting codes is available at: **https://usaf.dps.mil/sites/11252/24048/CO%20Support%20TRIRIGA%20Deploy/TRIRIGA%20Ops%20Wiki/Resolution%20Description.aspx**.

1.5. Additional Information. See **Attachment 1** for a list of references and supporting information. In addition, contact the Air Force Civil Engineer Center (AFCEC) Reach-Back Center when looking for information not found in this publication or attached references. Contact the Reach-Back Center at 1-888-232-3721 (toll free), 1-850-283-6995 (commercial), DSN 312-523-6995, or email at **AFCEC.RBC@us.af.mil**.

Chapter 2

STRUCTURAL REPAIR CONSIDERATIONS, AREA SAFETY, AND DEBRIS CLEARING

2.1. Structural Repair Considerations. After an attack, disaster, or other base emergency, expedient structural repairs may be necessary to mitigate damages and allow continuation of important base functions. Structural engineers should examine facilities with damaged structural components or that show signs of possible structural failure to determine feasibility of repair and proper repair methods. If a facility is determined to be beyond repair, consider its potential as a source of material for expedient roof patching, confining walls, and shoring for other repairable structures. If electing to perform structural repairs, consider issues related to safety, expediency, mission, practicality, and flexibility.

2.1.1. Safety. War and contingency environments are hazardous enough without endangering personnel through unsafe acts during repair activities. For example, weakened structures; live electrical wires down; explosive gas vapors, chemical, or biological contamination; or unexploded ordnance littering the installation are hazards that may exist. Additionally, base medical facilities may be crowded with casualties, and the CE workforce may likely be at critical levels. These conditions make it essential not to further strain limited resources with injuries resulting from neglect of safety procedures. Consider steps to calm or moderate enthusiasm for getting the job done with a prudent assessment of the risks confronted. Take the time to make a preliminary survey of any suspect structures before repairs are attempted. Especially, when CE personnel are providing assistance to off-base civilian agencies during a major disaster, because they could encounter various structures and hazards uncommon to the installation environment.

2.1.2. Expediency. CE recovery efforts immediately following an incident should be limited to minimum-essential repair of crucial facilities. Work performed should concentrate on structural integrity, mitigation/safety, then functional rather than cosmetic repairs. Focus structural repair efforts toward making a facility safe for occupancy and providing minimal protection from the elements to persons using the facility.

2.1.3. Mission. Predetermined facility priority lists establish repair priority of facilities to the overall base mission. In the absence of a priority list, damaged facilities accommodating activities that are not essential to the assigned mission and do not present a hazard should be left as they are until time and resources permit conventional repairs.

2.1.4. Practicality. Consider other related repair activities affecting the facility. For example, if the facility provides service to aircraft and access pavements are so severely damaged that they are not usable for days, then structural repairs can usually wait. Similarly, if supporting utility systems to a facility are far beyond emergency repair, consider delaying the structural portion of the repair effort. On the other hand, lack of full utility service does not mean a building will be useless. A facility with partial utility service, e.g., electricity but no water can usually continue functioning for its wartime purpose. The CE unit control center (UCC) will have to make real-time decisions as to the practicality of repairs.

2.1.5. Flexibility. Flexibility is essential to any expedient repair effort—including ones of a structural nature. During wartime, expect repair priorities to change; engineer efforts should adjust accordingly. As might be expected, no two attacks on the base will be identical; therefore, no structural repair tasks will be identical. Even during peacetime contingencies, engineer forces should not be locked into an unyielding standard set of facility priorities or spend a lot of time on minor repairs to the detriment of other more pressing requirements. For example:

2.1.5.1. Emergency repairs to a power generating plant may prove more important at some point in time than minor repairs to either an installation command and control (C2) center or other normally high-priority facility.

2.1.5.2. There may be some facilities damaged beyond the unit's expedient repair capabilities. If such a facility is vital to the base mission, consider converting another facility to meet the uninhabitable facility's role. Using an understanding of the function of the destroyed structure, engineers can evaluate potential alternate facilities in terms of size, utilities support, and other special functional requirements.

2.1.5.3. Base Civil Engineers (BCE) consider two main factors, among others, when selecting or recommending facilities for conversion: First, what other structures on the base come closest to satisfying requirements for an alternate facility? Second, how much work will be required to convert the facility for its intended use? If there are no special concerns, the structure meeting the functional requirements and taking the least amount of time to convert may be the best option.

2.2. Area Clearing and Safety Practices. Area clearing and safety are important considerations before performing expedient repairs following an emergency. Whether on base or off base, some hazards may not be identified or quickly cleared after an incident. Problems could arise when setting up for emergency repairs even after first responders have been through the facilities. As addressed below, some of the hazards you could encounter include unexploded ordnance, downed electrical wires, broken gas lines, and loose hazardous materials (airborne, liquid, or solid); biological hazards; animals and insects; and asbestos and lead contamination. Consider these and other potential health and safety problems before accomplishing repairs.

2.2.1. Unexploded Ordnance (UXO). After a wartime or terrorist attack, or during humanitarian assistance efforts, UXOs can be a problem for engineers recovering facilities and utilities. In a war zone, sometimes weapons used against facilities may not all detonate. During floods, currents can move UXOs and hide them under debris. Both situations can create significant hazards.

2.2.2. Biological Hazards and Disease-Causing Contaminants. Biological hazards and disease-causing contaminants can be a problem after an attack or natural disaster. Whether accidental or deliberate release and dissemination, they could have adverse effects on human, plant, or animal health. These hazards include medical wastes, microorganisms, viruses, or toxins (from a biological source). Natural biological hazards and hazardous wastes can also be problems for engineers conducting emergency repairs after floods, hurricanes, and other natural disasters. Debris and floodwaters may expose rotting animal carcasses and sewage (blackwater) that contain pathogenic microbes, viruses, bacteria, and fungi. Some buildings affected by conventional attacks, hurricanes, or contaminated floodwaters have walls, insulation, floors, and ventilation systems that can become breeding grounds for biologic pathogens. Building materials can exhibit a wicking effect that draws water into and up the walls—as much as three feet above the water line. Even if workers avoid becoming contaminated while repairing the facility, occupants working in the buildings afterwards may quickly become seriously ill as the pathogens (disease-producing microorganisms) grow and become airborne. Drying building materials to less than 30 percent moisture will inhibit spore growth. If time is available, make sure that the work area and critical facilities are free of contaminants, even if it requires ripping out wallboard, floor covering, and insulation. Consider hosing off impermeable surface contaminants with clean water or disinfectant at the work site.

2.2.3. Structural Damage. As emergency repairs are underway, efforts may halt if the building incurs additional consequential structural damage by wind and water after the initial onslaught. When sheetrock becomes wet, it loses strength and becomes heavier. The additional weight and loss of strength can cause further damage or collapse. If repair delays occur, provide temporary protection and early cleanup to avoid additional damage. Shoring procedures may also be necessary, if so, see subsequent chapters for structural shoring and bracing information.

2.2.4. Electrical Hazards. Electrical lines can be a potential problem following bomb damage, hurricanes, tornados, or floods. Overhead electrical lines are vulnerable and easily knocked down. They can be especially hard to see at night and others may not have made the wires safe. Damaged underground electrical lines can charge soil, standing water, and be difficult to find. A generator powering a nearby work site can send power through damaged electrical systems and reenergize wires at the work site. When working in this type of environment, watch for loose wires and ensure main power panels are off before entering a building for emergency repair, especially when working on metal roofs or metal structures near damaged electrical lines.

2.2.5. Gaseous Hazards. Leaking or ruptured gas tanks and lines are serious hazards with a potential for explosions and fires. Winds and flooding can carry away compressed gas tanks or drums containing chemicals from damaged facilities. As the floodwaters and wind move the containers about, they can easily penetrate building walls. Be alert for leaking gas from tanks or ruptured utility lines and pay particular attention to smells when around buildings. An extremely offensive, garlicky odor is usually associated with mercaptans (a class of sulfur-containing compounds) added to natural or bottled gas. Even moderate damage can turn deadly when leaking gas is involved. A weak chlorine odor may indicate arcing electrical wires. **Note:** Some gas hazards can be extremely dangerous but do not have a smell.

2.2.6. Flammable or Combustible Liquid Hazards. Hazards related to flammable and combustible liquids include explosions, burns from fire, chemical burns, asphyxiation, inhalation of vapors, absorption through the skin, skin irritation, and eye damage from direct contact or exposure. After an airfield attack or natural disaster, response, cleanup, or construction crews could be exposed to flammable or combustible liquids from leaking containers or ruptured storage systems and distribution lines. Common examples of flammable and combustible liquids are gasoline, acetone, lacquer thinner, kerosene, fuel oil, mineral spirits, etc. The volatility of flammable or combustible liquids is increased by heat, and when heated to temperatures higher than their flashpoints they present a greater hazard. In addition, some flammable and combustible liquids are highly reactive with other substances, subject to explosive decomposition, or may have other properties that dictate extra safeguards. Consult your local ground safety and (or) BE or fire protection staff when in doubt. For spills and leaks, follow local spill and containment control protocols. Spills of flammable or combustible liquids should be cleaned up promptly. With major spills, remove ignition sources, evacuate, and ventilate the area, and provide appropriate PPE to the cleanup crew. Flammable or combustible liquids should not be allowed to enter a confined space, such as a sewer, because of the possibility of an explosion.

2.2.7. Fugitive Dust Hazards. The Environmental Protection Agency (EPA) refers to fugitive dust as “particulate matter that enters the air without first passing through a stack or duct designed to direct or control its flow.” Several CE operations that generate fugitive dust sources include roadway/airfield paving and patching, asphalt and concrete batch plant, earthmoving, mining and quarries, hauling and trucking, explosive demolition, and building construction. Fugitive dust from these operations could cause both respiratory issues (especially to sensitive individuals) and visual impairment issues. In addition to wearing PPE when practicable, consider consulting your local ground safety and BE offices for methods to control or mitigate the effects of fugitive dust hazards. For other mitigation options consider reviewing the EPA summary document on fugitive dust at https://www.epa.gov/system/files/documents/2022-02/fugitive-dust-control-best-practices.pdf.

2.2.8. Animal and Insect Hazards. Live animals and insects can be just as dangerous as the effects of dead animals during floods. Animals, reptiles, and insects often take refuge in damaged buildings. Snakes and venomous insects can be especially problematic in coastal areas affected by floods and hurricanes.

2.2.9. Asbestos and Lead Hazards. Exposure to asbestos, lead fibers, and lead dust can be a problem, especially when an explosion or windstorm has damaged the work area. Flying debris or blast waves can expose enclosed areas of buildings where previously concealed and brittle asbestos reside. Formerly encapsulated asbestos shingles, wallboard, plaster, insulation, or stucco can fracture and disperse asbestos fibers. Base control and removal efforts may limit exposure to asbestos on the installation, but off-base facilities may present serious exposure problems. Workers should immediately notify BE if asbestos or lead hazards are suspected or confirmed. If confirmed, BE can provide specific respiratory protection and protective clothing requirements. At locations or job sites where BE nor occupational or environmental health personnel are readily available, supervisors should contact the supporting medical facility or the next higher headquarters for assistance and guidance.

2.3. Debris Clearing. When clearing debris from work areas and facilities, provide enough room around the facility for access by high-reach trucks, cranes, ladders, or for required scaffolding during the repair. Remove or completely isolate utility and communication lines (i.e., telephone and fiber optic) from the work area. Hot power lines may contact and energize wires, cable, metal fences, pipes, and roofs causing electrocution. At times, it is safer to remove damaged building parts when it is extremely dangerous to repair the component. This is often the case with heavy hangar doors when dislodged from their tracks after an explosion or windstorm. Doors of this type normally require special equipment and training to allow recovery or repair. Large doors or smaller hangar door sections may be valuable as temporary replacement wall sections if equipment is available to move them safely. Always clear out hazardous materials and debris, especially wet debris. If workers cannot make immediate repairs to walls and roofs using plywood, protect the area with tarps and/or plastic sheeting. Keep in mind that little adjustments can make the job much more manageable.

2.3.1. Debris Removal Priorities. The priorities for debris removal will vary depending on base mission and type of disaster. The Emergency Operations Center (EOC), Incident Commander, and CE UCC assigns debris removal priorities. In the instance where damage is limited to a military complex, debris removal personnel should expect the EOC to assign the highest priorities to those areas most critical to the mission.

2.3.2. Debris Removal Resources. As might be anticipated, the type of equipment required to clear an area depends on the size and amount of debris. For example, large pieces of wreckage will necessitate the use of heavy equipment such as loaders and cranes (**Figure 2.1**). These and other heavy equipment can be effective in debris clearance operations. If equipment is scarce, consider using hand tools to clear areas with large amounts of smaller-sized debris.

Figure 2.1. Debris Removal Using Heavy Equipment.

2.3.2.1. Crane. For removing extremely large chunks of debris, a crane may be the only suitable piece of equipment. A crane can clear destruction on upper floors of a structure beyond the reach of an excavator or front-end loader. **Note:** Cranes may not be available at some locations.

2.3.2.2. Bulldozer. A bulldozer has the power to push large pieces of debris out of an area and can quickly clear large areas of smaller debris. One skilled dozer operator can clear an area that would require several hours of labor if done by hand. However, bulldozers may be in short supply if runway repair is required.

2.3.2.3. Front-End Loader. Front-end loaders are especially useful in loading debris on dump trucks and other vehicles for removal from the site. They also are adequate for clearing paved areas and streets of large amounts of small debris.

2.3.2.4. Dump Truck. Dump trucks haul debris to disposal sites; however, after an attack, they may be essential during airfield damage repair, and only be available in limited numbers for debris removal. If necessary, consider using other suitable vehicles, such as cargo trucks and tractor-trailer units, to haul debris.

2.3.2.5. Sweepers. After removing the larger debris, use street sweepers to clear smaller items from aircraft operating surfaces and primary access streets. If sweepers are not used, small metal items left on roadways and working areas can cause tire damage to equipment used in cleanup operations. Time spent repairing and replacing flat tires on these vehicles can delay the overall recovery effort.

2.3.2.6. Towing Devices. Steel cable, chains, hooks, and similar items can be fashioned into towing devices for debris removal.

2.3.2.7. Hand Tools. Various hand tools are useful in debris clearance. Workers can use chainsaws and axes to cut fallen trees into smaller sections for easier removal. Shovels are useful in loading smaller debris on vehicles for transport to a disposal site. Use brooms and rakes to clear surface areas of scattered debris.

2.3.2.8. Manpower. The amount of labor required to clear an area of debris will depend upon the availability of the laborsaving equipment discussed in the previous paragraphs. If mechanical equipment is available, the unit will need fewer workers for cleanup. However, personnel assigned to cleanup detail must be skilled in operating the equipment. Less equipment means a greater number of persons required, but their skill levels need not be as high.

2.3.2.9. During recovery operations on a military installation, likely, the EOC will task other installation agencies, whose attack recovery missions may not be critical to aircraft generation, to supply augmentees for debris removal efforts. In such instances, CE personnel will have to supervise these individuals during debris removal activities and provide them with necessary tools and protective gear. These augmentees may not be cognizant of the dangers involved with debris removal nor be trained in explosive ordnance reconnaissance; therefore, consider these limitations when assigning their tasks.

2.3.3. Debris Removal Operations. Available equipment and labor usually dictate the extent of debris removal. Immediately following a disaster or enemy attack, the EOC or Incident Commander makes decisions regarding how debris removal operations should proceed. Often, debris remains in nonessential areas until additional resources become available, unless it hampers recovery operations or presents a safety hazard. Personnel should be assigned debris clearance tasks and allocated required equipment on a priority basis.

2.3.3.1. Preparations. This step consists of establishing debris removal crews, positioning equipment for removal activities, attaching cables and other devices to large pieces of debris, breaking or cutting up larger debris pieces for ease of removal, and similar actions. Any debris salvageable for recovery operations should be set aside.

2.3.3.2. Removal and Disposal. Under certain circumstances, operators may bury the debris by pushing it into craters or prepared holes. When not burying the debris or otherwise disposing of it at the scene of destruction, move it to a central location where it can be loaded into dump trucks or other vehicles for transport to a remote location for burial or burning. Consult the local installation management flight before establishing any landfill or debris-burning operation.

Chapter 3

STRUCTURAL SHORING

3.1. Introduction. Immediately after an attack or natural disaster, there may not be time to make a detailed engineering analysis on structural soundness of damaged facilities. During an emergency, structural engineers may instead rely on field experience, facility appearance, common sense, and instinct. If a facility appears beyond repair, demolition is probably in order. Conversely, when resolved to "save" a damaged facility, several expedient repair options are usually available. Once crews remove debris and assure safe access, the first concern before starting structural repairs may be to shore up and stabilize any weakened areas to restore a minimum degree of structural integrity to the facility. Most expedient shoring requires common engineering materials readily available on base or from off-base vendors. Examples include lateral shoring (guying and bracing), vertical shoring, and horizontal shoring. Stabilization of concrete columns, beams, and slabs may include the use of splinting, tension ties, welding, and stitching dogs. This section addresses these options. Some of the structural shoring construction methods illustrated in this chapter were adapted from the Department of Homeland Security (DHS), *Field Guide for Building Stabilization and Shoring Techniques*, and the U.S. Army Corps of Engineers (USACE) Structures Specialist, *Field Operations Guide*. Work crews should consult with the Engineering Flight for specific shoring design requirements and procedures when addressing structural instability of collapsed and damaged buildings.

3.2. Lateral Shoring. Damaged and collapsed buildings often contain both lateral and vertical instability. Generally, we use bracing, guying, and shoring to stabilize a facility from lateral movement, keeping it from moving side to side.

3.2.1. Guying. Guywires are usually fashioned from wire rope and tensioned by turnbuckles, if available. We commonly see guywires providing stabilizing support for power poles and tall antennas. Engineer work crews normally install them to function in opposing pairs to provide lateral restraint from such forces as wind or ice loading. They are particularly effective when damage occurs to end walls or sidewalls, yet roof members have been essentially untouched. Depending upon the situation, crews can install guywires either inside or outside a facility. The number of pairs required will depend on the situation at hand, based upon the size of the facility requiring shoring and extent of damage sustained.

3.2.1.1. Although several different wire rope fittings are available commercially, by far the most common means of attachment of guywires is the use of wire rope clips (**Figure 3.1)**. When properly installed, clips can provide up to 80 percent of the rope's strength. The size of the wire rope dictates the number of clips used and their spacing. A good rule of thumb is to use a minimum of three clips spaced about 3-3/4 inches apart for 1/2- or 5/8-inch rope, and four clips spaced 4-1/2 inches apart for 3/4- or 7/8-inch rope. These standard practices prevent kinking of the rope and fraying of the cable due to friction when connected to a turnbuckle or other attachment. Also, note how the clips attach to the rope. The bend of the U-bolt compresses the dead end of the rope, whereas the clip compresses the live end of the rope. The live end of the rope leads back to the structure the crew is guying. See **Figure 3.2** for assembly instructions.

Figure 3.1. Wire Rope and Clips.

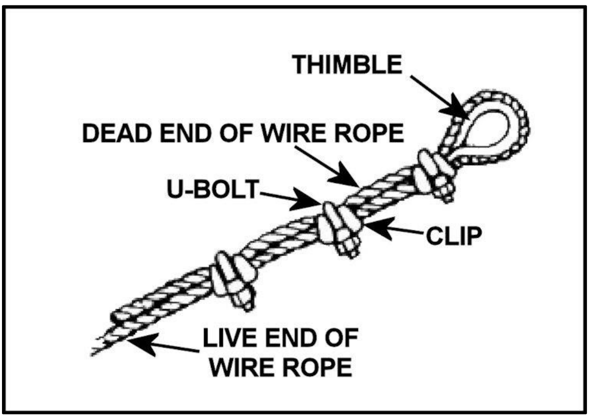
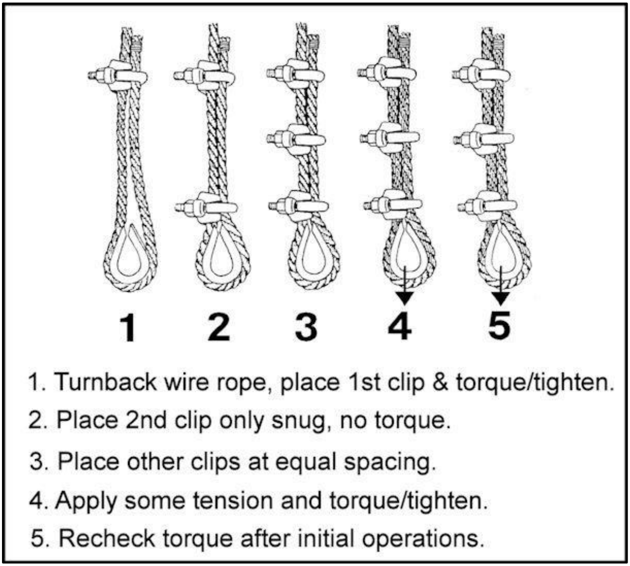
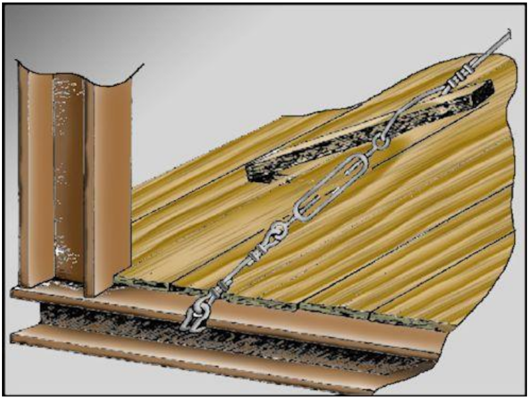


Figure 3.2. Wire Rope Clip Assembly.



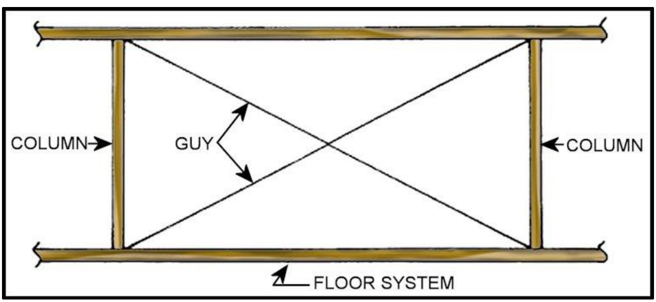
3.2.1.2. Illustrated in **Figure 3.3** is a typical guywire connection to a structure. The wire rope attaches to a turnbuckle that attaches to the building. This example shows a connection to a steel beam using a beam clip. A beam clip is merely a C-shaped connector that workers can fabricate in the shop, if necessary. Other connections to a structure are possible using eyebolts and even wrapping the rope around the structural member the workers are stabilizing. Note the use of the 2"x4" board as a brace to prevent the guywire from twisting when crews tighten the turnbuckle. If an external guywire is to be used, one end of the guywire must be connected to a solid, immovable object, commonly referred to as a "deadman." The deadman can be a nearby foundation, another part of the structure to be guyed, screw-anchors similar to what linemen use for pole guying, or even a piece of unserviceable equipment, provided it is heavy enough.

Figure 3.3. Typical Guy Wire Connection to a Structure.



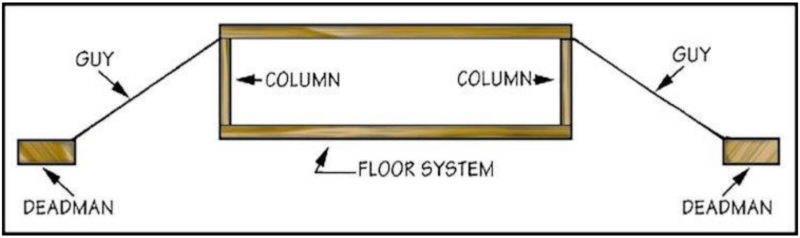
3.2.1.3. As mentioned earlier, work crews can install guywires either internally or externally. **Figure 3.4** illustrates an internal configuration. Always tighten guywires in pairs and concurrently, to avoid placing too much stress on the structure's frame at any particular point. However, use caution to prevent over tightening; the intent is to take all the sag out of the wire ropes.

Figure 3.4. Internal Guy System.



3.2.1.4. Work crews also install and configure external guywires in pairs (see **Figure 3.5**). The major difference is instead of using the structure itself as the endpoints for the guywires, external anchors or deadmen are used. The stabilization effect is essentially the same.

Figure 3.5. External Guy System.



3.2.2. Bracing. Braces are a type of lateral (diagonal) shoring with compression members usually made of structural steel and heavy timbers (**Figure 3.6**). Similar to guywires, their installation is either internally or externally. Depending upon the situation, crews can place them in opposite pairs or use them individually. Regardless of the method used, ensure brace(s) adequately connects to the structure. If not well attached, the probability that the bracing will slide out of position is great, risking further facility damage or collapse. Footings for bracing require the same attention; they must be of sufficient mass so they will not move when force is applied. Do not expect a brace that is just shoved into the ground to hold. If necessary, build an expedient footing out of rubble, heavy metal, or timber if another part of the structure's foundation or the foundation of an adjacent building is not available.

3.2.2.1. In most cases, work crews will install braces in pairs. **Figure 3.7** shows externally opposed braces. Like guywires, more than one pair of braces may be required. This will be an on-site decision, generally driven by the size of the building requiring shoring and severity of damage incurred.

Figure 3.6. Typical Brace Configuration.

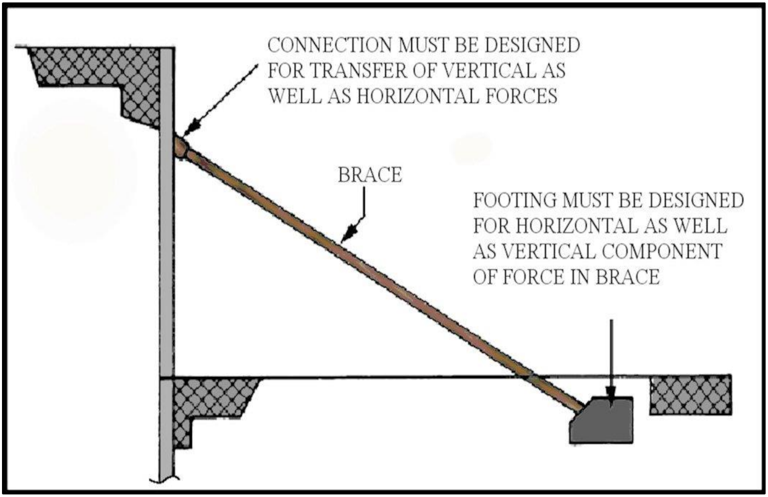
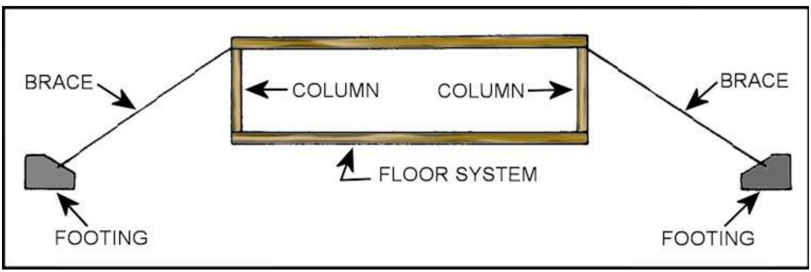
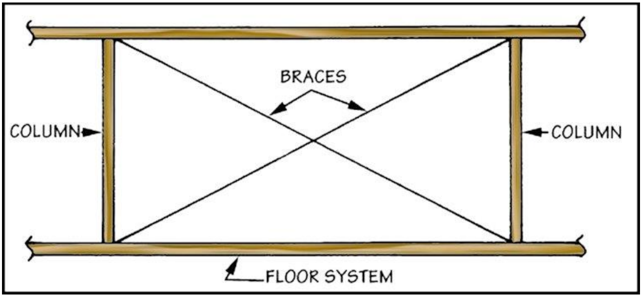


Figure 3.7. Externally Opposed Braces.



3.2.2.2. **Figure 3.8** depicts a pair of internally opposed braces. Remember; be sure the braces attach firmly to the facility to prevent slipping out of position when pressure is applied.

Figure 3.8. Internally Opposed Braces.



3.2.3. Raker Shoring. Raker shores help to stabilize leaning or damaged walls. There are three types of Raker shores (**Figure 3.9**), Flying, Solid Sole, and Split Sole. The Flying Raker is a temporary spot Raker used when a debris pile is next to the base of the wall needing shoring. The Solid Sole Raker is a “full triangle” shore and the most desirable Raker; normally built in groups of two or more. The Split Sole Raker is an option when there is a limited amount of soil or debris next to the wall (**Figure 3.10**).

Figure 3.9. Raker Shores.

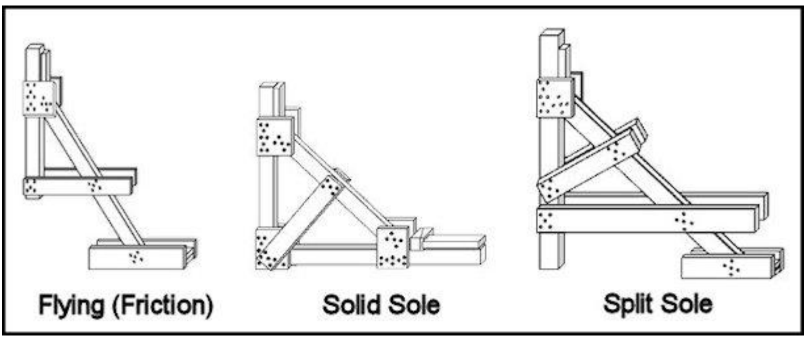


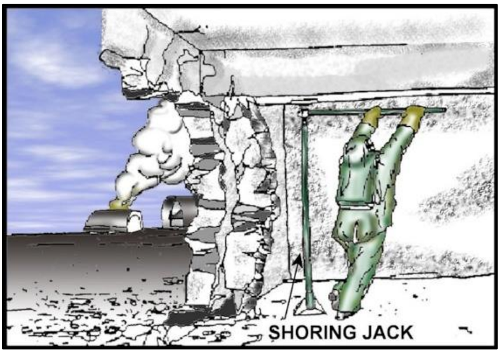
Figure 3.10. Building a Split Raker Shore.

3.3. Vertical Shoring. Sometimes, the structural integrity of a facility may be in jeopardy due to damaged structural members directly affected by vertical loads—in other words, the effects of gravity. In such situations, there may be deflected or cracked beams/girders that need vertical support, or damaged columns that will eventually need replacement. See **paragraph 4.2.2** for more information on roof shoring techniques. Shoring jacks and constructed wood shoring systems addressed below provide expedient solutions for vertical instability, however, engineers may later add some lateral bracing for stability. Basic preliminary steps for using vertical shoring may include:

- Removing debris and floor covering.
- If soil supported, using 18”x18” footing under shoring post locations.
- Installing temporary shores to reduce risk (T Spot or Double T).
- Prefabricating shoring as much as possible to reduce risk further.
- Adding bracing after tightening shoring wedges.

3.3.1. Jacks. Shoring jacks (also called shores) are placed immediately under the point of deflection, or adjacent to the damaged column, and extended until they are firmly wedged into position (**Figure 3.11**). Use base and top plates to distribute the compressive forces so as not to further deteriorate either floor or roof, which may happen if large force is placed in a small area, i.e., punching shear. Clear away any debris around the base of the jacks so the jacks remain positioned level on the facility floor. While not shown in the illustration, it is also advisable to brace the jacks once they are in position. One option to prevent accidental movement is to create bracing (using metal and lumber materials) and attached it to the jacks and floor. Use bolts, epoxy, or other fasteners to secure the bracing to the floor.

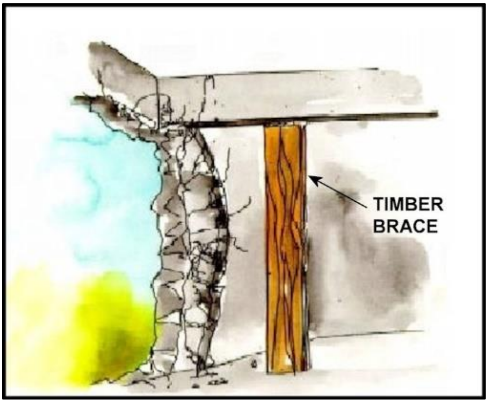
Figure 3.11. Shoring Jack Installation.



3.3.1.1. In most cases, shoring jacks will be in short supply and too valuable to leave in damaged facilities. As illustrated in **Figure 3.12**, an alternative to leaving the jacks is using timbers as supporting members. The procedures for installing timbers are similar to jacks but are somewhat more worker intensive.

3.3.1.2. Begin by clearing debris from the work area and place a shoring jack immediately adjacent to the location where the timber is going to go. Then raise the jack until it reaches the desired height or can no longer be extended. Measure the distance from the top of the jack to the floor and cut the timber 1/2-inch shorter than the measurement. Once cut, raise the timber into position and pound several wedges into the 1/2-inch gap between the top of the timber and the damaged beam; this secures the timber into position. Then lower and remove the shoring jack. The final step is to brace the timber in two directions, similar to that done earlier with nails and 2"x4" stock.

Figure 3.12. Timber Column Brace.



3.3.2. Constructed Wood Shoring Systems. Wood and timber are common options to shore damaged structural components because of their availability and economy. Work crews use a variety of elements, ranging from tree logs, sawed timbers, and utility poles, to industrially made items with different cross sections, such as planks, boards, and beams. One final note concerning the use of timbers; if heavy timbers are not readily available, consider potential options. Other facilities damaged beyond repair may contain salvageable timbers. Also, consider nailing, gluing, bolting, or banding 2"x8" or 2"x10" stock together to form usable substitutes. The focus of this section is on constructing temporary vertical shoring elements from lumber materials.

3.3.2.1. Design Basics. The strength of constructed wood systems depends on the following:

- Perpendicular to grain bearing of the Post on the Header.
- Vertical capacity of Posts (based on height or length).
- Strength of Header and Sole.
- Strength of ground or floor slab below the Sole.

3.3.2.1.1. Using 4"x4" and 6"x6" headers is desirable since this maintains a relatively stable 1 to 1 height to width ratio. This allows the use of 1-sided connections to headers. Using 4"x4" headers for 4' on center (o.c.) posts and 6"x6" headers for 5' o.c. posts is for supporting normal wood floors and intact concrete floors. For badly cracked concrete floors, and shores with larger post spacing, contact the Engineering Flight for specific design requirements.

3.3.2.1.2. Consider using backing (2"x10" or 2"x12" full length, centered on top of the header, or 8' long strips of 12" to 16" wide, 3/4" plywood) above headers if one is supporting a badly cracked concrete or masonry structure. Use backing under the sole at each post when bearing on soil. Use 3-2"x6"x18" (**Figure 3.13**) or 2-layers of 18"x18"x3/4" plywood centered under posts.

3.3.2.1.3. It is desirable to use 2-sided connections at posts to sole plates at wedges to confine the wedges. The connectors should be 6"x12" half gussets. Cut gussets from 5/8" or 3/4" plywood (or may use Oriented Strand Board [OSB], only where wet conditions will not occur).

3.3.2.1.4. Construct plywood gussets as shown in **Figure 3.14** (Full Gussets) and **Figure 3.15** (Half and Double Gussets). Use 8d nails for gusset construction. For wood or light metal floor/roof systems, consider using 1-sided connections at wedges in situations where lateral displacement of the shore is unlikely. **Note:** Displacement may result from lateral loads, vibrations, and structural shifting.

3.3.2.1.5. Construct plywood braces for plywood laced posts (PLP) as illustrated in **Figure 3.16**. Use 8d nails in each end. **Note:** Bracing between the vertical timbers is a common construction technique that increases the efficiency of the timber shoring by limiting lateral movement and reducing the potential for buckling under any increases in load.

Figure 3.13. Post to Sole Drawing with 2-Sided Connectors.

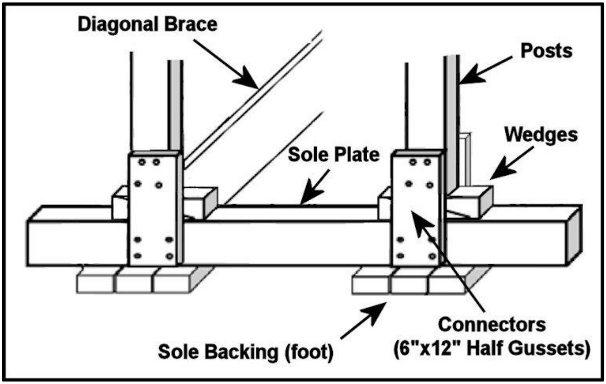


Figure 3.14. Full Gusset.

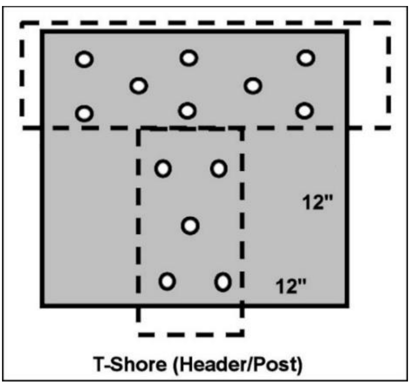


Figure 3.15. Half and Double Gussets.

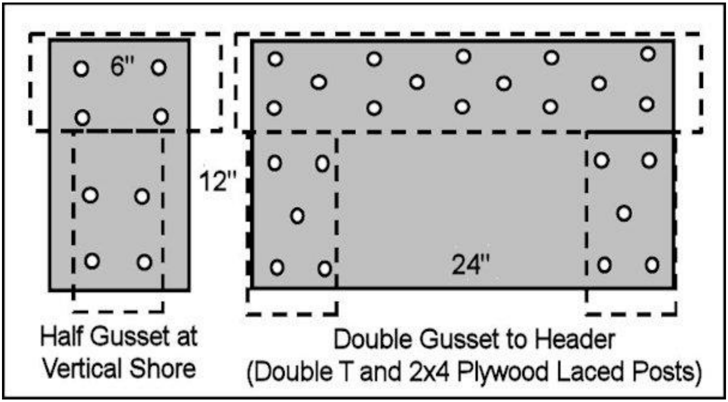
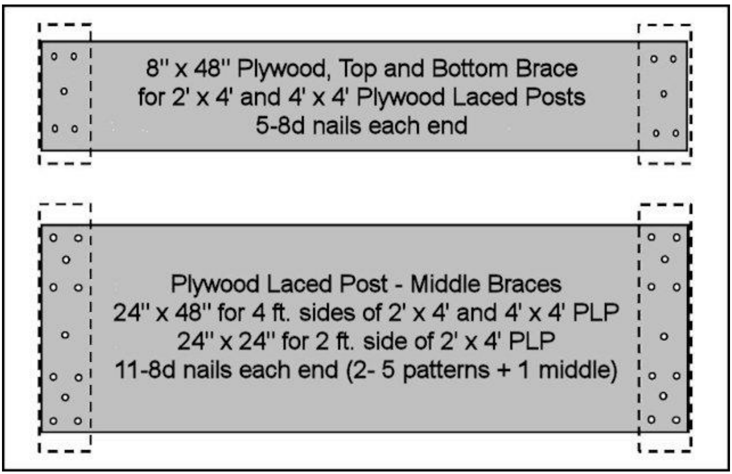


Figure 3.16. Plywood Braces for Plywood Laced Posts.



3.3.2.1.6. As illustrated in **Figure 3.17**, when nailing connections for 2”x6” and 2”x4” braces to posts, consider using 16d coated nails (0.148” x 3.25”) to reduce splitting. Also, try to place nails away from the ends of 2”x4”s and 2”x6”s.

3.3.2.1.7. When nailing 2”x6” and 2”x4” diagonal braces to headers (**Figure 3.18** and **Figure 3.19)**, the braces connect the post to the header and provide bracing. Carefully place the diagonal brace so required nails can be driven without splitting the post. For conditions where 5-16d nails will split the post, 3-16d nails may be used.

3.3.2.1.8. When building vertical shoring, the nails connect wooden members together, but they should not transfer direct loads. Use either hand or gun-driven nailing methods; however, gun-driven nails normally produce less impact vibration. Full head nails are best, but the head is set off-center for most nail guns. Clip head nails are also an option but be careful not to over-drive the nails. Do not use wedge cut nails. The preferred 16d nail is a 0.148”x3.25” coated nail. Standard 16d nails are 0.162”x3.5” and tend to split the wood. Consider using duplex nails on the wedges, so you can easily pull the nails when adjusting the wedges. **Figure 3.20** illustrates standard nailing patterns for shoring construction.

Figure 3.17. Nailed Connections for 2”x6” and 2”x4” Braces to Posts.

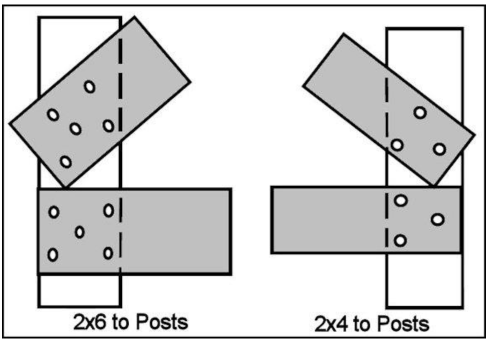


Figure 3.18. Nailed Connections for 2”x6” Brace to Header.

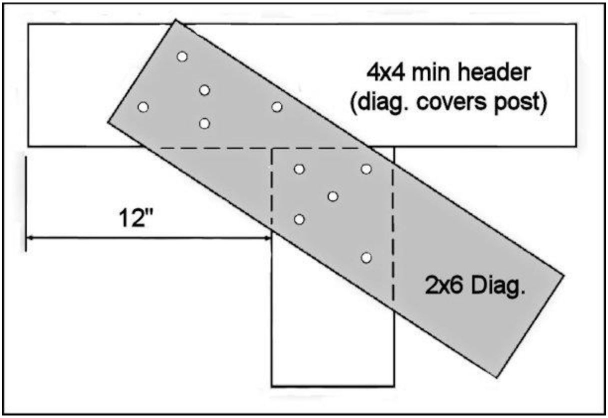


Figure 3.19. Nailed Connections for 2”x4” Brace to Header.

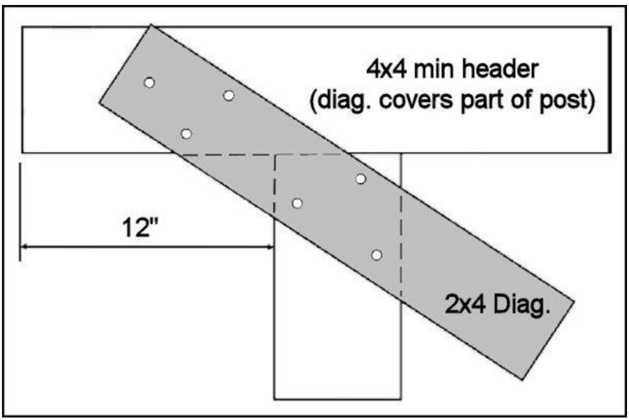
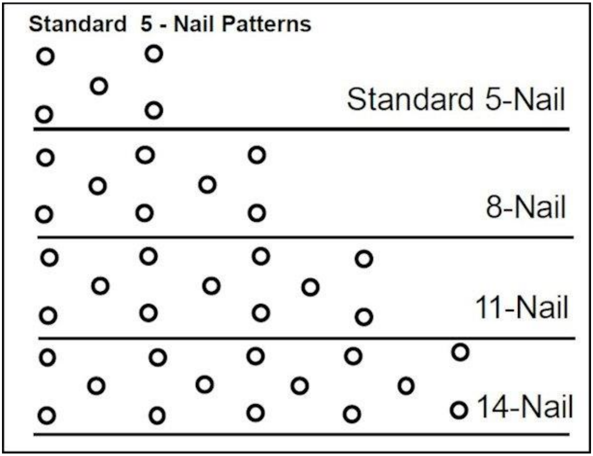


Figure 3.20. Standard Nailing Patterns.



3.3.2.2. T Spot Shore. The T Spot shore is a rapidly installed temporary shore for use only until a complete shoring system can be installed. It can become unstable if it is not centered under the load. Using the wooden materials listed in **Table 3.1**; build the T Spot shore (**Figure 3.21**) according to procedures below:

3.3.2.2.1. Determine where to build the T Spot shores to reduce risk quickly (prior to building more stable shores).

3.3.2.2.2. Determine the height of the area to shore; remove the least amount of debris required to place shore.

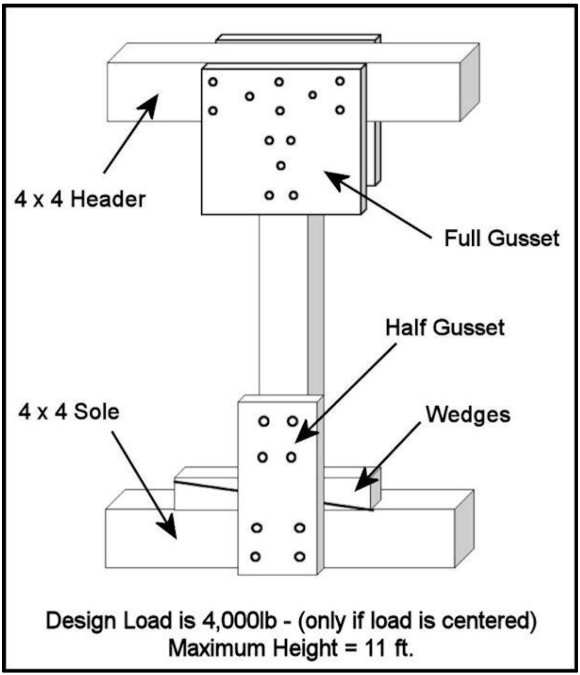
3.3.2.2.3. Measure and cut the 4"x4" header and sole to 3 feet.

3.3.2.2.4. Cut the post to proper height (max length 10'3") so that the total height of the shore is not more than 11', after adding the 4"x4" header (3.5"), 4"x4" sole (3.5"), and 2"x4" wedge height (2").

Table 3.1. T Spot Shore Materials.

Header and Sole	4”x4”x36” (max)
One Post	4”x4”x10’-3” max long
One Wedge Set	2”x4” wedges
Two Full Gussets	May use 5/8” or 3/4” plywood (or OSB unless wet conditions are present or expected)
One Half Gusset	

Figure 3.21. T Spot Shore.



3.3.2.2.5. Prefabricate header to post as follows:

- Toenail post to header and make square.
- Place and nail Full Gusset plate on one side.
- Flip shore over and place/nail another full gusset on the other side.

3.3.2.2.6. Place T Shore in position, centered under the load.

3.3.2.2.7. Position header across (perpendicular to) the roof/floor joists and position the post directly under a joist.

3.3.2.2.8. Slide sole plate under T and tap wedges into position. Check for straightness and position directly under the load, and then tighten the wedges.

3.3.2.2.9. Install bottom half gusset; nail 4-8d nails to post and sole. **Note:** A 2”x4”x18” cleat may be used, but the 3-16d nails to post and to sole may tend to split the cleat. In addition, the nailing of 16d causes more impact within the danger zone than for 8d nails.

3.3.2.2.10. Anchor the shore to the floor above and sole to floor below, if practical.

3.3.2.3. Double T Shore. The Double T shore is the most stable spot shore, and more preferred to the marginally stable T Spot shore. Using the wooden materials listed in **Table 3.2**; build the Double T shore (**Figure 3.22**) according to procedures below:

3.3.2.3.1. Determine overall height of the area to shore and remove the least amount of debris required to place the shore.

3.3.2.3.2. Measure and cut the 4”x4” header and sole to 3’ long.

3.3.2.3.3. Cut the 4”x4” post to proper height (max length 11’3”) so the total height of the shore is not more than 12’, after adding 4”x4” header (3.5”), 4”x4” sole (3.5”), and 2”x4” wedge height.

Table 3.2. Double T Shore Materials.

Header and Sole	4"x4"x36" (max)
2 - Posts	4"x4"x11'-3" max long
2 - Wedge Sets	2"x4" wedges
1 – Mid-Point Brace	12"x24" plywood
2 - Double Gussets	May use 5/8" or 3/4" plywood (or OSB unless wet conditions are present or expected)
2 - Half Gussets	May use 5/8" or 3/4" plywood (or OSB unless wet conditions are present or expected)

3.3.2.3.4. Prefabricate header to posts as follows:

- Toenail posts to header and make square.
- Place and nail Double Gusset plate on one side of both posts.
- Nail 5-8d nails to each post and 14-8d nails to the header.
- Flip shore over and place another Double Gusset on the other side.

3.3.2.3.5. Nail mid-height plywood, Double Gusset to one side of posts (8-8d nails to each post).

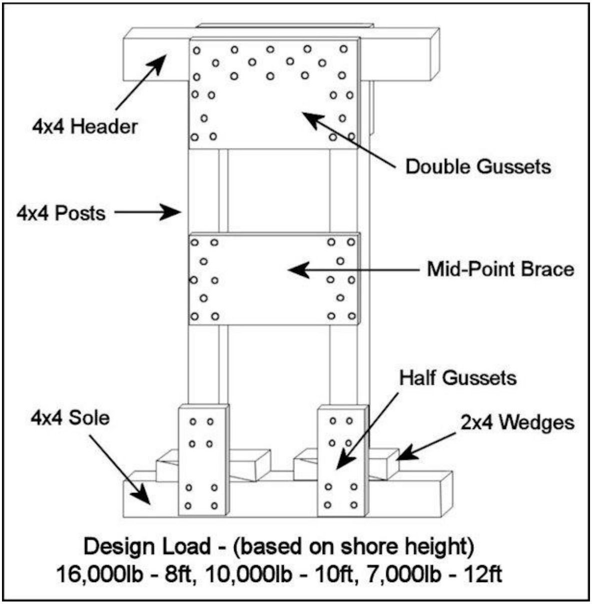
3.3.2.3.6. Place Double T in position, centered under the load.

3.3.2.3.7. Slide the sole plate under Double T and tap wedges into position. Check for straightness plus stability, and then tighten wedges.

3.3.2.3.8. Install bottom Half Gussets and nail 4-8d nails to each post and sole.

3.3.2.3.9. Anchor the shore to the floor above and sole to floor below, if practical.

Figure 3.22. Double T Shore.



3.3.2.4. 4-Post Vertical Shore. Normally, work crews build this shore in-place in the danger zone. To reduce risks, spot shores such as T Spot and Double T should precede the erection of this shore. Using the wooden materials listed in **Table 3.3**; build the 4-Post Vertical shore (**Figure 3.23**) according to the following procedures. **Note:** Crews may adjust procedures for either three or five posts.

3.3.2.4.1. Survey, install spot shores (if needed), and remove the least amount of debris required to place the shore.

3.3.2.4.2. Lay the sole plate on the floor or ground directly under and in line where installing the header. The sole plate should be as level as possible.

3.3.2.4.3. Measure and cut the posts to the proper height:

- Place the header on top of the sole plate.
- Place the end of the tape measure on top of the header at both ends and at its middle, to find the distances to the bottom of the structure needing shoring.
- After deducting for wedges, use the smallest dimension for all posts (assumes near-level conditions).

Table 3.3. 4-Post Vertical Shore Materials.

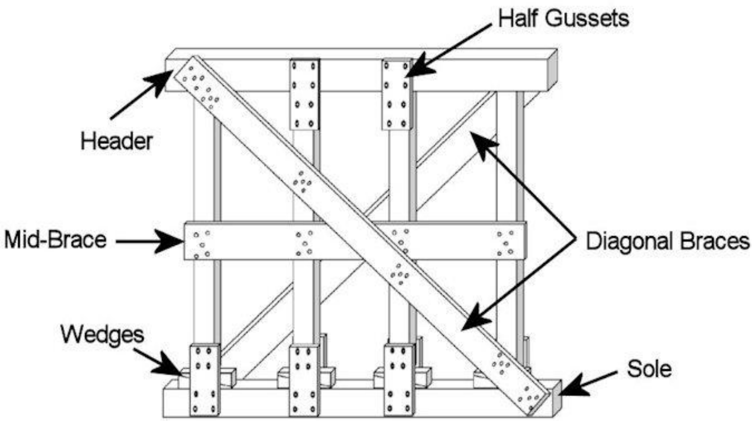
Header and Sole	Same size as posts in most cases, 4”x4” or 6”x6”
2 or more Posts	4”x4” (12’ minus height of header/sole/wedges) 6’x6” (20’ minus height of header/sole/wedges)
1 - Wedge Set each post	2”x4” wedges
1 - Mid-Brace	1”x6” or 6” plywood
2 - Diagonal Braces (“X”)	2”x6”
Half Gussets	5 for 3-post, 8 for 4-post, and 11 for 5-post

3.3.2.4.4. If possible, anchor the header to the area that is to be shored, square and in line with the sole plate. Secure it at the lowest point and shim the structural elements down to the header trying to keep it as level as possible.

3.3.2.4.5. Install the posts between the header and sole plate under each structural element needing support. The 4”x4” posts should be spaced 4 ft o.c. (maximum).

- Install first two posts 12" from ends of header.
- Toenail each post to header and sole and keep the posts in line & plumb with header and sole plate.

Figure 3.23. 4-Post Vertical Shore.



Design Load 4 x 4 Posts:		Design Load 6 x 6 Posts:	
Height = 8 feet	8,000lb each post	Height = 12 feet	20,000lb each post
Height = 10 feet	5,000lb each post	Height = 16 feet	12,000lb each post
Height = 12 feet	3,500lb each post	Height = 20 feet	7,500lb each post

3.3.2.4.6. Install a set of 2"x4" wedges under each post, on top of Sole, and tap them together simultaneously until the posts are tight. Nail behind the wedges to secure them.

3.3.2.4.7. Attach the diagonal braces to each side of the vertical shore.

- Install mid-point brace prior to the diagonal braces, when needed.
- Diagonal braces should be long enough to span its entire length and attached to the sole plate and header and each post.
- If possible, installed diagonal braces should be in a "X" pattern on opposite sides of the system.

- Very long vertical shoring systems may require several sets of diagonal braces.

3.3.2.4.8. Attach half gussets to one side of header to post, except where diagonal braces attach. Add Half Gussets to each side of each post to sole plate, except where diagonal braces attach (then only one side). Nail with 8-8d nails.

3.3.2.5. Door and Window Shores. Use door and window shores in unreinforced masonry buildings to support loose masonry over openings. The shores may also be usable in other building types with damaged door or window headers. Build shores using the wooden materials listed in **Table 3.4** and according to the following procedures. **Figure 3.24** illustrates basic shore design with open access for doors or windows. **Note:** If not using door or window opening for access or egress, consider reinforcing the shore with diagonal bracing.

3.3.2.5.1. Survey, remove finishes (if required), and remove debris.

3.3.2.5.2. Measure and cut the sole plate and header to the proper length, deducting the width of the wedges used. Make the header 1" deep for every foot of opening; 4"x4" minimum. Design headers for openings over four feet.

3.3.2.5.3. Measure and cut the posts to the proper height.

- Place the header on top of the sole plate.
- To determine post height, place the end of the tape measure on top of the header where installing the posts, slide the tape up to the bottom of the structural element to be shored, deducting the thickness of the wedges to be used. (Use the shorter of the two measurements).

3.3.2.5.4. Install the sole with a set of wedges at one end and tap them together simultaneously until the sole is tight. The sole should be as level as possible: use shims as necessary under the sole plate.

Table 3.4. Door and Window Shore Materials.

Header and Sole	4”x4”x36” (max)
2 – Posts	4”x4”x11’-3” max long
4 - Wedge Sets	2”x4” wedges
1 - Half Gusset	12”x24” plywood
3 – Cleats	2”x4”x18”
Shims	As required
2 - Diagonal Braces	2”x4” (if door/window not used for access)

3.3.2.5.5. Install the header with a set of wedges at the opposite end of the sole and tap them together until the header is tight. The header should be as level as possible; use shims as necessary above the header.

3.3.2.5.6. Install the posts between the header and sole, and against the sides of the opening. Install the first post under the wedge side of the header to prevent movement if the header wedges loosen.

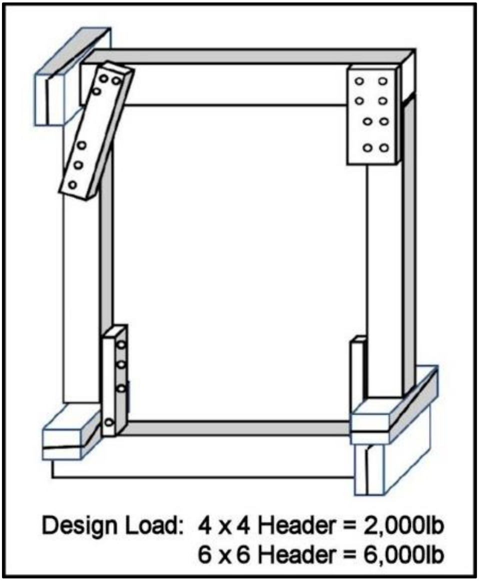
3.3.2.5.7. Keep posts in line and plumb with header and sole.

3.3.2.5.8. Install a wedge set under each post, on top of the sole. Tighten the wedges to lock shore in place.

3.3.2.5.9. Attach cleat and half gusset to at least one side of the header and posts (as shown) and nail in place.

3.3.2.5.10. Confine the wedges by placing a cleat against the inside face of each post at the bottom and nail them in place with 3-16d nails to each post and 2-16d toenails to the sole. **Note:** May use duplex nails for future adjustments of the wedges.

Figure 3.24. Door and Window Shore.



3.3.2.6. Cribbing. Cribbing is an easily adjustable shore for height and width dimensions. Height must be limited because of a large amount of deflection due to crushing, especially when different crushing rates occur at different bearings. The materials used depends on the height, number of pieces per layer, and the height of each piece. The recommended maximum height for systems using 4x4s is 4 feet, and for 6x6s is 6 feet. Build the cribbing as illustrated in **Figure 3.25** and according to procedures below. **Table 3.5** lists cribbing design loads.

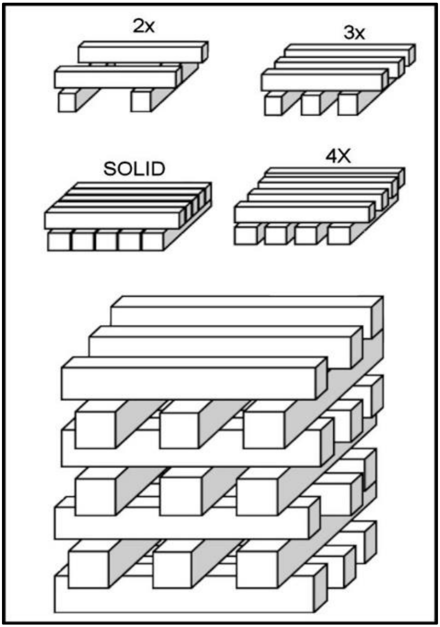
3.3.2.6.1. Determine where to build cribbing to reduce risk quickly.

3.3.2.6.2. Determine overall height of the area to be shored and remove least amount of debris required to place shore.

3.3.2.6.3. Determine the desired width dimensions of the crib; the size of the members required; and the configuration of the crib layers.

- Use 6"x6" members if crib needs to be more than 4 ft. high.
- Note that the 3-member x 3-member configuration is more than 2 times as strong as 2-member x 2-member.

Figure 3.25. Cribbing.



3.3.2.6.4. Decide if the first layer needs to be a solid layer, depending on the type of bearing material (soil or other surface softer than a concrete slab). If the supporting surface is concrete, make sure that it has the required stiffness and capacity, and there is not a basement story below.

Table 3.5. Cribbing Design Loads.

Design Load for 4x4 Douglas Fir and Southern Pine	
• 2 member x 2 member system	24,000lbs
• 3 member x 3 member system	54,000lbs
Design Load for 6x6 Douglas Fir and Southern Pine	
• 2 member x 2 member system	80,000lbs
• 3 member x 3 member system	180,000lbs

3.3.2.6.5. Carefully slide the members in for each layer, and keep the crib aligned and as square as possible.

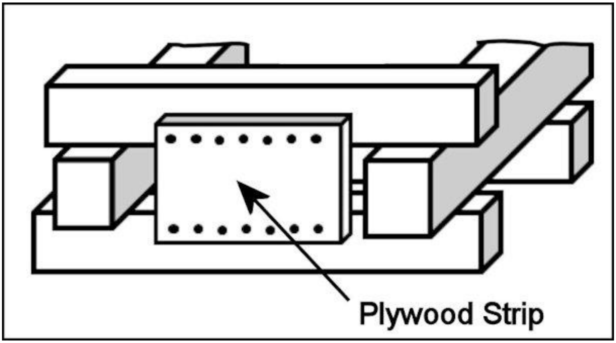
3.3.2.6.6. When the crib reaches required height, add shims to make sure that all intersections of crib members are in solid contact with the supported structure.

3.3.2.6.7. Attach the crib to the supporting surface (or confine its movement), if practical.

3.3.2.6.8. Where vibration and aftershocks may occur, interconnect the crib layers with 3/8" min x 16" long plywood strips that are 1.5 times as high as the cribbing members are (**Figure 3.26**).

- The plywood strips need to be placed on all 4 sides of the crib.
- Nail plywood strips at top and bottom edges to crib members with 8d at 3 inches on center.

Figure 3.26. Attachment of Plywood Strips to Cribbing.



3.4. Horizontal Shoring. Use horizontal shores to stabilize damaged, parallel vertical walls, especially walls that are bulging. The shores may be designed to permit access or for non-access. Fabricate horizontal shores as illustrated in **Figure 3.27** and **Figure 3.28**, and according to following procedures.

3.4.1. Measure and cut the wall plates and struts (4”x4” or 6”x6”) to the proper length. The maximum shore width for 4”x4” struts is 10 feet; for 6”x6” struts, 16 feet. Measure between the wall plates where the struts are to be installed, deducting the width of the wedges.

3.4.2. Place both wall plates next to each other and attach cleats and single 4x wedges to the wall plates just below where the struts will be installed. If 4x wedge is not available, use 2x wedge on top of a 2x cleat; nail with 5-16d nails.

3.4.3. Place the wall plates in the area that is to be shored, square and in line with each other and as plumb as possible by shimming any void spaces behind the wall plates. Install the struts between the wall plates. Keep the struts in line and plumb with the wall plates. Space 4”x4” struts a maximum 4 feet o.c.; for 6”x6” struts, a maximum 5 feet o.c.

3.4.4. Install a set of wedges horizontally between the wall plate and each strut and tap them together simultaneously until the struts are tight. Toenail the wedges from top into wall plate. Consider using duplex nails for future adjustment. Add 2”x4”x18” cleat from wall plate to strut (on top if possible) to secure wedges and strut. Use 3-16d nails on each end. At non-wedge end of the strut, place half gusset on one side. If possible, attach the wall plates to the walls.

3.4.5. Attach the diagonal braces to each side of the horizontal shore if not used for access or egress. The diagonal braces should be long enough to span the entire length and attach to both wall plates and each strut. When used, install diagonal braces in a "X" pattern on opposite sides of struts. Use 5-16d nails on each end.

Figure 3.27. Horizontal Shore (3-Strut, Non-Access).

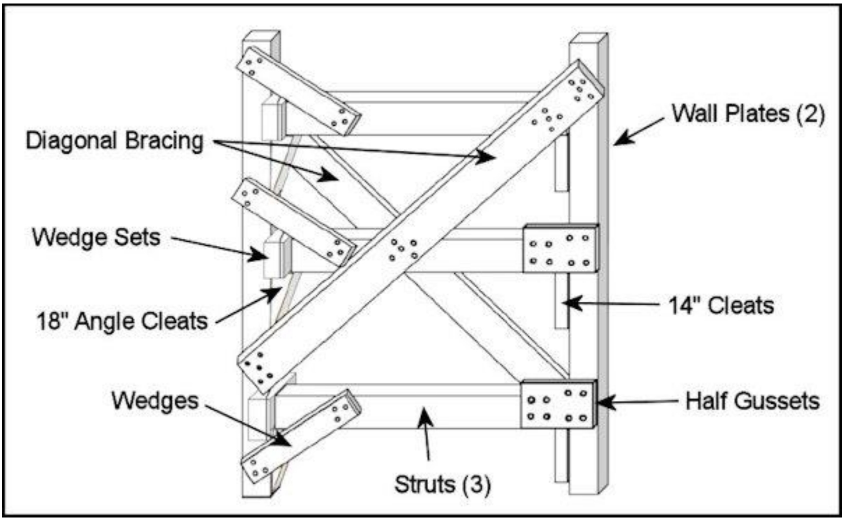
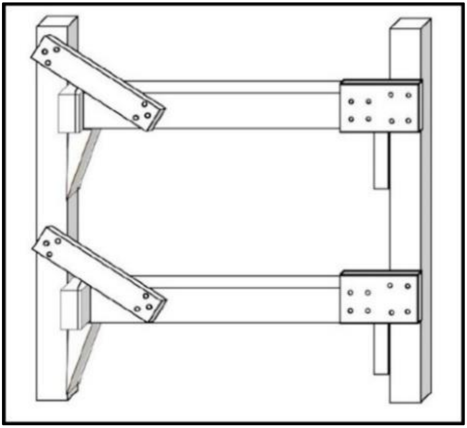


Figure 3.28. Horizontal Shore (2-Strut, Access Type).



3.5. Splinting. Splinting is a method of enhancing the structural integrity of columns, particularly the reinforced concrete type, that have not been seriously damaged but show signs of cracking or minor fracturing. Using steel and iron components to reinforce, strengthen, and delay further degradation of damaged concrete columns is a common engineering practice. The techniques below describe how steel plates, strapping, angle iron, and wound wire/cables are used for this purpose.

3.5.1. One technique involves "sandwiching" the damaged column between two steel plates connected by threaded rods. The plates have slotted holes so they can fit various sized columns (**Figure 3.29**). In this repair, splints are set around the column at the location of the crack(s) to provide a lateral restraining force (**Figure 3.30**). If cracks are at several locations on the column, consider using multiple splints. This repair is preferable to column replacement when a damaged column is still capable of carrying a significant load, because it requires less workers and is a faster repair (under good conditions, between 5 and 15 minutes). However, for severely damaged columns appearing near the point of collapse, column replacement using jacks or timber supports may be the better option.

Figure 3.29. Steel Plate Splint Dimensions.

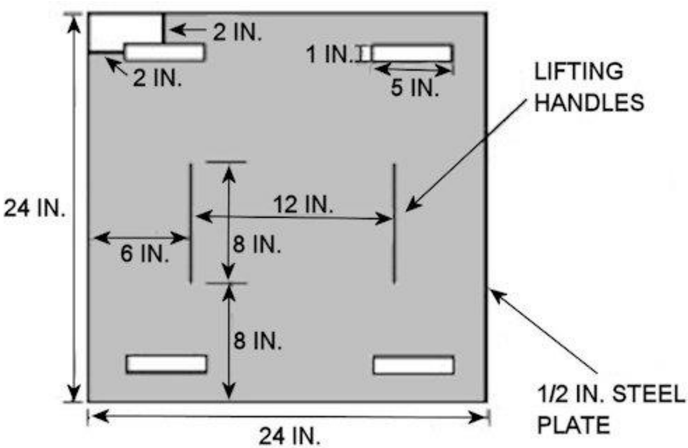
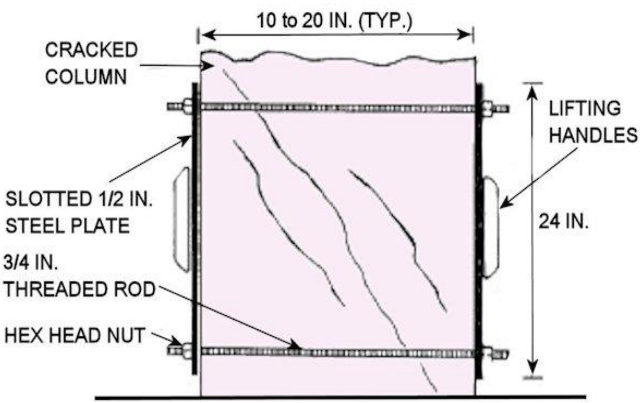


Figure 3.30. Steel Plate Splint Installation on Cracked Column.



3.5.2. A second splinting technique involves placing angle iron at the corners of a damaged column and connecting the angles with steel straps (**Figure 3.31**). Use steel plates at the ends of the angles to avoid load-bearing problems at the bottom of the column where it attaches to the slab. A third method of splinting again uses angle iron at the corners of the damaged columns but uses wire rope or similar cabling to connect the angle irons together (**Figure 3.32**). Weld one end of the wire rope to the top of one of the angles, and tightly wind the rope around the column. Weld the other end of the wire rope to one of the angles at the base of the column. Additional welds may be necessary at various points to secure the cable to the angle iron. **Note:** The required size and thickness of the angle iron, steel straps, wire rope, etc., can vary depending on the degree of damage to the column and potential for further degradation. While angle iron that is 1/4" thick with 4" to 4.5" legs may be sufficient for concrete columns with minor cracks and fractures, structural engineers can determine specific requirements for this and other reinforcing materials.

Figure 3.31. Use of Steel Angles at Corners of a Damaged Column.

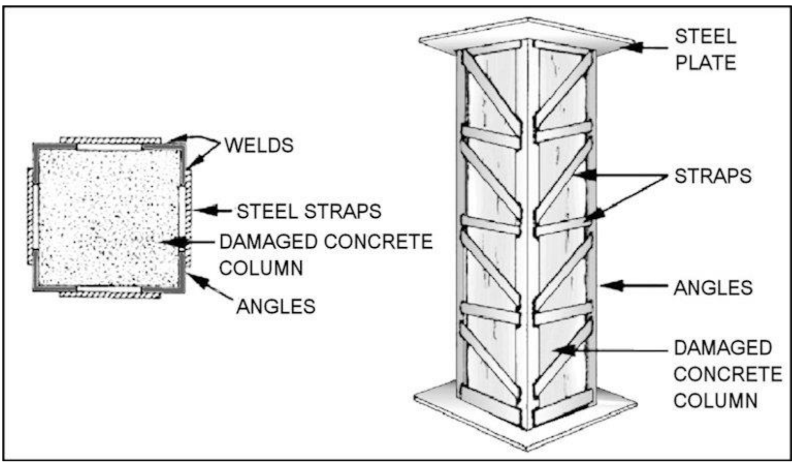
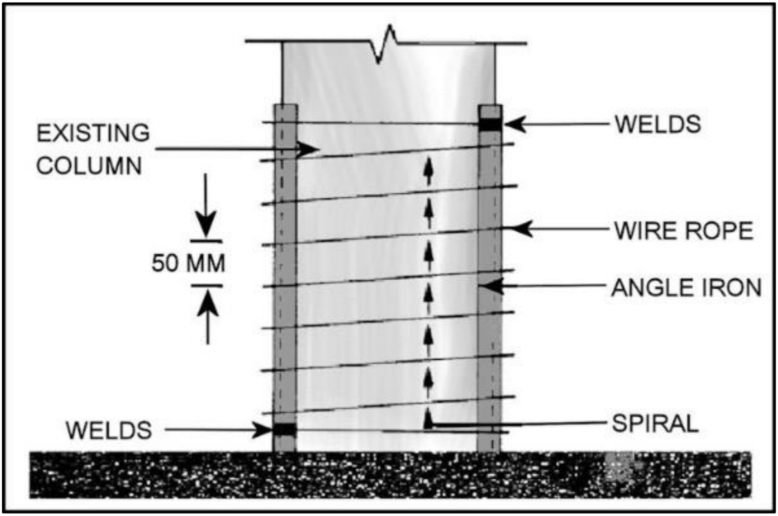
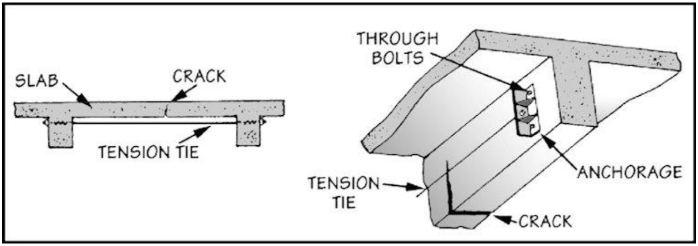


Figure 3.32. Use of Wound Spiral to Reinforce Column.



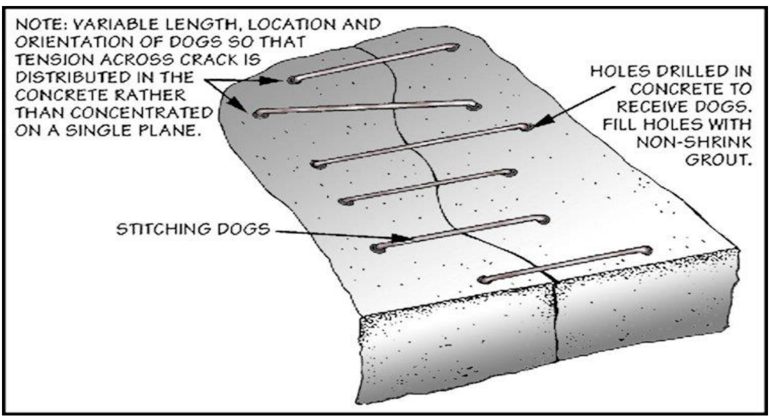
3.6. Tension Ties. Some facilities at overseas locations are essentially all reinforced concrete construction. In such cases, slabs and beams will be of unitary construction, meaning that they are formed, reinforced, and poured as a single unit. After an attack or natural disaster, some of the slabs and beams may develop minor cracking. Tension ties are a method of providing a compressive force on the slabs and beams that aids in the prevention of further cracking (**Figure 3.33**). For slab repair, anchor a threaded rod to the beams on both sides of the cracked area of the slab. For beams, bolt anchor plates to the beam on both sides of the crack and place a threaded rod parallel to the beam, connecting the two anchor plates. Tightening the nuts on the threaded rod induces a compressive force into the beam or slab, thereby restricting further cracking. **Note:** Structural engineers can determine specific size requirements for threaded rods and anchor plates.

Figure 3.33. Tension Ties.



3.7. Stitching Dogs. Yet another method of restoring structural integrity into a cracked concrete slab is the use of "stitching dogs." These dogs are steel bars, normally rebar, formed into a U-shape and set over the crack, rather like staples, as shown in **Figure 3.34**. The dogs should be of random length and variably spaced along the crack. To ensure a tight fit, well grout the holes after inserting the stitching dogs.

Figure 3.34. Stitching Dogs.



3.8. Welding. Welding steel sections back into place to restore the stability of a steel framework is a common shoring method. Welding repairs will usually be limited to a relatively small section of a facility. To attempt more than this as an expedient repair will take too much time and effort. For the most part, such repairs will involve erecting scaffolding, positioning steel plate and structural shapes, and accomplishing the welding.

Chapter 4

STRUCTURAL REPAIRS

4.1. Introduction. Emergency building repairs after a wartime or terrorist attack are generally limited in scope and considered adequate when they allow mission-critical functions to continue. For peacetime emergencies, the type and extent of the disaster will dictate, to a large degree, the type and extent of the repairs and recovery response. Military installations and surrounding communities may experience tornados, hurricanes, fires, floods, or even the effects of a volcano. The potential devastation from these threats reinforces the necessity that CE personnel possess the skill sets to make expedient repairs to facilities and equipment damaged by hostile action or disasters. This chapter presents common techniques for making expedient and emergency repairs to damaged structures, and miscellaneous wooden joint construction. The information and illustrations shown present notional repair options from Army Technical Manual 5-620, *Facilities Engineering Maintenance and Repair of Architectural and Structural Elements of Buildings and Structures*, and does not replace applicable Air Force, theater, or International Building Code repair standards.

4.2. Roof Repairs. It is important to recognize that some roofs and support systems perform various functions. While some are simply a weather cover, others act as part of a structural frame or diaphragm. When repairing a damaged roof structure, initial efforts must focus on safety. Ensure that bracing and shoring are adequate as addressed in the previous section; take additional steps to protect personnel and essential equipment from the elements. Local climate and prevailing weather are major factors. If the weather is warm and rainfall is not a detrimental factor, some openings may be left exposed temporarily without significant impact. However, if patching is required, consider the various materials and expedient repair options covered later in the chapter. Before starting any repairs, assess roof damage and brace or shore up any damaged beams or trusses, which may be unsupported due to the damaged roof, using expedient structural shoring methods in **paragraph 4.2.2**. Additionally, see **paragraph 4.5** for information on constructing wooden joints and splices.

4.2.1. Assess Roof Damage. Analyze failed sections and holes in the roof to determine the need for emergency repair. Inspect both the top and bottom portions of the roof to make sure that the areas are sound. Be aware that even though roof structural members and the deck are intact, emergency repairs may still be necessary. One example is that even after hurricane winds subside, persistent rains can cause severe damage or building collapse. Some roof covers have insulation boards, and high winds can leave the decking intact but blow off felts and expose insulation boards; and some insulation boards soak up rain like a sponge. The additional dead load from the water-soaked insulation, and ponding of trapped water, can collapse structures, especially warehouses and large hangars.

4.2.1.1. Rafters, beams, trusses and other roof framing should be easy to check because they are usually uncovered and accessible on the roof's underside, and therefore defects and damage should be visible. Damage assessments and periodic checks should identify areas where remedial action is necessary to repair or replace trusses and prevent roof failure.

4.2.1.2. Inspect roof framing from ground level to determine if there is obvious failure that would make an inspection from inside the roof framing itself unsafe. If unsafe, first take precautions to mitigate risk, then use a ladder or lift machine for close-up inspections.

4.2.1.3. Check framing members for noticeable bowing, warping, or vertical sagging that could lead to failure. Bowing could indicate an overloaded compression member; however, harmless warping may occur in an unloaded redundant member.

4.2.1.4. Inspect framing members for ruptures or freshly exposed wood fibers, indicating the member experienced unusual loads. Look for evidence of leakage such as water stains, mold, or decay.

4.2.1.5. Check framing members for splits and seasoning checks that could lead to failure. Seasoning checks and splits are normal reactions in most timber as it dries out. However, continued development of checks or splits toward line of bolts or through a bolt area or connector area may require corrective action. If records indicate increases in size, location, and depth of checks and splits, stitch bolts, yokes, or clamps may be used to prevent any further enlargement. Refer to **paragraph 4.2.4.2.1** for repair options.

4.2.1.6. Check truss members for proper construction and evidence of separation at joints. Loose or absent nuts can permit the timber members to separate and render the shear connectors less effective. Replace missing nuts and tighten all nuts to snugness without embedment into the wood.

4.2.1.7. Check the condition of the roof framing. Be sure to examine the rafter-to-plate connection. Look for evidence of movement of the rafter (spreading or slippage), or exterior wall movement (outward thrust).

4.2.1.8. If the structure was exposed to fire, check fire-damaged wood structural members for structural integrity. Scrape the charred wood off the member in various sections to check the extent of damage. Fire-damaged wood can remain in place if it retains most of its structural integrity. The amount of remaining strength will depend on the extent of charring or exposure to high temperatures. There is no definitive, in-place test to determine if fire-damaged wood is still structurally sound. Engineering judgment is needed to decide which charred members can remain in place, be repaired, or replaced. As indicated in U.S. Department of Agriculture (USDA) General Technical Report FPL–GTR–234, *Wood and Timber Condition Assessment Manual*, some engineers choose to repair or remove lumber showing any signs of charring, while others elect to repair or remove only lumber that has lost over 10% of its cross section to charring or has a charring depth greater than 1/16", on the assumption it would not significantly reduce the lumber's strength. In any case, engineers should consider the importance of the member to the structural integrity of the building and decide if a conservative approach is needed. For definitive results, an engineering test and analysis is normally required.

4.2.2. Shoring Roof Trusses. After assessing the damage, it may be necessary to shore up trusses and roof framing to prevent collapse or to provide security while making repairs. **Figure 4.1** through **Figure 4.3** indicate proper locations and number of shores to support common flat trusses. If desired, place shores at all panel points. In shoring Warren-type trusses, it is advisable to place a temporary strut to prevent introducing serious secondary stresses in the truss members. **Note:** See **paragraph 4.2.4.1** for a description of other common trusses.

4.2.2.1. Shoring may be made of steel or seasoned timber. Place sufficient planking under shore jacks to distribute load on the floor. Raise the trusses slowly and carefully, jacking each shore in small increments one at a time. Otherwise, additional failures may occur due to secondary stresses and distortion, potentially damaging the roof membrane of the structure. Be sure to eliminate hazardous hanging materials (i.e., lights, wires, cable trays, mechanical ducts, etc.) below the roof and assess the extent of damage to the roof support system.

Figure 4.1. Shoring Pratt Trusses.

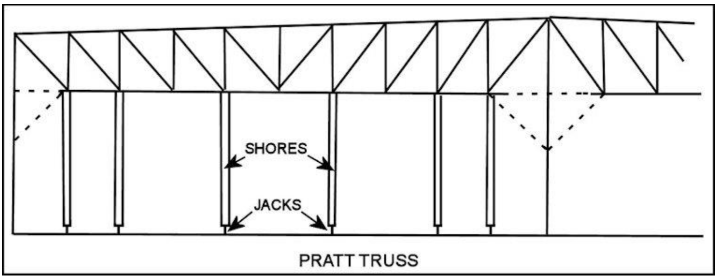


Figure 4.2. Shoring Howe Trusses.

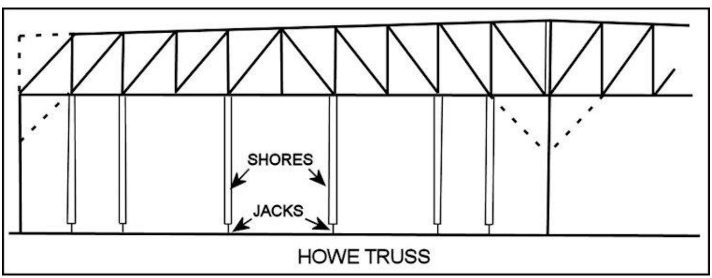
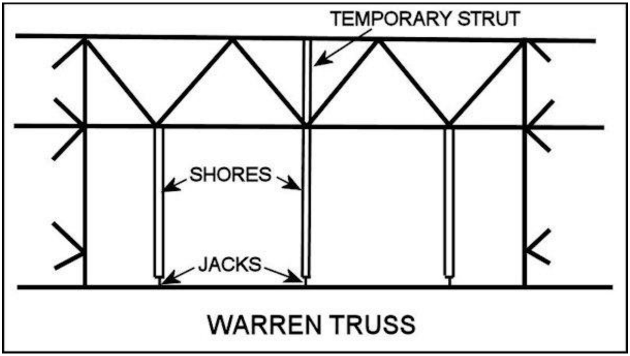


Figure 4.3. Shoring Warren Trusses.



4.2.3. Weather Tightness. After ensuring the structural integrity, you can begin returning the weather tightness to the structure. From an expedient aspect, it will be difficult to seal off the building completely from weather, but you can keep out most of the ill effects of bad weather. Consider nailing sheets of plywood over the opening. Sheet metal, plastic sheeting, and canvas are options in lieu of plywood. **Figure 4.4** show personnel using plastic sheeting as expedient roof protection on a housing unit after a hurricane damage.

4.2.3.1. For flat roofs, consider fabricating sheets of plywood into a patch a bit larger than the hole and nail in place. If the roof is concrete, consider using bolts, epoxy, or other suitable fasteners to attach the plywood patch. **Note:** The repair sequence in **Table 4.1** is an example how expedient weatherproofing and hole repair may proceed during a contingency.

4.2.3.2. If available, nail rolled roofing to the patch for added weather protection. Once covering is in place, maintain positive drainage to divert rainwater and prevent ponding. This may involve stacking sandbags above the repair to divert the water or changing the slope at the repair itself. For larger areas, raise the center of the tarp or sheeting to divert water.

Figure 4.4. Using Plastic to Cover a Damaged Roof.

Table 4.1. Expedient Weatherproofing and Hole Repair.

1. For small holes (holes under 3’ diameter):

- Cut and install 3/4” plywood
- Apply roofing cement around the hole
- Place the plywood over the hole and secure it with the screws
- Holes 3” diameter and smaller can be filled with spray foam

2. For large holes (over 3’ in diameter):

- Shore up damaged trusses or beams that may be unsupported due to the damaged roof
- Use 2”x4”s or 4”x4”s as shoring materials and cut them to the proper length; small hydraulic jacks can be used to push them back into place
- Stretch plastic sheeting or a tarp over the hole and secure it to the roof deck; realize this is an intermediate step and if it starts to rain, the water may pond on the tarp/plastic and tear it
- Take 2”x4”x16’s and lay them on edge across the hole about 24” on center

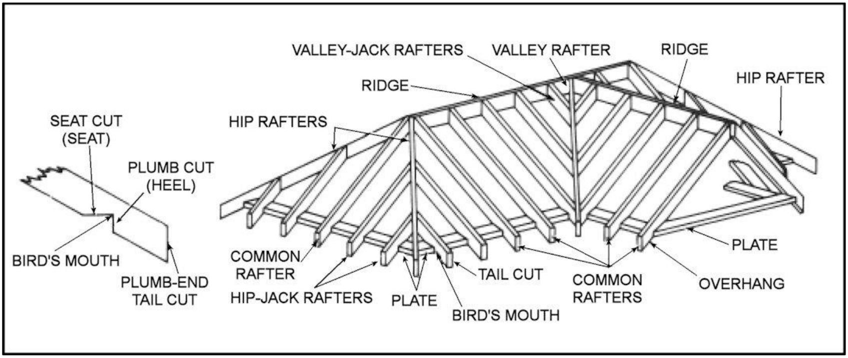
- Nail a single top plate and a bottom plate on them
- Lay plywood across your 2”x4”s just like you would when decking the roof
- Apply a liberal amount of plastic roof cement around the perimeter 2”x4”s and toenail it to the roof decking
- Cover the plywood with felt, plastic, tarp, or anything else that would make it water-resistant. Now, the temporary repair will be water-resistant and should not collapse under pressure

4.2.4. Timber Roof Repairs. During contingencies, expedient repairs to timber roofs (framed or trussed) are often necessary when there is damage to sheathing, rafters, purlins, or other framing members. The following paragraphs provide a brief overview of timber roof structure, expedient repair options and procedures, and common repair tools and equipment.

4.2.4.1. Structural Components. The primary components used in the framework of wooden roofs are lumber and metal fasteners. Framed roofs vary widely, from the simple lean-to type of flat roof to complex hipped and gabled roofs. Roof rafters are the structural members of a frame roof. Truss roofs have a structural framework of pitched, flat, or curved units used in place of rafters, for supporting loads over long spans. All roof framing, including rafters, trusses, roof beams, purlins and girders support roof loads in much the same way as joist beams and girders support floor loads. The notable difference is that pitched roofs must resist lateral forces such as those caused by wind.

4.2.4.1.1. Rafters. Rafters are beams that slope from the roof ridge to the eaves making the main body of the roof. As illustrated in **Figure 4.5**, there are four types of rafters: common, hip, valley, and jack. Common rafters are framing members that extend at right angles from the plate line to the roof ridge. They are “common” to all types of roofs and are the basis for laying out other types of rafters. Hip rafters are roof members that extend diagonally from the corner of the plate to the ridge. Valley rafters extend from the plate to the ridge along the lines where two roofs intersect. Jack rafters may be a combination hip-jack (extends from plate to hip rafter), valley-jack (extends from the ridge to the valley rafter), or cripple jack (extends between the hip and valley rafters).

Figure 4.5. Various Rafters and Details.



4.2.4.1.2. Trusses. Trusses are the most common roof support in use today. **Figure 4.6** illustrates a few common types of trusses. Roof trusses can span large areas to give wide, unobstructed floor space for large buildings such as shops and hangars. Builders sometimes use trusses in small buildings to save material; they act as rafters and give the roof rigidity. The timber truss is a framed or jointed structure composed of connected wood members in various triangular configurations. The necessary number of subdivisions depend upon the length of the span and the type of construction. Over the years, construction innovations have changed the way most builders make and assemble timber trusses. Previously, many builders constructed heavy timber and double-chorded trusses and connected the members using bolts, glue, nails, screws, and plywood gussets. Today, common trusses are lightweight and single ply with pressed or stamped metal plate connectors joining the truss members together; expect to see all types when making repairs. See **Table 4.2** for basic truss terms and descriptions.

4.2.4.1.2.1. Flat Trusses. Most used for long spans, the flat-type Pratt trusses have spans up to 120 feet. Both the Pratt and Warren flat-type trusses, as well as the

Howe Truss, have relatively high stress in the web members in relation to the chord member stresses.

4.2.4.1.2.2. Bowstring or Curved Trusses. Generally, bowstring trusses are in the smaller hangars, warehouses, and some recreational buildings. These trusses have relatively high chord stresses with the web members carrying proportionally lighter stress. The upper chords of bowstring trusses are generally of laminated construction. Failures occur more often in the chord members. However, this type of truss gives comparatively less maintenance trouble than other types.

Figure 4.6. Common Truss Types.

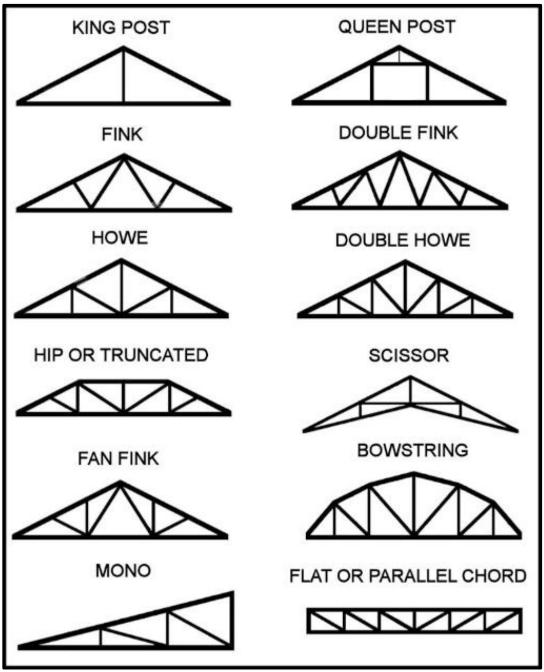
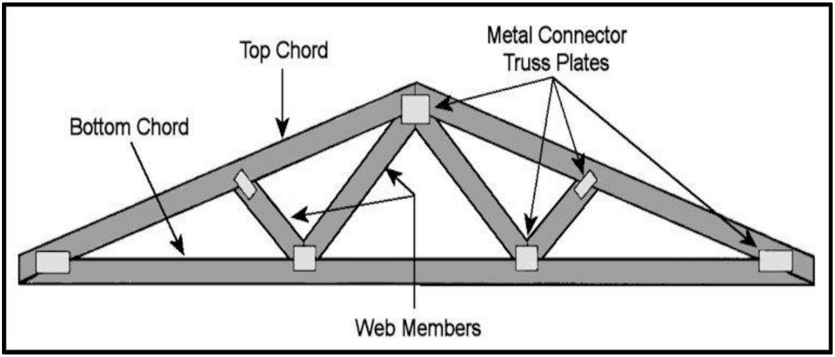


Table 4.2. Truss Terms.

Term	Description
Bottom Chord	A member that forms the lower boundary of the truss.
Top Chord	A member that forms the upper boundary of the truss.
Chord Member	A member that forms part of either the top or the bottom chord.
Member	The component that lies between any adjacent joints of a truss; it can be of one or more pieces of structural material.
Web Member	A member that lies between the top and bottom chords.
Joint	Any point in a truss where two or more members meet; sometimes called a panel point.
Panel Length	The distance between any two consecutive joint centers in either the top or the bottom chords.
Pitch	The ratio of the height of the truss to the span length.
Height of Truss	The vertical distance at midspan from the joint center at the ridge of a pitched truss, or from the centerline of the top chord of a flat truss, to the centerline of the bottom chord.
Span Length	The horizontal distance between the centers of the two joints at the extreme ends of the truss.

4.2.4.1.2.3. Pitched Trusses. Pitched trusses of the Fink, Howe, Scissors, and related types are for shorter spans, usually 60 feet and under. They are common options in recreational, chapel subsistence, garage, barracks, and similar type structures. **Figure 4.7** is an example of a contemporary, lightweight, single ply pitched truss.

Figure 4.7. Contemporary Pitched Truss (Single Ply).

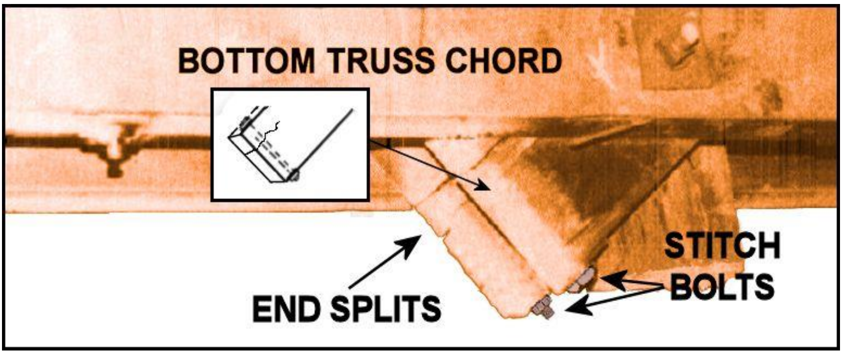


4.2.4.2. Roof Framing Repair. Damage to roof framing may result from roof cover or sheathing damage; extreme roof loading; impact damage; poor construction or maintenance; or use of unseasoned or defective lumber during construction. Depending on the specific damage encountered, repair options could range from the use of scabs (short pieces of lumber used to splice or prevent movement of two other pieces), splices, gussets, metal plates, support braces, metal fasteners (bolts, screws, nails, etc.), adhesives, epoxy, and clamps, to complete timber replacement. The following paragraphs address some of the expedient repair options for damaged timber roof framing.

4.2.4.2.1. Splits and Seasoning Checks. The standard practice of using unseasoned lumber for trusses invites splits (opening separating the wood, extending from one surface to the opposite surface or to an adjacent surface) and seasoning checks (separation of wood fibers by drying) that could lead to failure in roof framing. Potential remedies for such splitting include the installation of stitch bolts, yokes and clamps, or steel banding on truss members.

4.2.4.2.1.1. Stitch Bolts. The stitch bolts prevent enlargement of splits and checks and further deterioration of the member. In truss members that have only one row of bolts, any split or check that occurs is normal and is not likely to be serious. However, if the split passes through the bolt holes and continues beyond into the member, it requires attention. The recommended remedy for such splitting and checking is the installation of stitch bolts in the ends of each such member that has split. The bolts used for this purpose are 1/2-inch diameter bolts, threaded on both ends; 9/16 inch holes are drilled 2 to 4 inches from the end of the split member and perpendicular to the axis of the member. The bolt is then inserted and 2-inch, square-cut washers are place at each end. Install the stitch bolts before tightening the bolted connection. Do not attempt to completely close splits or checks because it could extend the split or check to the other side of the member. If the split is serious and continues well into the member, place a second stitch bolt on the opposite side of the connection about 6 to 12 inches from the ring connector. **Figure 4.8** is an example of a stitch bolt repair used on a double-chorded truss member. Exercise care in drilling stitch bolt holes so that holes are parallel to the face of the member.

Figure 4.8. Stitch Bolt Repair on Truss Member.



4.2.4.2.1.2. Yoke Angles and Clamps. **Figure 4.9** illustrates the expedient repair of a minor split occurring at or near the joint of a truss chord member. Yoke angles or clamps are preferable in this case because stitch bolts would reduce the effective area of the chord member. Note the boring of a small hole immediately beyond the termination of the split. In some cases, when the split passes through the connection but does not pass too far up into the member, consider drilling a small hole through the thickness of the member at the end of the split to stop its progression. This hole should relieve any abnormal stresses at that point. Shown in **Figure 4.10** are typical yoke and clamp details.

4.2.4.2.1.3. Steel Banding. High strength steel banding such as that used to seal shipping cartons has proved effective in arresting the spread of splits. The bands should be of high tensile strength steel 1-1/4 inch wide and 0.035 inch thick. Apply the bands with a strapping tool (stretcher) that has no part remaining under the strapping during tightening that may cause slackening when removing the stretcher. Secure strapping using a push seal (for steel) and manual sealer. **Figure 4.11** illustrates a typical steel banding for arresting splits.

Figure 4.9. Temporary Split Repair with Yoke or Clamps.

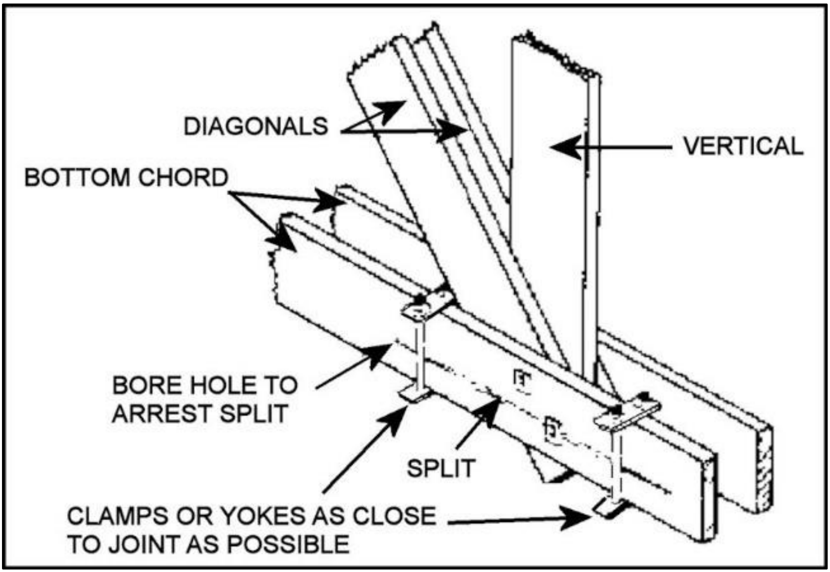


Figure 4.10. Typical Yoke and Clamp Details.

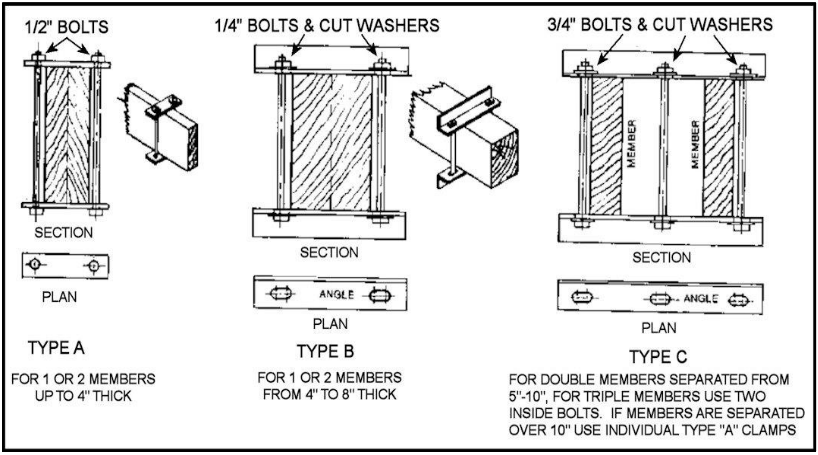
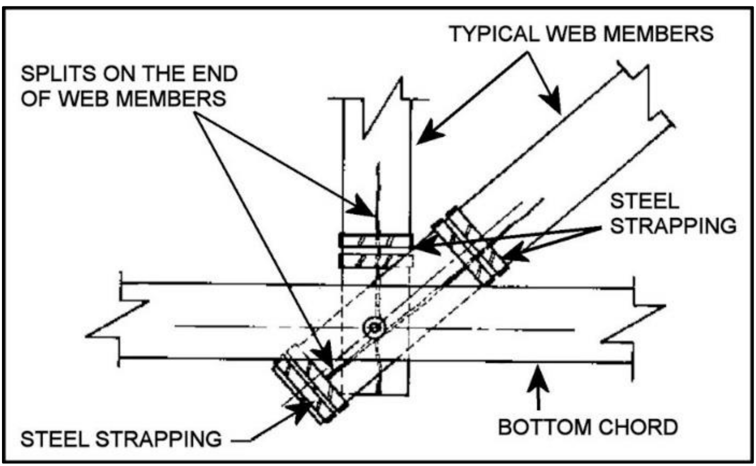
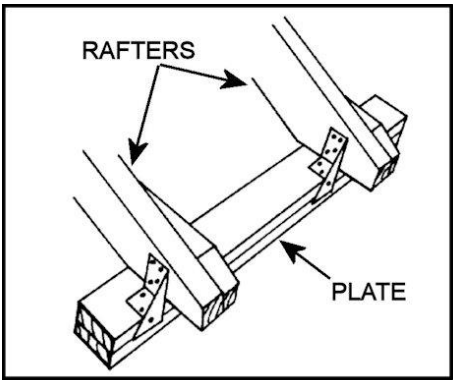


Figure 4.11. Arresting Splits with Steel Banding.



4.2.4.2.2. Rafter Movement or Shifting. Sustained overload on pitched roofs usually results in the rafters spreading with the consequent sag in the ridgeline. Include an examination of rafters' connection to the plate during the roof framing inspection. If rafters slipped outward on the plate, consider realigning them by pulling the ends of the rafters together with rods and turnbuckles or other devices. A similar effect would be noticeable if the exterior walls were thrusted outward by the rafters. Remedy this condition in the same manner as for slippage. To limit movement, the best way to anchor the rafters to the top plate is by applying framing anchors, such as shown in **Figure 4.12**.

Figure 4.12. Common Rafter to Plate Connection.



4.2.4.2.3. Warped Lower Chord and Splice Members. **Figure 4.13** shows a lower chord splice in which both the splice and lower chord members were badly warped. This condition usually occurs when trusses are made of light material generally 2 inches thick with depths 8 to 10 inches or greater. The omission of outside splice plates and an inside filler block between the chords was a contributing factor to the conditions shown. The remedy is to install outside splice plates using 4-inch split rings with 3/4-inch bolts and the addition of an inside filler block for stiffness, as illustrated in **Figure 4.14**.

Figure 4.13. Warped Lower Chord Splice on Double-Chorded Truss.

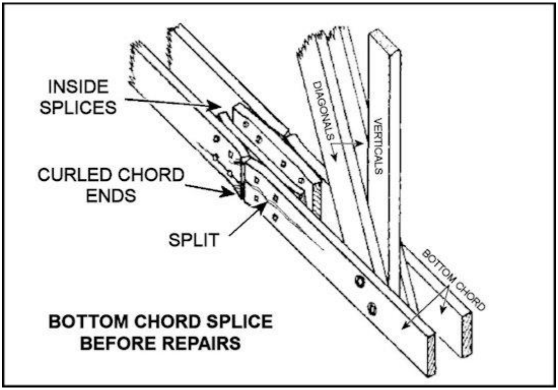
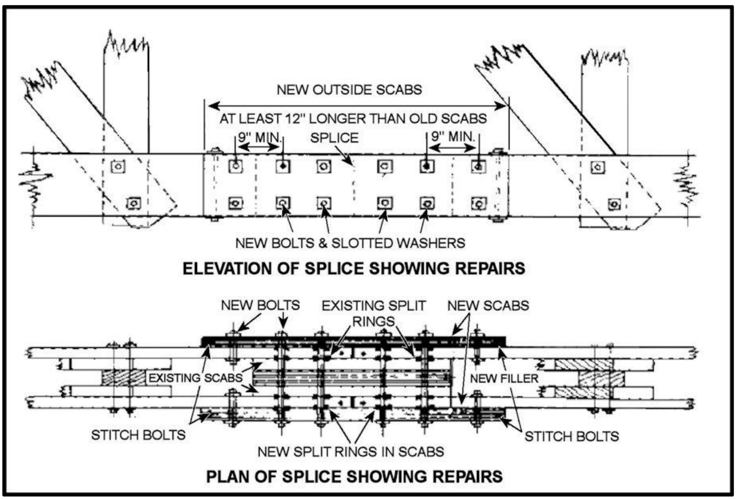
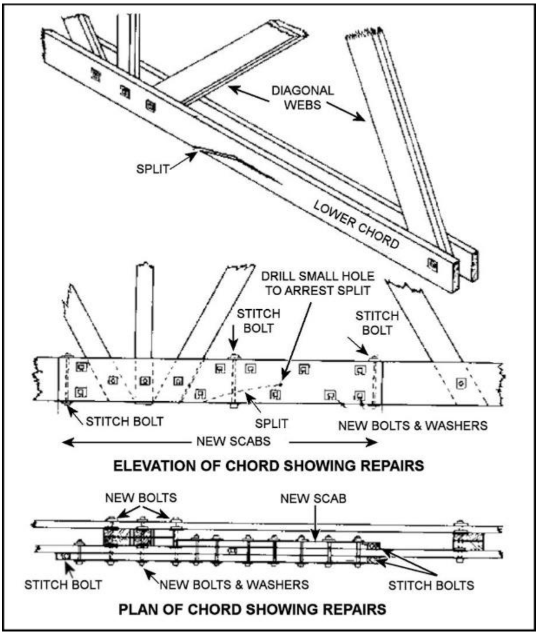


Figure 4.14. Repair of Lower Chord Splice.



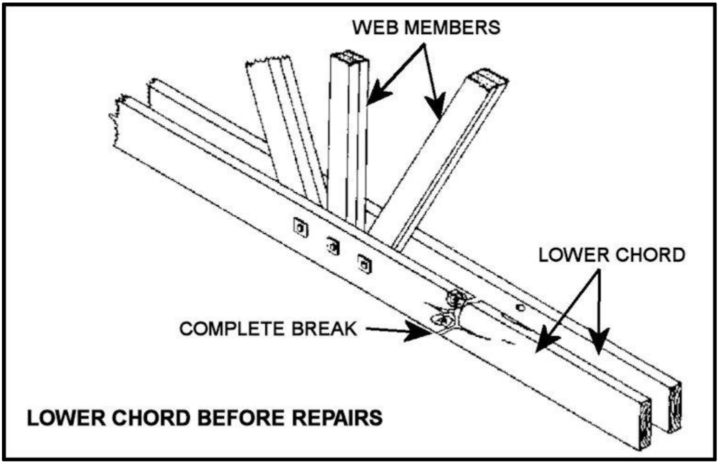
4.2.4.2.4. Split Lower Chord. **Figure 4.15** illustrates the repair of a split in a lower chord. Accomplish this repair by adding two splice plates, one on either side of the lower chord and the outside plate, carried through the panel point nearest the fracture. Use this procedure in carrying the splice plate through the nearest joint if there is insufficient room on each side of the fracture to develop the full strength of the member when the splice is bolted in place. Before applying the splice plates, drill a small hole ahead of the split to arrest further splitting. Next, apply a clamp of sufficient size to draw the broken member together. If a member has a thickness greater than 2 inches, place a stitch bolt through the member to retain this position. Next, bolt two scabs to the fractured member using sufficient bolts on each side of the break to develop the full strength of the member.

Figure 4.15. Repair of Major Split in Lower Chord.



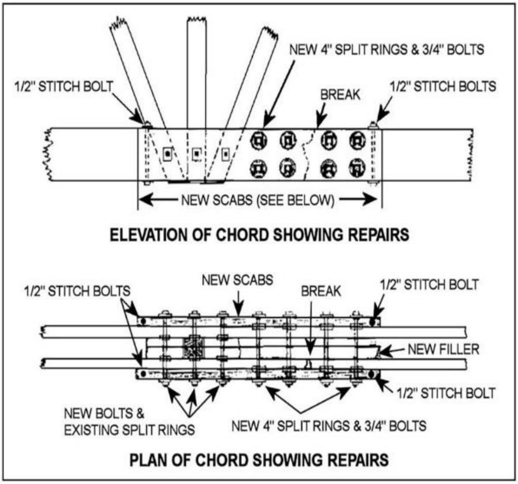
4.2.4.2.5. Complete Lower Cord Break. In many cases due to extreme knotty conditions and the use of brash (brittle) timber, it will be necessary to repair lower chords when one or more of the members has completely failed (**Figure 4.16**).

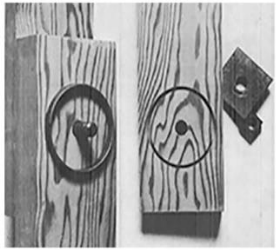
Figure 4.16. Lower Chord Break on Double-Chorded Truss.



4.2.4.2.5.1. **Figure 4.17** illustrates a lower chord repair in a double chord truss using split ring connectors. The split rings permit the use of fewer bolts and a shorter plate than would be necessary for a bolted connection. However, experience has shown that when such a break appears near a panel point, it is good practice to carry the splice plates completely through the panel point. The illustration also shows the installation of new filler blocks between the chord members. A break of this type cannot be adequately repaired by adding splice plates to the failed members alone, due to the difficulty in installing split grooves on the inside face of the broken member. Therefore, the splice plate, which would normally be on the inside face of the broken member, is placed on the outside face of the opposite chord member where split rings can be readily installed.

Figure 4.17. Lower Chord Break Repair Using Split Ring Connectors.

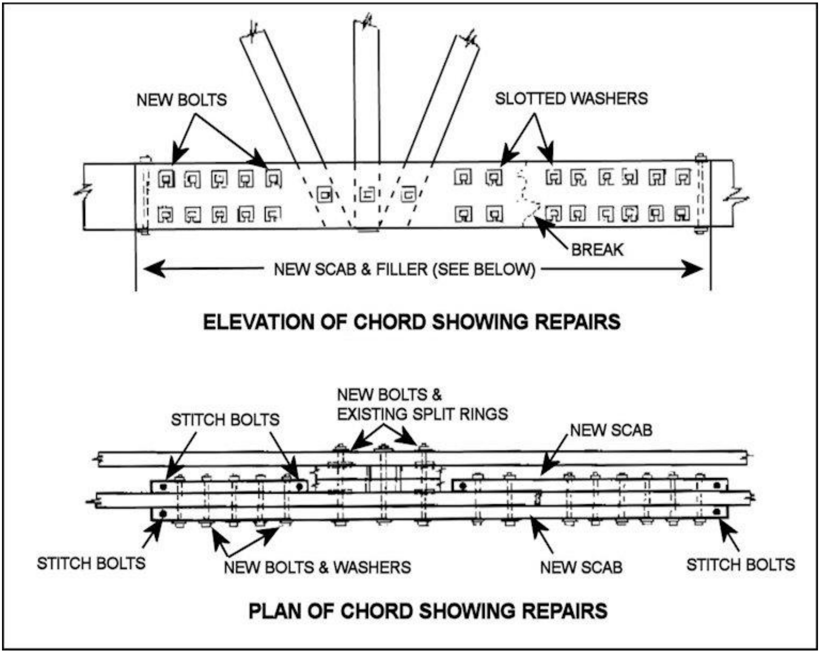




(Above is an example of split ring connector installed in one member. The facing member has been drilled to receive the connector)

4.2.4.2.5.2. Illustrated in **Figure 4.18** is an alternate method of repair for the same type of failure. It involves using bolts without connector rings. In the example, the repair is to the single broken chord member. The same principles described above apply here, except split ring connectors are not used. To develop the full strength of the failed member, it is necessary by this method to use a considerably larger number of bolts than required by the former method. It is also necessary to use longer pieces of repair timber. This method is not advisable for large fractures and should only be an option when split rings and the equipment necessary for their installation are not available.

Figure 4.18. Lower Chord Break Repair Using Bolts.



4.2.4.2.6. Sagging Rafters or Beams. If rafters are sagging due to overload, consider repairing by splicing additional member or members to the existing ones. Sustained overload on pitched roofs can also cause the rafters to spread with a resultant sag in the ridgeline. Jacking and/or shimming may be necessary to repair sagging beams. However, sometimes a sagging timber beam will appear overloaded when it is not overloaded. An inelastic deformation called creep will give an appearance of excessive deflection at the midpoint. Damage might occur if such a beam is jacked back into a level position. Check the beam first, to find out if there is any evidence of recent motion. In a real overload, there will be fine breaks revealing unexposed wood fiber or flaking of paint or other finish material. Consider taking measurements and monitor the beam to determine if any other deflection has occurred. If additional creep is evident, and the roof deck requires leveling, use shimming between the beam and roof deck.

4.2.4.2.7. Warped or Broken Rafters. If the roof surface is sound, one option is to replace the warped, twisted, or broken rafter. However, a more expedient option may be straightening the warped or twisted rafter by adding solid bridging and bracing. Additionally, a broken rafter can be scabbed without harming other roof framing or the roof covering.

4.2.4.2.8. Fire-Damaged Trusses. Emergency repair of fire-damaged trusses normally involves scraping off the charred material and attaching a similar piece of wood onto the damaged section, splinting the damaged area between two sound pieces of wood, using gusset plates (**Figure 4.19**), or using a combination of these procedures.

Figure 4.19. Gusset Plate Repair.

4.2.4.3. Roof Sheathing. Most contemporary roof sheathing or decking is constructed using well-seasoned sheathing lumber, nominal 1 inch in thickness, not more than 6 inches wide and preferably tongued and grooved, or of plywood with exterior glue, not less than 1/2 inch thick. The sheathing is usable with various roof covers, including asphalt shingles, asbestos-cement shingles, wood shingles, slate, tile, flat metal sheets, etc. Damaged and improperly repaired sheathing can lead to eventual roof failure. Sheathing damage may result in leaking roofs that no longer protect the framing, thus allowing weathering and eventual failure of the roof structure. Check the sheathing under the roof covering for movement, decay, and warping or cupping. Also, check the roof topside for signs of damage and movement of sheathing under the roof covering. It is sometimes necessary to redrive nails to tighten sheathing and prevent cupping of the individual pieces. Threaded nails of various types are useful since they have more withdrawal resistance than plain shank nails. When repairing sheathing, remove applicable roof covering and complete the following:

4.2.4.3.1. Remove all protruding nails and renail sound sheathing where necessary.

4.2.4.3.2. Remove rotted or warped sheathing boards or delaminated plywood and install new decking. **Note:** Sheathing boards should be fastened to each rafter with two nails to provide a smooth, even surface.

4.2.4.3.3. Cover all large cracks, knotholes, and resinous areas with sheet metal. For asphalt-shingled roofs, cover the exposed decking with an underlayment of Type 15 asphalt-saturated felt before laying shingles. **Note:** Do not use coated felts as an underlayment for shingles since they constitute a good vapor barrier and might cause condensation or frost to form at the roof deck.

4.2.4.3.4. Repair or replace flashing as necessary.

4.2.4.3.5. Apply applicable roof cover according to specifications.

4.2.4.4. Solid Beams and Columns. With heavy timber beams and columns, severe checking sometimes occurs. In most cases, this checking, although of considerable width and depth, is parallel to the axis of the member and usually requires no attention. An attempt to close such checks with stitch bolts will only aggravate the condition and cause the checks to extend completely through the members. Whenever this checking occurs in cross-grained members, corrective measures must be taken. In extreme cases, the members should be replaced. In some cases, repairs can be effectively made by bolting channel or angle iron parallel to the member and connecting them with bolts and shear plates.

4.2.4.5. Repair Tools and Equipment. The tools and equipment needed to make repairs to timber roofs will vary depending on the type and size of the structure, and the extent of the damage. The focus here is on those materials needed to perform expedient roof repairs for rapid restoration of vital facilities rather than permanent repairs. For many expedient roof repairs, the tools and equipment shown below should be sufficient. However, if roof structural members have significant damage such as serious splits, breaks, or other failures, then the use of stitch bolts, clamps, steel rods, plates, bands, or other repair materials may be necessary as a temporary measure until replacing the structural member.

- Drill with Apex.
- Handsaw.
- Circular Saw.
- Ladder.
- Hammer.
- Nails.
- Screws.
- Plywood.
- Plastic roof cement.
- Plastic sheet.
- Tarp.
- Lumber (2 x 4s).

4.2.5. Metal Roof Repair. Commonly, metal roof repairs consist of removing the damaged surface material and replacing it with new or cannibalized material. Overlap the good metal roofing with the replacement metal roofing by at least a matching corrugation or rib section. Catch as many purlins as possible for support and tack in place with sheet metal screws along the edges. Use caulk or construction adhesive on the upslope side for additional water protection. For large holes where purlins are too badly damaged to allow fast repair, and where reuse and immediate coverage is required, expediently patch the hole with similar materials, but provide at least 24 inches of overlap to distribute loadings. Add purlins later as time allows.

4.3. Wall Repairs. For the most part, wall repairs are similar to roof repairs, except they should be somewhat easier since there is no longer a requirement to lift all materials to roof height. However, be sure to consider shoring and bracing the structure as described in **Chapter 3**, if required. Damaged walls may be covered with common materials such as plywood, sheet metal, tarpaulins, and plastic sheets. During wartime, if the wall damage is near the ground level and the structure is strong enough, earth can even be bermed against the facility for added protection from a possible future onslaught. Alternative materials may also be an option for this purpose. A few examples include lumber from packing crates and shipping dunnage, salvaged and cannibalized materials from other facilities, and precast concrete revetments.

4.3.1. Temporary Repair with Plastic Sheeting. Before beginning wall repair, ensure the structure is strong enough to withstand pounding from additional winds when using plastic sheeting. When using plastic sheeting as an expedient repair to cover a hole in a wall, use nailing strips to attach the sheeting to the structure. Size the nailing strips and plastic based on the size of the hole. Normally, required materials include nailing strips (at least 1"x2" furring strips or 12-gauge, 1” wide metal strips), plastic sheeting (at least 6-mil plastic or reinforced sheeting, 10-mil plastic, or plastic with woven fiber is preferable), and fasteners of sufficient length to penetrate the sheathing at least 1.5 inches into the stud. Avoid black, recycled plastic sheeting for repairs because it has a high rate of deterioration, especially when exposed to harsh elements for more than a month. Use nails, staples, or screws in wood and self-tapping metal screws to fasten nailing strips into metal siding. The side nailing strips should fit between the top and bottom nailing strips.

4.3.1.1. Wrap plastic sheeting around nailing strips and nail the strips around the hole as a rectangular frame to create a tight plastic surface. When possible, provide 6 to 12 inches of plastic overlap around the edges of the hole.

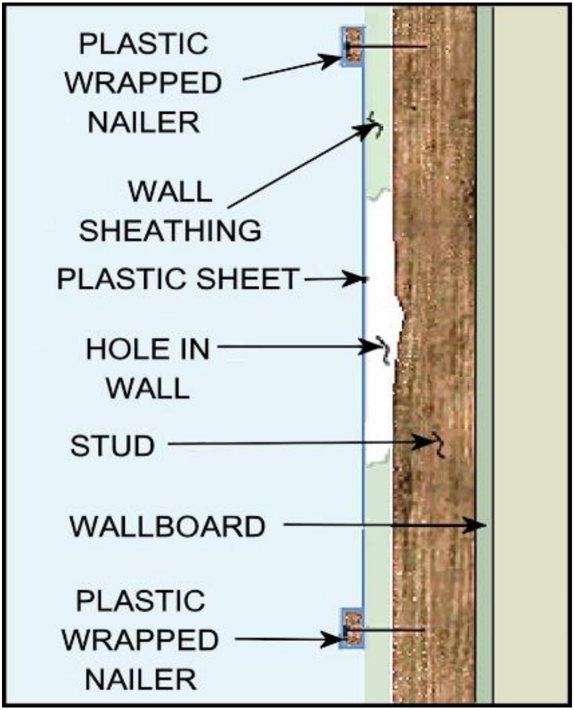
4.3.1.2. For holes in plywood (or other nailable substrate) cut the nailing strips 12 to 24 inches wider than the hole and cut the plastic sheeting yet another 24 inches wider.

4.3.1.3. For holes in a non-nailable substrate, locate the nailing strips over the closest undamaged wall-framing studs. Then cut the plastic sheeting 24 inches wider than the nailing strip. Wrap 12 inches of plastic around both the top and bottom nailing strips. When installed, the plastic should be flat against the building with the wrapped nailing strip on the outside.

4.3.1.4. Position the strips and fasten in place to the wall (or studs for non-nailable surfaces), stretching tight vertically (**Figure 4.20**). However, be aware that plastic sheets only provide protection against the elements. More substantial, structural repairs are often necessary. If more weather protection is needed than that provided by plastic sheeting, consider using plywood sheathing.

4.3.1.5. Repair any miss-cuts or tears in the plastic with flexible duct tape. Use caulk to fill in larger gaps between the nailing strips and wall surface. For metal skin walls with deformations, use expanding foam to fill in gaps as necessary between the metal and the nailing strip.

Figure 4.20. Typical Plastic Sheeting Wall Repair.



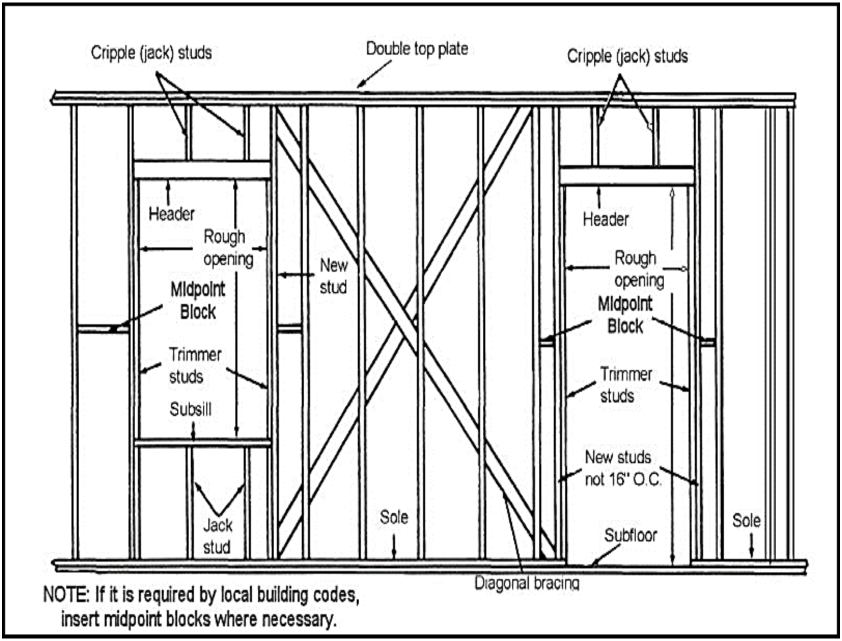
4.3.2. Temporary Repair with Tarps. Secured tarps also provide good protection from rain and can withstand greater wind loads than plastic sheeting (**Figure 4.21**). **Note:** Usually large tarps and high-strength plastic sheets are special order but are generally available as a construction material item. Contact local logistics personnel or the AFCEC Reach Back Center for information on how to obtain large tarps and sheeting material.

Figure 4.21. Temporary Tarpaulin Protection.

4.3.3. Wood Frame Wall Repairs. Wood-framed walls are typically the easiest wall systems to repair. Determining the best repair procedure depends on the use of the building, extent of damage, life expectancy of the structure, and possible future uses. Relative to repairs, explosions, projectiles, or flying debris causes similar types of damage in wood-framed walls. Depending on the size of the hole or damage, repair options may include replacing the damaged area in kind, replacing a wall section, or providing a structural or non-structural patch.

4.3.3.1. General Information. Common wall framing consists of studs, diagonal bracing, cripples, trimmers, headers, and fire blocks. **Figure 4.22** illustrates typical wall framing details. The studs are usually closely spaced, 2”x4” vertical members; arranged in a row with their ends bearing on a long horizontal member called a bottom plate or sole plate, and their tops capped with a top plate. Double top plates tie walls and partitions together. See **paragraph 4.5** for information on wooden joint construction.

Figure 4.22. Typical Wall Framing Details.



4.3.3.1.1. During contingency operations, units may accept some distortion, warping, and settling of the structure, and make only wall framing repairs necessary to safely occupy and operate the structure. The severity of the damage may make it necessary to repair cracking plaster, surface irregularities, sticking doors or windows, and other localized faults for personnel safety.

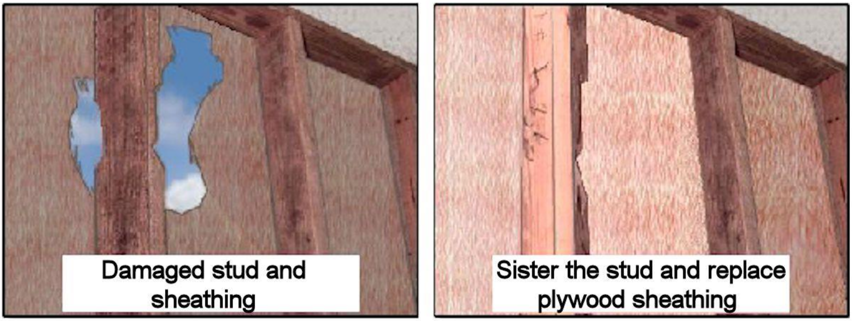
4.3.3.1.2. Do not perform major structural repairs or stud replacement on load-bearing walls without first removing the load from the wall under repair using adequate shoring and jacking. Consider the same precautions when replacing doors, arches, and windows; other structural failures often affect the framing around these openings.

4.3.3.2. Hole Repair. Hole repair requirements will vary by the size of hole, location, and wall function. Consider repairing smaller holes that have little damage to framing members with a sheathing material (plywood, fiberglass, metal sheet, etc.) or plastic sheeting. Plywood or OSB sheets are normally used. Holes larger than 3 feet in diameter usually require some reframing before applying new plywood/OSB. Still larger holes may require replacing the wall section with new framing and plywood/OSB on the outside of the wall. If the damaged wall is a shear wall, a cross wall providing lateral support, or a load-bearing wall, the required repair may be a structural frame wall having plywood on both sides.

4.3.3.2.1. Small Hole Repair. Use plywood or OSB sheathing to repair small holes (< 3 feet in diameter) when the substrate is nailable. If possible, provide at least a 6-inch overlap over the undamaged siding. When the substrate is not nailable, cut the sheathing to fit between the closest studs on both sides of the hole. Position sheathing over the hole and fasten into a stud or nailable substrate. Be sure to caulk along edge of the sheathing before fastening in place.

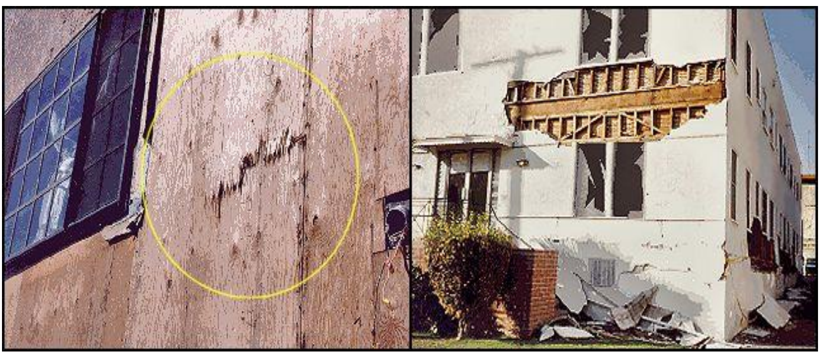
4.3.3.2.2. Large Hole Repair. Where sheathing is missing and framing damaged, the wall usually requires repair or replacement of damaged framing and new sheathing. For larger holes, remove damaged framing, but be particularly careful around any load-bearing joists, beams, or wall top plates. Replace damaged or missing framing and blocking. After shoring and bracing adjoining walls and ceiling, replace any missing studs and top and bottom plates. Attempt to maintain normal stud spacing at 16 inches o.c. For partially split or gouged studs (i.e., 60 to 80 percent of the damaged stud cross section remains), and where some sheathing is still present, sister another stud to the damaged stud to strengthen it and replace damaged sheathing (**Figure 4.23**). Apply construction adhesive between the damaged stud and new stud for additional strength. To add strength to walls that must withstand additional wind loads, apply construction adhesive on stud surfaces and then nail the members together.

Figure 4.23. Repair Damaged Stud and Sheathing.



4.3.3.3. Sheathing Repair. Emergency sheathing repair is usually required on structural walls when shear walls fail. As shown in **Figure 4.24**, shear failure in plywood can be either localized to a small area that appears as a tearing pattern in the plywood or involve a complete failure where the sheathing itself is dislodged.

Figure 4.24. Examples of Sheathing Damage.



4.3.3.3.1. When sheathing is entirely missing, add new material as necessary. To do this, remove damaged wall covering and/or sheathing back to the nearest exposed stud. Apply 1/2-inch nominal sheathing to the studs for most walls. However, for shear walls, use 3/4-inch plywood when available. If additional nailing surface is necessary for securing the new sheathing, add another stud to the exposed stud. When the wall must act as a hold down for the roof, nail the sheathing at 6 inches o.c. vertically and horizontally, except on the top and bottom plates where nailing is at 4 inches on center. Block the wall at sheathing edges if it is taller than the sheathing. For additional strength and less nailing, apply construction adhesive on framing members near edges. Adhesive should meet any adopted industry performance specifications. In addition, if repairs will become exposed to heavy rains, cover with plastic sheeting and/or caulk the butt joints.

4.3.3.3.2. For shear walls wider than 4 feet, apply plywood horizontally on both sides of the wall. When dealing with shear walls between floor levels, if possible do not align plywood butt joints with any of the floor joints. Instead, stagger end joints and block all edges that require nailing. For other walls, except shear walls, apply sheathing vertically or horizontally per standard nailing procedures. **Note:** Some failed shear walls may have been constructed with vertical sheathing. If new building standards require three-by (3x) lumber at edges, consider running the plywood horizontally and block at all horizontal edges. Blocking provides additional stiffness support to shear walls.

4.4. Wood Frame Floor Repairs. Wood floor framing includes floor joists, girders, sills, columns or posts, splices, scabs, footings, and required bracing used to support the floor. Typically, framing plans will include the floor components, their sizes and spacing, and the methods of anchoring joists and girders to the columns or posts and foundation walls or footing. **Figure 4.25** and **Figure 4.26** illustrates typical floor framing details using light wood-framing techniques. See **paragraph 4.5** for information on wooden joints and splices.

4.4.1. Posts and Columns. Posts and columns are the vertical members that transmit loads directly to the foundations. They are the “legs” of the building and should be strong enough to transmit the vertical loads to the foundation (sills) and resist lateral or side forces. Columns differ from posts only in their length, and usually are above grade for support of second- or upper-story floor and roof loads. In finished buildings, wallboard, sheathing, etc., often covers the columns making them difficult to check and repair.

Figure 4.25. Typical Light Wood-Framing Flooring Details.

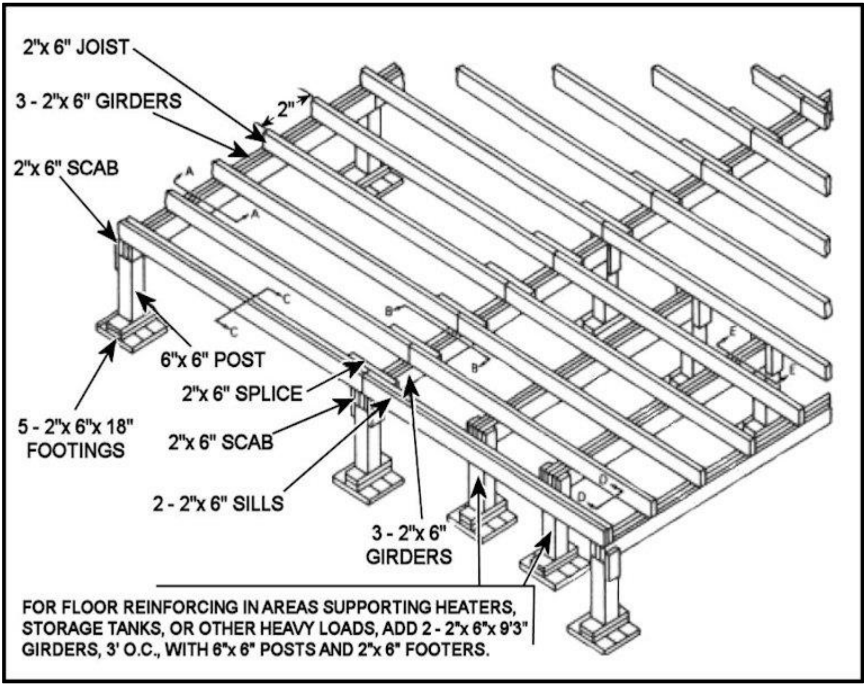
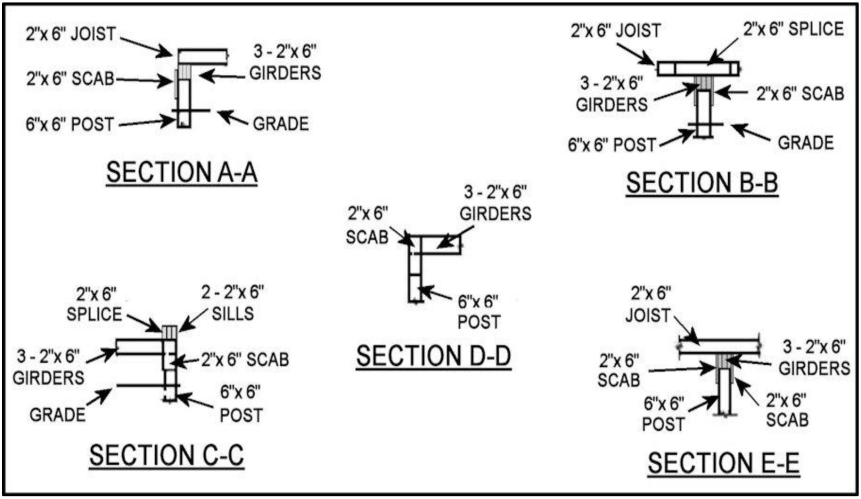


Figure 4.26. Floor Framing Section Details.



4.4.1.1. If posts are out of alignment or plumb, consider shoring the floor above with jacks or other devices, and realign the posts. If the foundation is not level because of uneven settling, correct the foundation before realigning the post or column.

4.4.1.2. Posts and columns are usually made of timber that has not been air- or kiln-dried. This results in seasoning checks (surface openings), which are caused by separation of the wood fibers by drying. Checks are not usually a cause for replacement, but carefully note their location, depth, and width. If inspections indicate these openings or checks are increasing in size, an engineer should examine them for possible replacement. If the post or column shows signs of failure from overloading, follow the engineer's recommendation for adequate repairs or replacement.

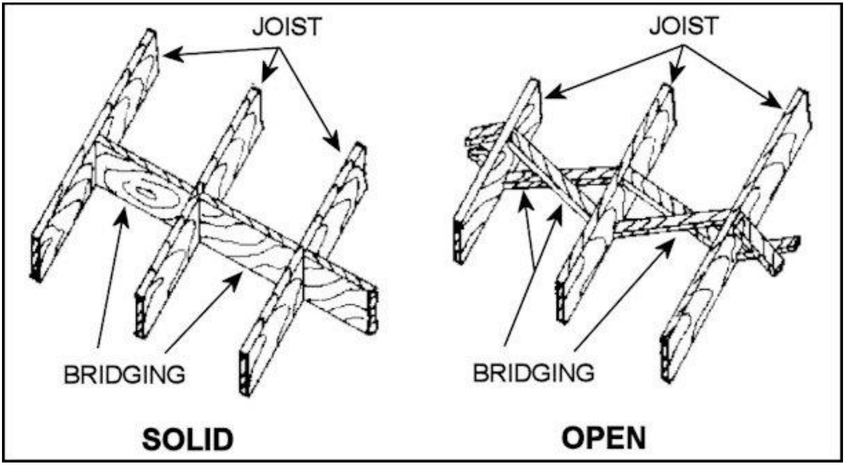
4.4.2. Floor Girders, Beams, and Joists. Girders and beams are those structural components of floors that span from column to column or wall to wall and transmit vertical loads to their bearings. These loads may be introduced into the girders by beams, joists, planks, or other surfaces. The sill provides a nailing base for joists or studs resting directly on the foundation.

4.4.2.1. Similar to posts and columns, large size girders, beams, and joists are made of lumber that is not kiln dried. Consequently, it is normal to expect seasoning checks as the wood loses its moisture. Just as for posts, be sure to examine checks for continued expansion. If increases in size, location, and depth continues, consider installing stitch-bolts to halt the expansion. The bolts used for this purpose are 1/2-inch bolts, threaded on both ends. Drill 9/16-inch holes perpendicular to the axis of the girder, beam, or joist. Insert the bolts and place 2-inch, square-cut washers at each end and tighten the nuts.

4.4.2.2. Beams or joists, which have failed in bending but have sound wood surrounding the failure, may be repaired by fastening scabs to the sides of the failed member. Many other methods are available to reinforce girders, beams, and joists. Selection of the proper method often depend on the loads carried, costs, clearances, and accessibility.

4.4.2.3. Bridging is a common method of reinforcing and stiffening floor-framing members (joists). **Figure 4.27** illustrates how to stiffen floor framing by adding or replacing the existing bridging. For the solid bridging method, it is important to accurately cut and fit the bridging neatly between the joists to ensure resistance to individual movement of the joists. This type of bridging can also function as a fire stop if correctly positioned in the floor. Fire stops are obstructions deliberately set in concealed airspaces to block passage of hot gases and flames from one area to another. For the open bridging example, ensure the bridging is tight by driving nails completely through the bridging and into the joist.

Figure 4.27. Typical Bridging Methods.



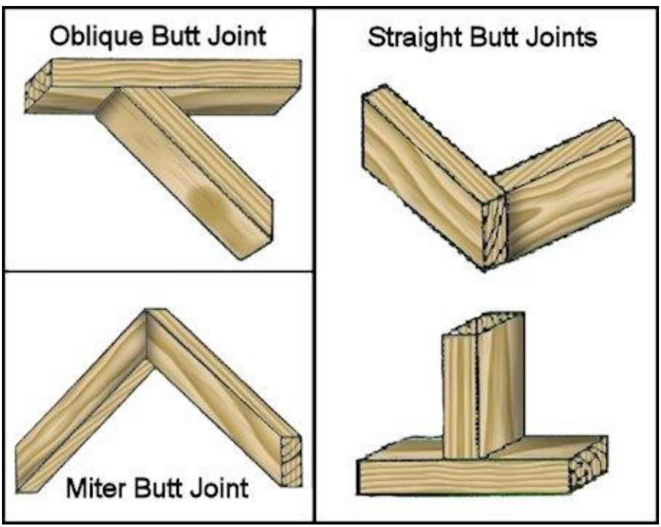
4.5. Wooden Framing Joints and Splices. Generally, structural repairs to existing or damaged wooden-framed buildings at contingency locations includes carpentry work on roofs, walls, and other structural features. When making repairs, remember structures with nailed wood connections will better resist the effects of ground forces and high winds if a continuous load path exists from the roof to the foundation. Weak points in a structure usually occur at the connections between pieces of lumber. The following paragraphs address typical joints and splices used in wood construction and repair along with their common applications.

4.5.1. Joints. Joints are connections between two pieces of timber that come together at an angle. The types of joints most used in carpentry are butt joints and lap joints. The following paragraphs address standard configuration of joints used during wood frame construction and repair of damaged framing components.

4.5.1.1. Miter Butt Joint. Builders use miter joints mostly in framing, usually at corners where the straight butt joint is not satisfactory. However, it is a very weak joint and should not be an option when strength is important. To form a right-angle miter butt joint, cut each piece of lumber at a 45-degree angle as illustrated in **Figure 4.28**.

4.5.1.2. Oblique Butt Joint. The oblique butt joint is a common method to brace other pieces of timber (**Figure 4.28**). However, this joint should not be an option where great strength is required. Form the joint by butting the mitered end of one board against the face of another board. The strength of the oblique butt joint depends upon the nailing. The nail size depends upon the timber size. Depending on the material, 3 to 5 nails should be sufficient to toenail into the joint for adequate strength.

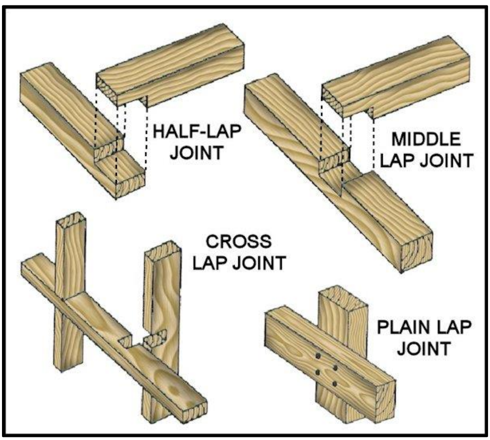
Figure 4.28. Types of Butt Joints.



4.5.1.3. Straight Butt Joint. To make this joint, the butt end of one board should be square and the face of the other smooth so that the pieces fit snug and perpendicular to each other (see **Figure 4.28**). For framing, secure butt joints with size 8d or 10d nails toenailed to strengthen the joint. Generally, the end grain is the weakest part of a piece of wood when used in joints. Butt joints are made at either one or two end-grain parts. It will be no stronger than the quality of those parts. Therefore, butt joints are the weakest type of joint. This is especially true if the joint is made of two pieces of wood only.

4.5.1.4. Lap Joints. The lap joint is the strongest joint. The plain lap joint is the simplest and most often used method in joining framing and general construction. The joint built in this manner is as strong as the fasteners and material used. To make the half-lap joint, cut away equal lengths and thicknesses from two boards and join them so the cut-away portions interlock, forming the joint. To maximize effectiveness, surfaces must fit snugly and smoothly. As shown in **Figure 4.29**, two other useful variations of the half-lap joint are the cross-lap and middle lap.

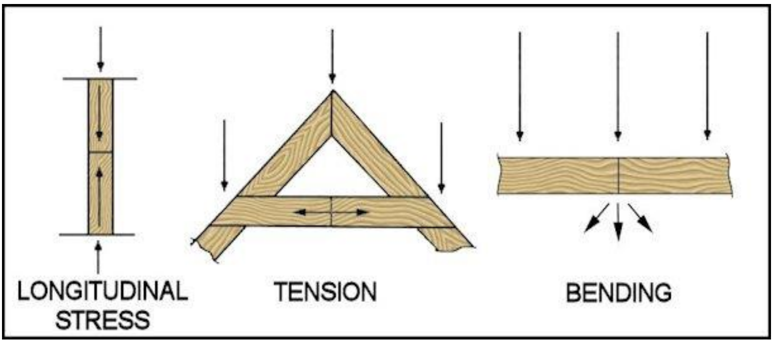
Figure 4.29. Typical Lap Joints.



4.5.2. Wood Splices. The splice is another way to join wood materials rapidly. Splices connect two or more pieces of material that extend in the same line. The joint will be as strong as the unjointed portions. The type of splice used depends on the type of stress/strain that the spliced timber must withstand. Vertical supports (longitudinal stress) require splices that resist compression. Trusses, braces, and joists (transverse and angular stress) require splices that resist tension. Horizontal supports, such as girders or beams, require splices that resist bending tension and compression (**Figure 4.30**).

4.5.2.1. Compression-Resistant Splices. Compression-resistant splices support weight or exert pressure and will resist compression stress only. The most common types of compression-resistant splices are the plain splice, butt splice, and the halved splice.

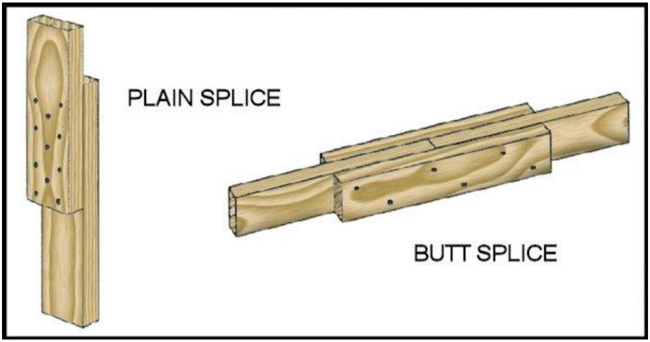
Figure 4.30. Splice Stresses.



4.5.2.1.1. Butt Splice. Construct a butt splice by butting the squared ends of two pieces of timber together and securing them in this position with two wood or metal pieces fastened on opposite sides of the timber (**Figure 4.31**). The two short supporting pieces keep the splice straight and prevent buckling. Metal plates used as supports in a butt splice are called fishplates. Wood plates are called scabs and are fastened in place with bolts or screws. Nails or corrugated fasteners are other options to secure scabs. If using nails, stagger and drive nails at an angle away from the splice. **Note:** Too many nails or oversized nails will weaken the splice.

4.5.2.1.2. Plain Splice. The plain splice is the easiest and most common splice used in vertical timbers, which require splicing. A long overlap of the two pieces is necessary to provide sufficient room for enough fasteners (**Figure 4.31**).

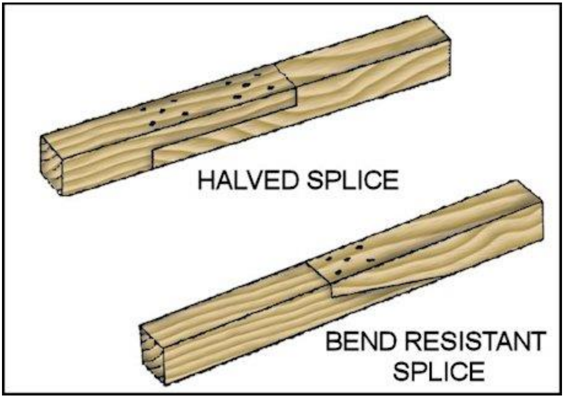
Figure 4.31. Typical Plain and Butt Splices.



4.5.2.1.3. Halved Splice. Make the halved splice by cutting away half the thickness of equal lengths from the ends of two pieces of timber, then fitting the tongues (laps) together splice (**Figure 4.32**). The laps should be long enough to provide adequate bearing surfaces. Consider using nails or bolts to fasten the halved splice. **Note:** To give the halved splice resistance to tension as well as compression, fishplates or scabs may be used.

4.5.2.1.4. Bend Resistant Splice. This type of splice is common where it is necessary to join horizontal members that support weight (see **Figure 4.32**). Consider fastening a scab or fishplate along the bottom of the splice to resist the tendency of the pieces to separate. **Note:** When this splice is not an option, a butt joint, halved splice, or square splice secured by fishplates or scabs may be used.

Figure 4.32. Common Halved and Bend-Resistant Splices.

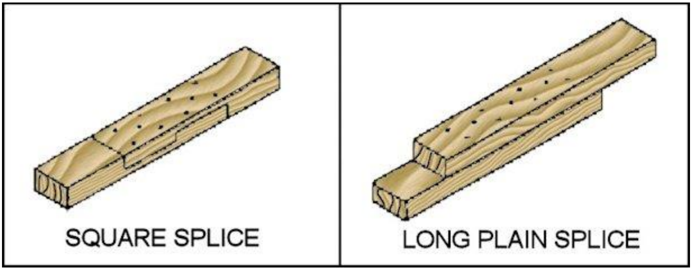


4.5.2.2. Tension-Resistant Splices. In members such as trusses, braces, and joists, the joint undergoes stress in more than one direction; this creates tension, buckling the member in a predictable direction. Tension-resistant splices provide the greatest practical number of bearing surfaces and shoulders within the splice. The square splice and long plain splice are two common tension resistant examples (**Figure 4.33**).

4.5.2.2.1. Square Splice. This splice is a modification of the compression-resistant halved splice. Cut complementary notches in the tongues or laps to provide an additional locking shoulder. Use nails or bolts to fasten the square splice. To increase the strength of a square splice significantly, use fishplates or scabs.

4.5.2.2.2. Long Plain Splice. This splice is a hasty substitute for the square splice. A long overlap of two pieces is desirable to provide adequate bearing surface and enough room for fasteners to make up for the lack of shoulder lock.

Figure 4.33. Typical Square and Long Plain Splices.



4.6. Emergency Wall Repairs on Masonry Structures. Emergency repair of masonry walls is usually more time-consuming, strenuous, and equipment and material sensitive than emergency repairs to wood walls. Masonry walls are usually block and/or brick; however, masonry buildings composed of rock and mortar walls may be encountered at some overseas locations. Use extra caution when performing emergency repairs on masonry walls. Failed masonry walls are normally more dangerous to work with than most other walls for several reasons. This added danger results from factors such as the increased dead weight of the building materials, the brittle nature of masonry products, and the limited ability to determine the actual extent of damage by simply viewing the apparent damage. In fact, workers may not know how or even if the wall is reinforced (i.e., reinforcing bars) or what is holding the cracked areas together.

4.6.1. Damage Assessment Considerations. Consider the following when assessing masonry wall damage. While a crack may appear to be small, the wall may still fail if there is inadequate reinforcing steel to hold the crack together. Reinforcing steel is usually in select cells. Determine if a crack crosses reinforced cells and if the cells are still solid. If the cells do not contain reinforcing steel, determine if the crack is being held in place temporarily by friction from dead loads. If such is the case, a small shift in the weight of a structure or ground tremors (i.e., seismic shaking from nearby movement of heavy equipment) can cause release and catastrophic collapse. Keep in mind that removal of debris, rain, snow, or wind can also cause shifting in multistory structures and subsequent collapse. Two additional factors associated with masonry walls to assess include determining if the wall can be shored to maintain lateral support when ornamental wall columns are damaged and if the wall's floor or roof attachments are damaged or have failed.

4.6.2. Masonry Wall Variations. Emergency repairs to masonry structures usually depend on whether the wall is a structural wall or a non-structural wall (infill or offset). However, structural walls can be infill walls that provide lateral support or shear walls built into a concrete or steel moment frame building. In addition, structural walls can be supporting walls that provide lateral and vertical support for the roof and other floors. Non-structural walls are usually constructed as infill walls (**Figure 4.34**) that have wall ties to flexible frames, or they may use tracks or offset walls that extend past the exterior frame and wrap around it without providing lateral support. If a structural wall is damaged, emergency shoring and bracing may be required along with repair. Once strengthened, the wall should be closed up with injection grout or some other means of confinement as discussed in this chapter. Emergency repairs for non-structural walls depend on the damage. Typical repairs usually involve removing and replacing damaged material and patching the open area with appropriate sheathing.

Figure 4.34. Damaged Brick Infill Wall.

4.6.3. Small Hole Repair in Structural Walls. The simplest emergency repair to a masonry wall is repairing a small hole through the wall involving no damage to the rest of the structure. Usually, this will occur from debris thrown through the wall from an exterior blast or high winds. The repair method for small, punched holes in masonry structures varies according to the type of wall involved. The emergency repair method for small holes cleanly punched through a non-structural masonry wall, where only a few blocks are missing, is to fasten a patch of wood sheathing over the hole. Cut a sheet of sheathing (plywood or OSB) that is large enough to extend several inches past the next undamaged blocks' grout joints around the hole. When positioning the patch on the outside of the wall, apply construction adhesive to the edges of the sheathing. Next, drill holes through the sheathing and into the undamaged grout joint (or a block with a filled cell); secure the sheathing in place with bolts, washers, and lead or expanding anchors. Do not use this repair method if there are loose blocks or cracks around the hole; rather, tie the wall together with sheathing on both sides. When only a few blocks are damaged (**Figure 4.35**) or missing, it may be easier to knock out the damaged material, square up the opening to size, and fill the void using new blocks and a fast-setting cement or epoxy grout mortar.

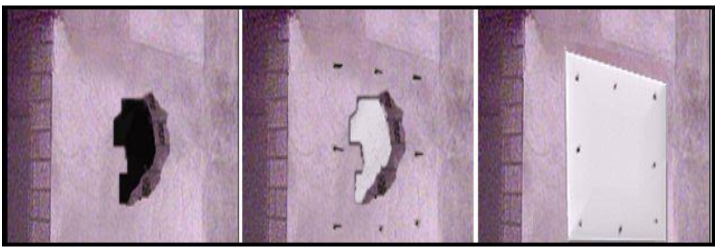
Figure 4.35. Damaged Blocks.

4.6.4. Large Hole Repair in Structural Walls. Structural masonry walls with larger holes (i.e., larger than about five blocks high and four blocks wide) or failed sections are dangerous. It is usually better to shore and brace the roof or floors above the failed area and then work somewhere else in the facility. However, avoid moving to another section of the building until the extent of the structural damage is thoroughly analyzed. Failed sections in one part of a masonry building can often lead to a progressive collapse in the rest of the structure when wind, rain, vibration, or shifting loads are involved. **Figure 4.36** is an excellent example of a progressive structural collapse after an earthquake. There are few options for making emergency repairs for larger holes in structural masonry walls. For a wartime repair of a larger hole in a shear wall or support wall, shore and brace the area around the wall, square up the hole, provide necessary bracing, and cover the hole. Leave the shoring in place if there will be continued blast or seismic shaking; cribbing is more stable than using a single support post. After shoring the area, square the hole, brace the hole with double 2"x8" headers and side braces, and use double 2"x4" cross bracing. Cover over each side with one or two layers of 3/4-inch plywood (depending on the expected shear loads). Cut sheets to run horizontally and allow at least 8 inches of overlap onto good masonry. Position sheets and drill holes through the masonry to align with the holes in the plywood. Tie together with threaded rods, washers, and nuts. When possible, use 2"x4"s between opposing bolts to prevent the tie rods, washers, and nuts from tearing through the plywood.

4.6.5. Structural Wall Confining. When unable to replace broken blocks for a small hole in a structural masonry wall, confining the wall is a safe option. This repair should be limited to small holes with seven or eight blocks missing and where there is no extensive cracking around the hole. Use at least 4- or 3-gauge sheet steel (i.e., about 1/4-inch thick) on both sides of the hole. Cut the steel to provide about 8 inches of overlap between the steel and the undamaged block. Drill through the sheet steel about 4 inches from the edges in the corners and midpoint on each side. Next, drill through the masonry so it will align with the holes in the sheet steel. Next, run a bead of construction adhesive around the hole on both sides before fastening the sheet steel together with threaded rods, washers, and nuts (see **Figure 4.37** graphic sequence).

Figure 4.36. Progressive Structural Collapse.

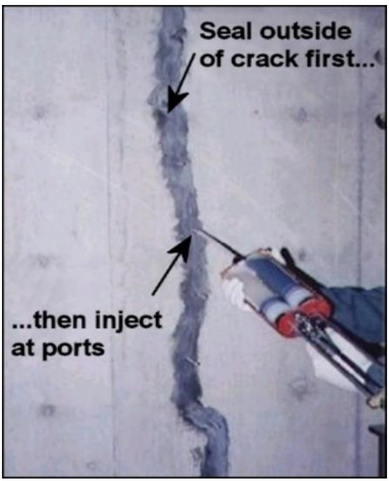
Figure 4.37. Masonry Wall Confining Sequence.



4.6.6. Large Hole Repair in Non-Structural Walls. Non-structural walls with large holes (i.e., up to about five blocks high and four blocks wide) can usually be repaired with a sheet of plywood, a couple of 2"x8" braces, and a header. Knock out or saw-cut loose block on the top and sides of the hole to provide nearly straight edges (i.e., square up the hole). Cut one or two 2"x8"s for a header to fit the top of the squared hole (if overseas and metric blocks are used, use a wider header, or add 3/4-inch plywood cut as wide as the block and nailed to the top of the header). Next, cut two side braces about 1/8 inch longer than the distance from the bottom of the hole to the bottom of the header and place one end of the braces at the bottom of the hole on each side and drive the top of the braces in place to hold up the header. Once in position, toenail the top of each header. Lastly, cut sheathing and fasten in place in the same manner as described for covering a small hole. If desired, and for additional rigidity, apply 1/2-inch sheetrock on the inside facing.

4.6.7. Crack Repairs on Reinforced Walls. When replacing a reinforced masonry or concrete wall is not feasible, an acceptable repair is to fill the cracks with a structural grout or epoxy (**Figure 4.38**). In most cases, epoxy injection works best (see **Attachment 2**, *Crack Repair Using Epoxy Injection Method*).

Figure 4.38. Epoxy Application.



4.6.7.1. The epoxy injection method is useful to repair cracks as narrow as 0.002 inch if the reinforcing steel has not been stressed beyond its elastic limit. If necessary, seal the top of the crack with the same epoxy troweled in place or use metal plates. This type of repair generally consists of drilling holes at close intervals along the cracks, in some cases installing entry ports, and injecting the epoxy under pressure. However, for small cracks, cartridges used with handguns may be an option.

4.6.7.2. For massive structures, an alternative procedure consists of drilling a series of holes, usually 7/8 inch in diameter, which intercept the crack at several locations. Typically, holes are spaced at 5-foot intervals.

4.7. Window Repair. In an expedient sense, there are not too many fixes for damaged windows. Attempting to replace glass is much too long an effort and during a conflict or earthquake, is almost self-defeating since it will probably all be lost again in the next attack or aftershock.

4.7.1. Repair Options. Normally, placing plywood over the window opening is sufficient. If the facility must remain occupied and requires daylight, consider using rigid plastic sheets to maintain a visible opening. Plexiglas sheets are usually an option for this repair. Use polycarbonate sheets if additional protection is required. Either way, it is important to first bond the rigid sheet to the building using construction adhesive, and then clamp it to the building using a simple wooden or metal frame and screws.

4.7.2. Repair Procedures. Do not drill or fasten through the sheets if there will be additional blasts or high winds. Instead, hold them in place with a wooden (or metal) frame. Cut the rigid sheets 2 inches wider and taller than the opening. Use 2"x4"s or 2"x6"s to frame the opening, sizing the frame to fit outside the dimension of the opening. After configuring the frame, apply a continuous bead of construction adhesive to the edge of the opening to set and hold the sheet in place. Sandwich the rigid sheet between the building and the frame and clamp in place by fastening the frame to the building with screws or other appropriate (removable) fasteners.

4.8. Door Repair. If damaged door openings must remain accessible for entry and exit, consider shoring and framing the door to keep the opening safe. To protect the opening against further damage from wind, weather, or blast forces, use expedient measures such as stacking sandbags at the opening. This is especially important when the damaged wall is a structural wall.

4.8.1. Shoring. The priority for an emergency repair of a door opening in a structural wall is to maintain the wall's structural integrity. Shore the opening at the top, bottom, and sides (see **paragraph 3.3.2.5**). Use spreaders at the top and bottom of the door to take the place of cross bracing. If blast or wind protection is required, use sandbags stacked at the entrance and along walls.

4.8.2. Weather Tightness. If weather tightness and further strengthening are required, construct a separate door. Tack the door framework to the opening to avoid causing additional stress on any weakened structures. Make sure the connections to the building are relatively weak. Rely on sandbag berms or other expedient berm structures for protection against blast.

4.8.3. Sliding/Roller Doors. Hangars, warehouses, and maintenance facilities are often critical facilities. Excluding hardened aircraft shelters, these facilities have doors that are vulnerable to exterior blast and high winds. Commonly, hangar doors are sliding doors, with top guide tracks and bottom rollers on support tracks. Other types of large doors are usable on large facilities when blast protection is not a problem or when snow and ice are a problem. Lightweight doors are often on newer permanent or deployable hangars and warehouses. Deployable hangars and some newer maintenance facilities and warehouses may have vertical lift, clamshell, canopy, or folded-fabric lift (panel) doors.

4.8.4. Heavy Metal Door Repair. Full metal, bottom-rolling doors that have come loose from their tracks usually are not expediently repairable. Limit repairs to patching holes. If the rollers and top tracks are undamaged, some doors can be jacked-up and pushed back on tracks.

4.8.4.1. The following failures require door removal and/or track repair:

- Rolling doors come loose from the top rail.
- Doors have fallen inward from the top when wind or blast pressures have racked the building or collapsed the metal overhead track system.
- High winds or floods lifted or pushed the doors off the bottom track.
- Door has hung up on the upper track and torqued the wall and supporting framework.

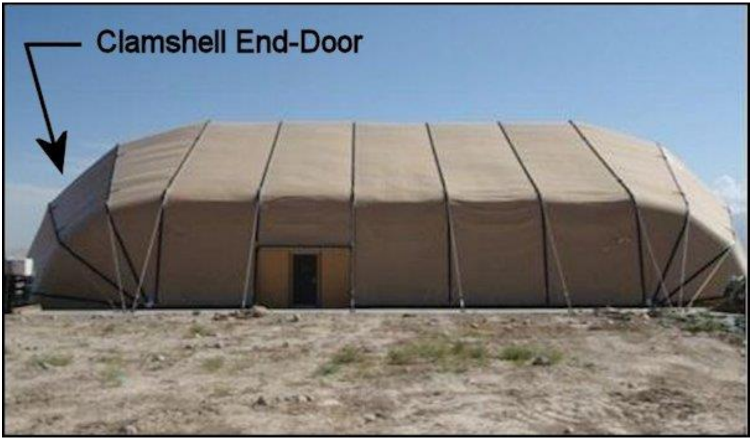
4.8.4.2. Be aware when assessing damage to very large metal rolling doors such as those on hangars; emergency repair is usually not feasible except by trained heavy repair teams supported by cranes and other special equipment. Also, check on the door and framing specifications before considering the repair of top rails using standard shapes of American Society of Testing and Materials (ASTM) A36 (36,000 pounds per square inch [psi]) steel. Large steel hangar door structures often use ASTM A50 (50,000-psi) steel and special fittings. If an ASTM A36 structural shape is used and the original specification was for 50,000-psi steel, the door framing and tracks will be grossly undersized for the load if 36,000-psi steel is used.

4.9. Fabric Structure Repairs.

4.9.1. Lightweight Metal/Fabric Door Repair. Primarily applicable to vertical lift, clamshell, canopy, and folded-fabric lift doors. Specialists can usually make repairs to these lightweight doors in an emergency without the use of heavy equipment. Deployable structures such as the Large Area Maintenance Shelter shown in **Figure 4.39** consists of clamshell end-doors with field-repairable fabric panels, and lightweight framing.

4.9.1.1. Door Structure Repairs. If the structure’s repair manual allows it, consider repairing bent framing by straightening, bolstering with additional piping, or replacing with similar common materials. In addition, damaged tracks can often be straightened, detached, or cut out and replaced using similar materials. Refer to the Operator’s Manual for specific repair guidelines.

Figure 4.39. Large Area Maintenance Shelter.



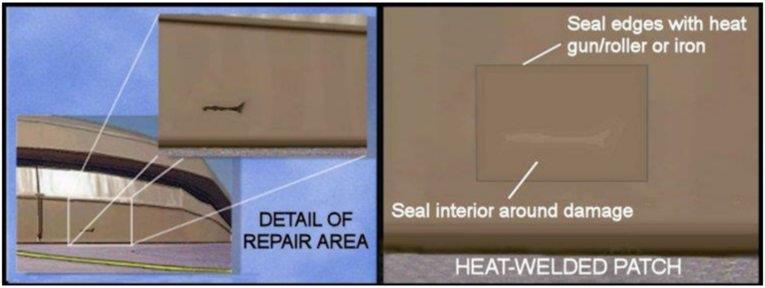
4.9.1.2. Door Surface Skin Repairs. Holes in lightweight rigid composite panels are usually repaired with a patch of 14-gauge sheet metal fastened over the hole. Use construction adhesive and sheet metal screws, screw-in shields, or expanding sleeve anchors, whichever is appropriate. Fabric panel systems can usually be quickly repaired. Coated fabric systems are used with many portable shelters, deployable hangars, and maintenance shelters. The most common coated fabric is Polyvinyl Chloride (PVC)-coated polyester. It is used with many clamshell-type structures and fabric hangars. Larger structures may use a tensile fabric design. Emergency repairs must maintain structural integrity of these larger structures. Emergency fabric repair kits are usually available from the manufacturer. If one is not available, consult with Fuels or Aircrew Flight Equipment shops, as some of their shop methods and equipment are similar to manufacturers' recommended methods and equipment. Depending on whether the material is a cover fabric or tensile fabric, there are usually two repair methods for fixing pierced fabric sections in walls and overhead doors: the Fabric Clamp and PVC-Coated Polyester Fabric system.

4.9.1.2.1. Fabric Clamp Repair. Fabric clamp systems are most often used for folded fabric-lift doors (**Figure 4.40**). The steps begin with loosening screws on the fabric-clamp strips above and below the torn section. Next, cut the repair fabric large enough to overlap the tear by at least 2 inches on each side. Once the repair patch is properly sized, extend the repair fabric under and between the two clamp strips. Then, retighten the clamp strips, trim off excess material, and tack down the fabric edges with adhesive or double-sided tape. Lastly, trim off or glue together any loose fabric that is under the patch and around the tear.

Figure 4.40. Fabric Clamp Repair on Folded Fabric Lift Door.

4.9.1.2.2. Repair of PVC-Coated Polyester Fabric Systems. The manufacturer for these fabric systems usually provides repair criteria; however, if criteria are not readily available, consider the general guidance here. Repairs usually require either a heat-welded patch (with either a heat gun or bonding iron and a roller) or a solvent-welded patch (with solvent). For coated fabric systems that have a slick, Teflon-like coating on the exterior surface, patch the hole from the inside using a piece of fabric and adhesive. As with the Fabric Clamp method, consult with Fuels or Aircrew Flight Equipment shop personnel to repair these types of fabrics. Begin the repair by cutting and positioning a fabric patch over the torn section. For tensile fabric systems that distribute load, cut the patch to extend at least 12 inches past each damaged edge, unless the manufacturer has other guidelines. For simple cover systems, cut the patch to extend 2 to 4 inches past each damaged edge. For heat-welded patches, provide heat between the fabric and the patch. Hold a piece of plywood on the inside surface and use the roller on the outside of the heated patch to roll the material together. Roll out air bubbles, keeping the temperature just under the point where smoke develops on the patch, or the two fabrics will melt. When done properly, the result should look similar to that in **Figure 4.41**.

Figure 4.41. Example of Heat/Solvent -Welded Patch Repair.

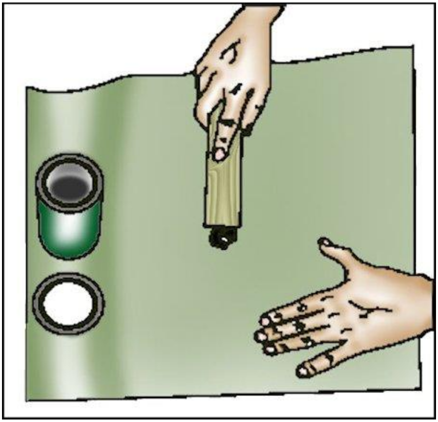


4.9.2. Cement and Sealer Fabric Repair. Other fabric-based deployable assets, such as Small and Medium Shelter Systems, are sheathed with a fabric outer covering over rigid framing. When damage to these units occur, it is not always possible or practical to make sewn repairs, especially when the shelter is already up and the damage is minor. Manufacturers usually provide specific repair kits to correct minor damage. Below are typical repair procedures for holes and tears.

4.9.2.1. Cemented Repair. The kind of cemented repair depends on the size of the holes and tears. If a hole or tear is small and it is not located near a seam, an edge, or hardware, a cemented patch or dab of adhesive may be a sufficient repair.

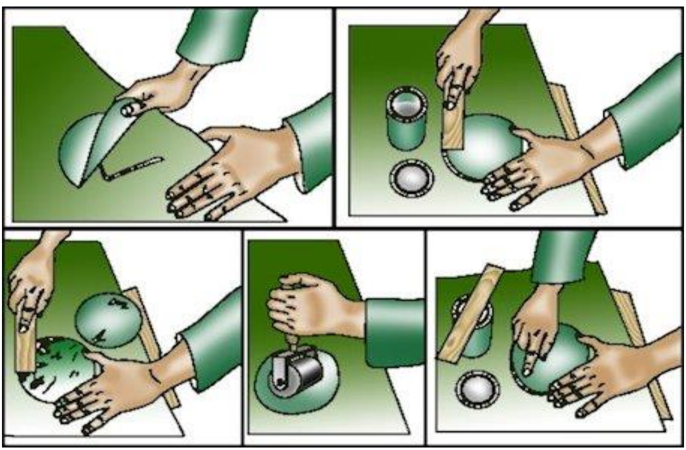
4.9.2.1.1. Small Hole Adhesive Repair. A dab of adhesive is used on a hole in a tent that measures 1/8 inch or less across. To seal a small hole, first use a wire brush to clean the area around the hole and raise the nap of the fabric (**Figure 4.42**). Next, simply use a small stick or paddle to put a dab of adhesive on the hole, working it into the fabric while being sure to bridge the damage with the adhesive to ensure a complete seal.

Figure 4.42. Cementing Small Hole with Adhesive.



4.9.2.1.2. Large Hole/Tear Adhesive Repair. Cemented patches are used to cover holes and tears that are more than 1/8 inch, but less than 4-3/4 inches across. Putting a cemented patch on a tent is similar to patching a bicycle tire. To apply a cemented patch (**Figure 4.43**), first obtain the following items (if not included in the repair kit): a ruler, chalk, wire brush, flat board, paddle, roller, tent-patching adhesive, and a piece of clean matching canvas. Next, measure the damage and cut a round patch from a piece of matching canvas, making sure the patch is large enough to extend 3/4 inch beyond the damage in all directions. Then, place the board under the damage for support. On an erect tent, another individual will be needed inside the tent to hold the board against the damage. Center the patch over the damage and draw a circle with chalk around the patch, then remove the patch. Use a wire brush to clean the fabric and raise the nap of the material inside the circle and the patch itself. Now, position the patch facedown over the damage and use the paddle to coat the patch evenly with adhesive. Let the adhesive overlap the edge of the patch a little so that it forms a circle on the tent. Next, remove the patch, flatten out the canvas and the edges of the hole or tear as much as possible and fill in the circle with a coating of adhesive. Let the adhesive dry, and then apply a second coat of adhesive to the tent and to the patch. Now, wait 10 to 15 minutes for the adhesive to become tacky (test the patch by touching it). The patch is ready to use when it is sticky. Once the adhesive reaches this point, center the patch face up on top of the damage and press the two sticky surfaces together. Use a roller to press the excess adhesive and the air bubbles from under the patch. Roll first in one direction and then in the opposite direction. If no roller is available, use the can of adhesive as a roller. Be sure to seal the can tightly first. Lastly, dip the tip of one gloved finger in the adhesive and run the finger around the edge of the patch to seal the edge with adhesive and prevent fraying. **Note:** With some fabrics, large tears must be sewn together prior to the application of adhesive or sealer. **Caution:** Seam sealer and solvent are extremely flammable and contain toxic fumes. Do not smoke or use seam sealer/solvent near an open flame. Use seam sealer and solvent with goggles and gloves. When indoors, wear a respirator, or use in an open, well-ventilated area, away from sources of combustion. Death or severe injury may result from explosion or fire. Inhalation of fumes may cause toxic sickness.

Figure 4.43. Large Hole/Tear Adhesive Repair Steps.



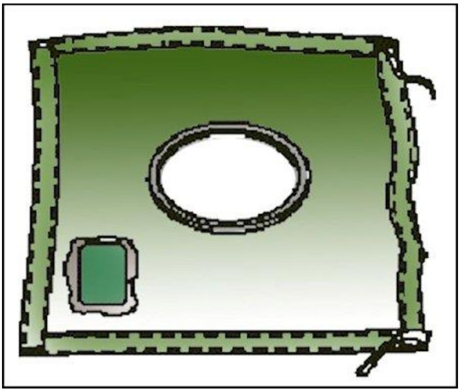
4.9.3. Sealer Repairs. Silicone sealer (MIL-A-46106) is used to repair holes and tears in stovepipes shields such as those in Legacy shelters (e.g., TEMPER tents). Just as cemented repairs, the kind of sealer repairs used depends on the extent of the damage.

4.9.3.1. Sealer Repairs for Small Holes/Tears in Stovepipe Shields. A layer of silicone sealer is used to repair holes or tears that measure 2 inches or less across. To make this repair, obtain cleaning materials, a dry rag, a can of silicone sealer, and a paddle. Then clean and dry the damaged area thoroughly. Next, spread a 1/16-inch thick layer of sealer on both sides of the shield, covering the hole or tear and at least 1/2-inch on each side of the damage (**Figure 4.44**). Smooth out the layer as evenly as possible. Brace the shield so that the sealer does not touch anything while it is wet and allow the repair to dry for 4 hours on a sunny day with low humidity or 6 hours on a humid day. Do not move the tent while the sealer is drying.

Figure 4.44. Repairing Small Hole in Stovepipe Shield.

4.9.3.2. Sealer Repairs for Large Holes/Tears in Stovepipe Shields. A patch attached with silicone sealer is used to repair holes and tears more than 2 inches across in stovepipe shields (**Figure 4.45**). To make this repair, first obtain the following items (if not included in the repair kit): ruler, cleaning materials, a dry rag, a craftsman's knife, a piece of matching patch material, a can of silicone sealer, and a paddle. Begin the process by cleaning and drying the damaged area thoroughly. Next, measure the damaged area and cut a patch from material salvaged from a shield that could not be repaired, making sure that the patch is large enough to extend 1 inch beyond the damage on all sides. Now, spread a layer of sealer on either the patch or the shield and press the patch in place at once. Finally, spread sealer 1 inch over all edges of the patch to eliminate fraying. Do not move the shield for 4 to 6 hours. **Note:** Additional details on fabric repair procedures can be obtained in the following documents: T.O. 35E4-219-1, *Large Area Maintenance Shelter*; T.O. 35E4-216-1, *Bare Base Dome Shelter*; T.O. 35E5-6-11, *Alaska Small Shelter System*; and T.O. 35E-6-21, *California Medium Shelter System;* and T.O. 35E5-6-1, *Tent, Extendable, Modular, Personnel (TEMPER)*.

Figure 4.45. Larger Hole Sealer Repair.



Chapter 5

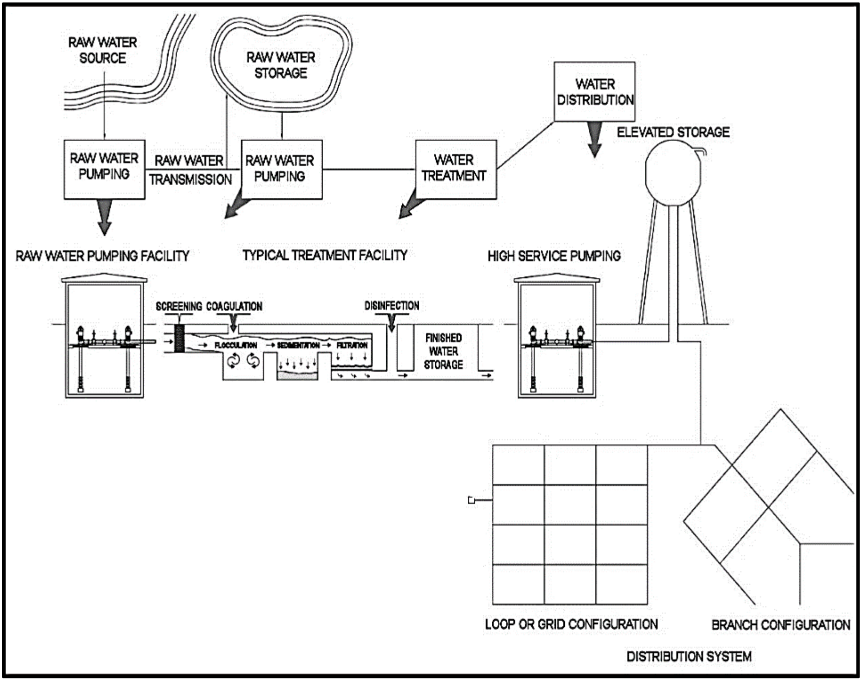
WATER AND WASTEWATER SYSTEMS REPAIR

5.1. Introduction. Timely repair of water and waste systems is essential after a disaster or enemy attack for obvious health, hygiene, and operational reasons. Since it is impossible to predict the extent of damage to these systems during a disaster or attack, units often establish specific priorities after an incident. Facility priorities listed in base recovery plans are generally a sound starting point. However, the EOC normally dictates repair priorities during emergencies. In most cases, service restoration to crucial base functions is a priority. If necessary, some creative engineering and cannibalization of non-critical systems may be required to establish or keep priority water and sanitation systems operating. Some expedient repairs to water and wastewater systems, and associated piping and fittings last a long time, but most expedient repairs are temporary measures that provide limited support for short periods.

5.2. Overview. Although local utility services and commercial utility companies may service or repair base water and wastewater systems via contract, this chapter provide CE Water and Fuel Systems Maintenance personnel with basic considerations and expedient repair options for the most vulnerable components of water and wastewater systems. For general safety-related considerations and issues, refer to **Chapter 2** in this publication. **Note:** Some water plants use chlorine (liquid or gas) for disinfection during water treatment. It can be very harmful on-site and off, and if overlooked can cause significant health impacts. Chlorine gas is very dense, travels downward in ditches, and can collect in depressed areas.

5.3. Water Distribution Systems. Water is an important utility that usually requires quick restoration following a disaster or hostile attack. Water systems normally have a high priority for repair due to firefighting requirements, decontamination purposes, personal consumption, cooking use, and both general and medical hygiene. The major components of any water supply system are source, treatment, storage, and distribution (**Figure 5.1**). Of these, the distribution network (including service connections or Point of Use), is the most extensive component of the installation water system and is where most expedient repairs are affected.

Figure 5.1. Typical Features of Water Supply Systems.



5.3.1. Anticipated Damage and Effects. Subterranean construction protects the distribution network from certain types of disasters. However, its widespread layout can make it more vulnerable to other emergencies.

5.3.1.1. High wind associated with a hurricane or tornado is not likely to break underground water mains, but a major enemy air attack is almost certain to disrupt some part of the dispersed layout of the distribution network. Damage to the distribution system is normally confined to pumps, valves, appurtenances, and water mains. Water mains may be broken in several locations resulting in easily recognizable leaks (**Figure 5.2**) as well as numerous hidden leaks producing delayed damage in the form of undermined streets or structures.

Figure 5.2. Obvious Water Line Break.

5.3.1.2. Contamination to a water system can easily occur when water mains and sewers in close proximity fracture. If water mains and sewers are on a steep gradient, sewage may enter water mains with enough head to flow to the consumers' taps below. Contamination may result when broken mains reduce pressure within the system, heavy draft for firefighting, valve closures, and supply failures occurring during enemy attack or sabotage. Contamination may also occur by waste debris entering open mains through open ends or fractures during repair operations. The more common diseases attributed to contaminated water are typhoid fever, cholera, and dysentery. Diarrhea may also result from contaminated water. An epidemic of any of these illnesses seriously hampers military operations.

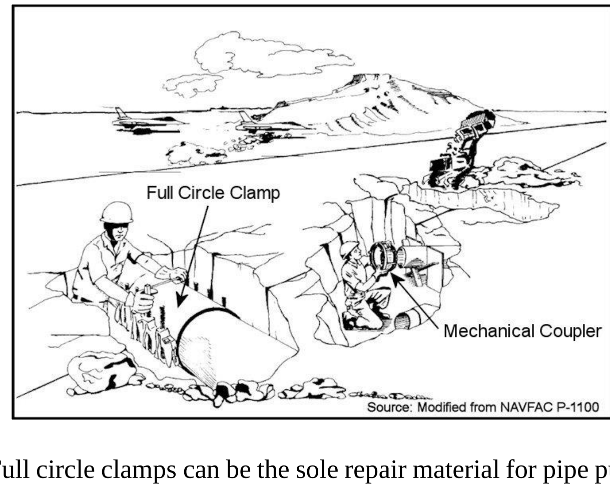
5.3.1.3. During periods of conflict, a retreating enemy or terrorists may purposely contaminate water supply systems by placing bone oil, refuse, bodies, lubrication oils, or other materials in wells, springs, reservoirs, tanks, or the distribution system. Consequently, units should take measures to secure easy access points such as well points, pumping stations, and storage vessels.

5.3.2. Expedient Repair Process. Once the situation permits, begin work on restoring water supply since water supply systems often have a higher priority in rehabilitation than other utilities. Time is normally a limiting factor during base recovery, and rapid completion of the job is by far more important than economy of labor, materials, and equipment. First responders typically attempt to isolate and/or bypass damaged lines. After assessing the damage, make temporary repairs to control water loss, maintain essential flow and pressure, and permit the reopening of valves. In making improvised repairs, consider using any suitable material or equipment available to meet the immediate need. A repaired water main does not have to be leak-proof to be functional. Work crews can improve expedient repairs as time and supplies allow. Water distribution systems include pipe from 1-1/2 to 24 inches in diameter and may consist of PVC rigid plastic pipe, steel, asbestos cement, cast iron, and ductile iron. Water pressure ranges from 60- to 120-psi. Most distribution lines should be repairable and, therefore, efforts should concentrate on quickly reestablishing major feeder lines. Generally, fixed system components, such as pumps, hydrants, valves, and purification units, are not expediently repairable due to the time required to accomplish a fix. Below are some expedient repair options for water distribution systems. See UFC 3-230-02, *Operation and Maintenance: Water Supply Systems* for more repair data.

5.3.2.1. Identify the Problem. The first corrective action is to identify the extent of the problem. Pipes, mains, valves, and pumping stations can be located from existing utility drawings. If available, local technicians should be able to assist greatly in this effort. Multi-frequency pipe locators and similar equipment can be used to locate otherwise hidden lines. As mentioned previously, water main breaks should be easy to recognize and is where most expedient repairs will be necessary. After locating pipe breaks, ensure the worksite is safe (see **Chapter 2**), and shut off the water supply to the damaged pipe section. For belowground repairs, remove standing water and debris, and excavate a repair trench as necessary to reveal the damaged piping so you can perform a damage assessment. Continue to excavate around the damaged piping until you locate undamaged pipe sections. The pipe sections must be round and in close alignment.

5.3.2.2. Select Repair Materials. Typical repair consumables include pipes (PVC, iron, steel, polyethylene, etc.), valves, fittings, couplers, and fuel for pumps and equipment. Mechanical repair clamps and couplings are generally desirable because of their quick installation, vibration resistance and minimal amount of equipment, labor, and repair times. Often made of stainless steel and ductile iron, manufacturers also use alloys, carbon steel, and other materials. The most common repair fittings are the full circle clamp, mechanical and compression coupling. Work crew can use clamps and couplers to make repairs in or out of water and above or below the ground (**Figure 5.3**).

Figure 5.3. Belowground Pipe Clamp and Coupler Repairs.



5.3.2.2.1. Full circle clamps can be the sole repair material for pipe punctures; but usually, the clamps along with hardwall pipe is required as a replacement for complete pipe breaks. **Figure 5.4** and **Figure 5.5** illustrate various pipe damage and typical repair options. Common tools and equipment used during pipe repair include those listed in **Table 5.1**.

Figure 5.4. Repair Using Pipe Section Replacement.

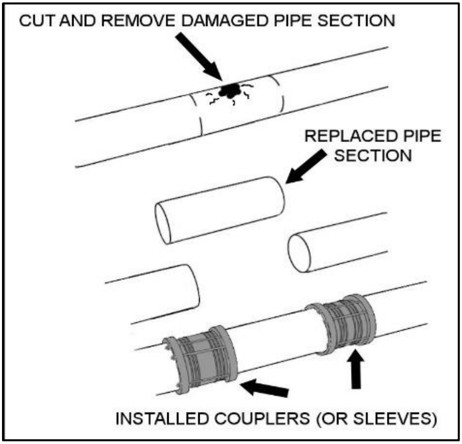


Figure 5.5. Pipe Damage and Common Repair Options.

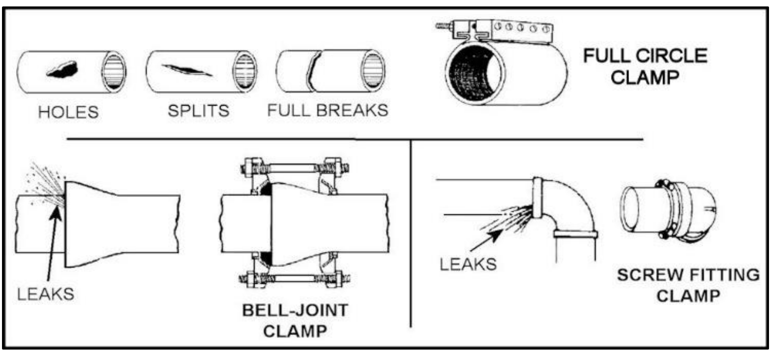


Table 5.1. Common Tools and Equipment.

Pipe Repair Tools and Equipment	
• Earth moving equipment	• File
• Shovel	• Brush
• Trash pump	• Wire brush
• Gloves	• Soapy water
• Goggles	• Clean rags
• Pry bar	• Pipe locators
• Wrenches	• Pipe cutter
• Hammer	• Pipe scraper and scale remover aids

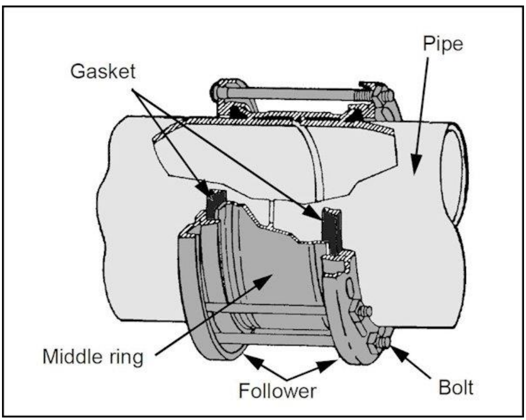
5.3.2.2.2. Full Circle clamps provide a full 360-degree seal around the pipe. They are the most preferred for water, sewer, and fuel line repairs. A full circle clamp is fast and simple to install. Workers wrap the clamp around the pipe, properly position it over the repair or connected area, and tighten the bolts. This compacts the rubber gasket tightly against the full circumference of the pipe wall, to form a leak resistant seal. They are available in various sizes and materials, primarily used for repairing holes, splits and breaks in distribution pipes. If necessary, work crews can install the full circle clamp underwater. Shown in **Figure 5.6** are examples of full circle clamps.

5.3.2.2.3. The mechanical coupling is primarily for steam line repairs. Workers push the pipe ends into the coupler and tighten the bolts. As the bolts tighten, the gaskets in the coupler compress to form a leak resistant seal. The Dresser coupling illustrated in **Figure 5.7** is suitable for small and large-sized pipes. It has a seamless body with gaskets and flanges bolted together to form a leak-proof joint.

5.3.2.3. Implement Repairs. Typically, expedient repair of water distribution systems consist of making repairs to piping systems using locally available materials or components from dismantled, non-critical systems. Although expedient repairs may not eliminate all water leaks, work crews should plan to repair small leaks when the tactical situation or mission permits. Consider the following methods when making expedient repairs to water distribution systems.

Figure 5.6. Typical Full Circle Clamps.

Figure 5.7. Dresser Coupling Pipe Repair.



5.3.3. Water Main Leaks and Breaks. Accomplish repairs to water mains as soon as the recovery situation permits. The repair techniques used depends on the location and type of leak present in the water main. If the main is underground, dig repair trench on both sides of the main. Ensure the repair trench is big enough to accommodate workers, equipment, and materials. If necessary, pump out any trench water capable of contaminating repair materials or the inside the water main. **Note:** Whenever work crews open a water main for repair, be sure to flush and disinfect the main before returning it to service. A boil water notice may need to be issued when returning the water line into service.

5.3.3.1. Small Holes. Use wood plugs to stop small holes temporarily (replace wood plugs with permanent metal plugs/couplers later). Temporary wood plugs are an option to plug the ends of pipes up to 8 inches in diameter. Brace plugs to withstand the pressure in the main. For joint leaks, if caulking was used in the joint, re-caulk the joint to repair leaks.

5.3.3.2. Cracks in Main. Cracks in the mains usually require valves be shut-off in the affected area, especially in severe main breaks. Notify Fire and Emergency Services in case of main shutoff. Consider repairing leaks in mains using mechanical couplings. Mechanical couplings, including joint clamps offer the best methods for quick, effective repairs. Mechanical-joint repair may involve cutting out a section of the cracked pipe and replacing it with a piece of pipe and mechanical couplings. Several companies manufacture mechanical-joint repair fittings; consult manufacturer data for selection and installation.

5.3.3.3. Replacing Pipe Sections. It may be necessary to replace a pipe section due to leaks from cracks, holes, or severe corrosion. To replace a damaged pipe section, follow the damaged piping until you find an area of undamaged pipe section. If the break or damaged area is too long for a short insertion piece, it may be necessary to insert a whole length of pipe. If it is necessary to replace a pipe section, consider laying a parallel pipe section relative to the damage pipe, tie in the parallel pipe with appropriate pipefittings, and leave the damage pipe in place. Continue the repair as follows:

5.3.3.3.1. Cut pipe ends square with a pipe cutter or saw and remove all burrs that result from cutting pipe. Clean all dirt, rust, oil, or loose scale from pipe ends. Check surfaces where gasket contacts the pipe to ensure that there are no imperfections, such as gouges or grooves that will impair the performance of the gasket seal.

5.3.3.3.2. Measure back on each pipe end one-half of the width of the coupler and mark. Use these marks to center the coupler over the joint.

5.3.3.3.3. Measure and cut a replacement section of pipe. Repeat deburring and cleaning process.

5.3.3.3.4. Clean and disinfect the inside of couplings, repair pipe section, and other fittings, typically with a solution of hypochlorite or chlorine. Clean both ends of the cut water main and repair pipe sections. **Note:** Avoid contaminating couplings and repair pipe sections with soil or trench water during the installation.

5.3.3.3.5. Wipe gaskets clean and lubricate gaskets and pipe ends with soapy water. Consider adding alcohol to soapy water in freezing weather.

5.3.3.3.6. Align replacement pipe on both ends. Place coupler over pipe end and align with mark. Rotate coupler until gasket is flat against pipe. Repeat process for other side. Tighten bolts uniformly to the manufacturer recommended torque.

5.3.3.3.7. Turn on the water supply and check for acceptable level of leakage. Flush and disinfect the affected water main section before returning it to service.

5.3.3.4. Bedding and Blocking Water Mains. When repairs require replacement of underground pipe sections or fittings, additional bedding or thrust blocks may be needed to counteract the effects of the internal hydrostatic pressure and prevent pipe joint separation. Improper bedding or blocking can result in reoccurring leaks and broken water mains. **Figure 5.8** and **Figure 5.9** illustrate common pipe bedding and thrust blocking techniques. Typically, granular bedding material is sand, and normally set in layers not more than 6” thick and thoroughly tamped.

Figure 5.8. Common Pipe Bedding Techniques.

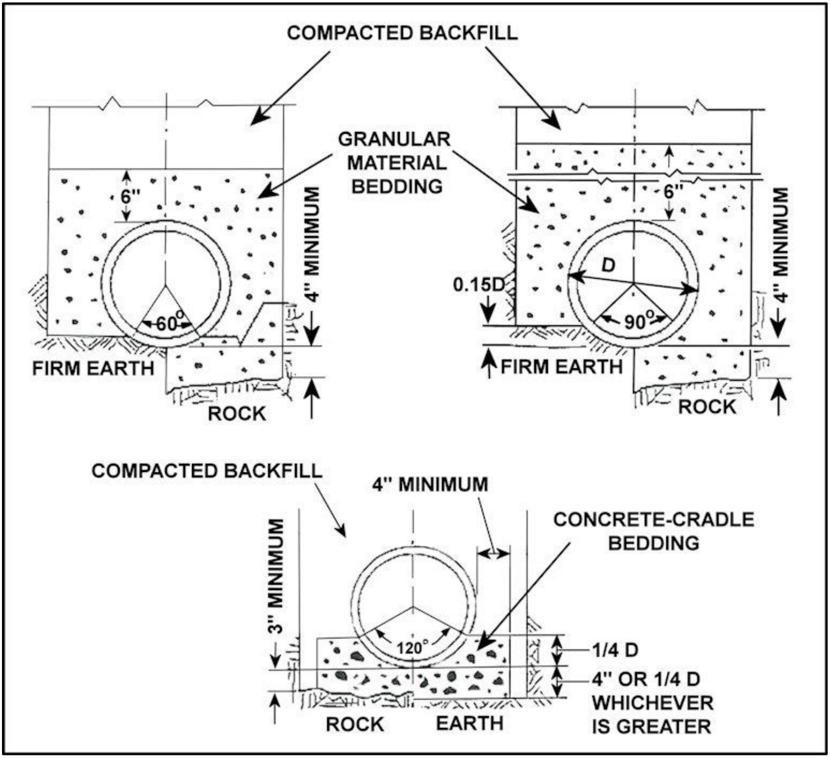
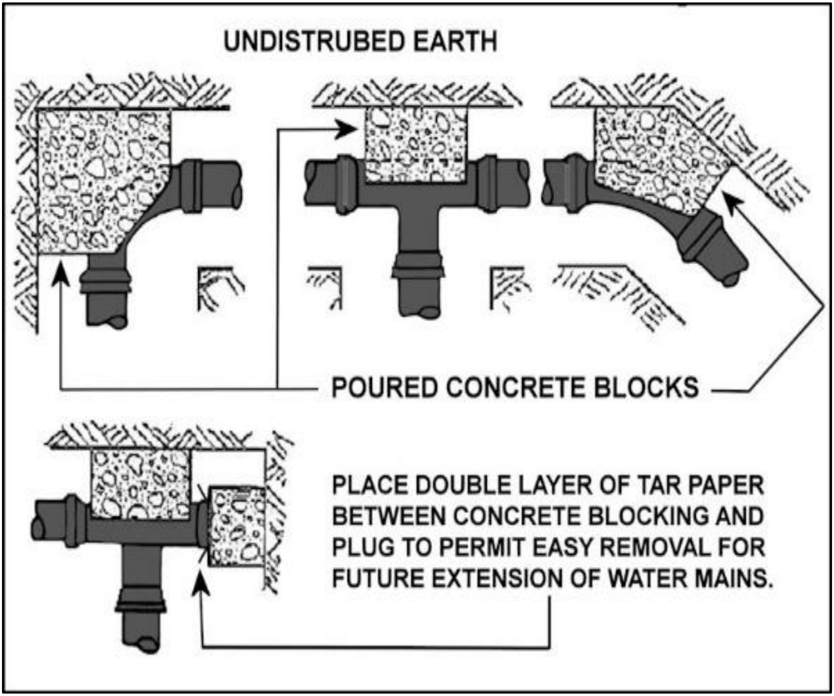


Figure 5.9. Water Main Thrust Blocking Details.



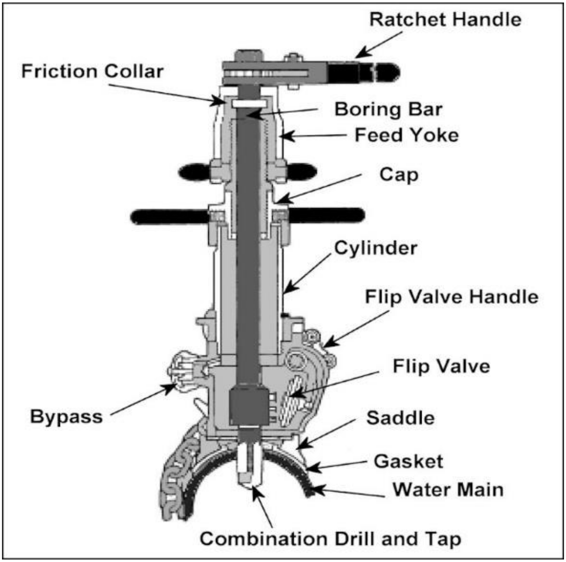
5.3.3.5. Tapping Water Mains. After a disaster or during a contingency, it may be necessary to tap into water mains to make expedient repairs or reroute essential service. Water mains are usually 4 inches or more in diameter, and constructed of PVC, ductile iron, Polyethylene, or asbestos-cement. If the involved main is less than 8 inches in diameter, taps should be 2 inches or smaller. **Table 5.2** and **Figure 5.10** address typical water main tapping procedures. **Note:** Refer to tap manufacturer's instructions for specific procedures.

Table 5.2. Typical Procedures for Tapping Water Mains.

Step	Procedure
1	Dig to expose pipe at the point where tap is to be made. Dig as close to the top of water main as possible.
2	Clean all dirt and rust off pipe at that point.
3	Place gasket of water-main self-tapping machine on pipe and set saddle of machine on the gasket.
4	Wrap the chain around the pipe and tighten it to clamp water main self-tapping machine to the pipe.
5	Remove cap from the cylinder of machine, and place combination drill and tap in boring bar.
6	Reassemble machine by putting boring bar through the cylinder and tightening cap.
7	Open flap valve between the compartments and start drilling the hole by applying pressure at feed yoke and turning ratchet handle until drill enters the main.
8	When tap starts threading the hole, back off the feed yoke to prevent stripping threads.
9	Continue to turn boring bar until the ratchet handle no longer turns without extra force.
10	Remove tap from the hole by reversing the ratchet. Then, back the boring bar out by turning it counterclockwise.
11	Close the flap valve between upper and lower compartments.
12	Drain water from cylinder through the bypass.
13	Remove cap and drill tool. Place a corporation stop in the boring bar, ensuring that the stop is closed.
14	Repeat steps 6 and 7.
15	Turn ratchet handle to thread corporation stop into pipe.

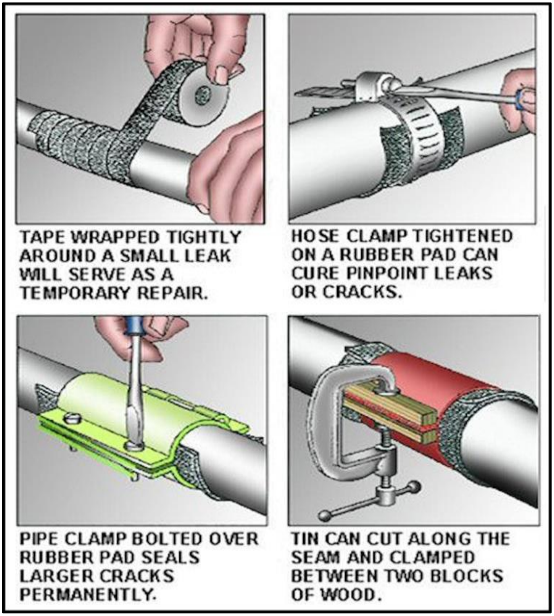
16	Repeat Step 13.
17	Remove cap from the cylinder and unbolt boring bar from the corporation stop.
18	Remove lower chamber from the pipe.
19	Inspect for leaks. If corporation stop leaks, tighten with suitable wrench.

Figure 5.10. Water Main Tap.



5.3.4. Plumbing Leaks. If the proper fittings, material, and tools are available, plumbing repair can be a relatively straightforward task. However, during contingencies or war, the proper supplies and materials may not be available. Therefore, the field engineer may have to improvise using expedient methods or dissimilar materials to effect temporary repairs. The following paragraphs and illustrations in **Figure 5.11** provide techniques and examples for making expedient or temporary repairs for small leaks in a plumbing system. Before making any repairs, shut off the water and relieve the pressure from the system. **Note:** Work crews should make permanent repairs as soon as practicable to replace the weak or defective part. Replace parts with a unit (and insulation if used) that is the same size and quality as the original installation.

Figure 5.11. Expedient Pipe Repair Techniques.



5.3.4.1. Rubber Hose or Plastic Tubing. Cut the pipe on either side of the leak with a hacksaw or pipe cutter. Remove the damaged pipe section and replace it with a length of rubber hose or plastic tubing. To do this, slip the ends over the pipe and fasten them with hose clamps. The inside diameter of the hose must fit the outside diameter of the pipe.

5.3.4.2. Sheet Rubber. Wrap the leaking area with sheet rubber. Place two sheet-metal clamps on the pipe (one on each side). Then, fasten the clamps with the bolts and nuts.

5.3.4.3. Electrician's Friction Tape. Wrap several layers of friction tape around the hole or crack, extending the tape about 2 inches above and below the leak.

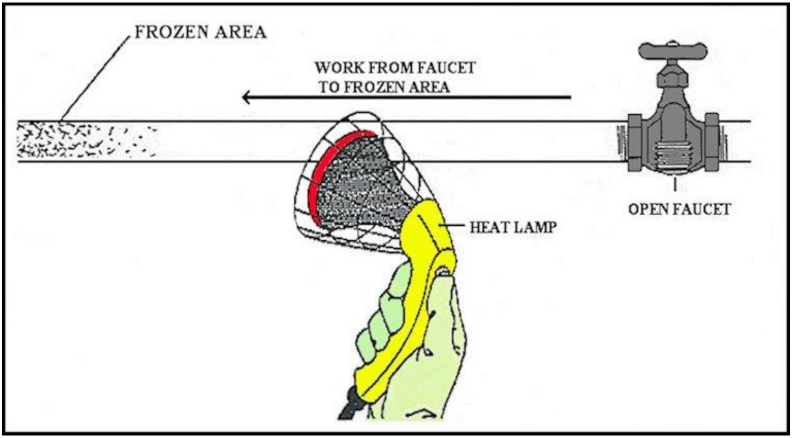
5.3.4.4. Wood Plugs. Similar to water main repairs, consider filling small holes in other water pipes with wood plugs. Drive a wooden plug into the hole after it is drilled or reamed. The plug will swell as it absorbs water, preventing it from being blown out by water pressure.

5.3.5. Frozen Pipes. Pipes may freeze in temperate as well as frigid zones. In frigid climates, freezing presents a major problem to a water distribution system, and pipes are normally insulated and heated. If a building’s temperature falls below freezing, inside pipes may also freeze causing the pipe to break at the weakest point. The best way to avoid frozen pipes is to insulate or wrap lines with electrical heat tape. In areas where the ground is permanently frozen, water pipes are set in heated conduits. Pipes are typically buried below frost penetration depth in temperate climates where freezing is only a seasonal problem. Even with proper protection, some pipes may still freeze. The paragraphs below examines procedures for thawing above- and below-ground pipes.

5.3.5.1. Heat Lamp or Blowtorch. A heat lamp or blowtorch is a good method to thaw aboveground pipes, but there is a risk of fire with the blowtorch, especially with plastic pipes. Use the following steps to thaw frozen pipes when using a heat lamp or blowtorch:

- Open the faucets in the line.
- Apply heat from the heat lamp or blowtorch at one end of the pipe and work along the entire length of the pipe (**Figure 5.12**).
- Continue to heat the pipe until the water flows freely. Be careful not to overheat pipes because solder joints will break loose if the solder melts.

Figure 5.12. Thawing Frozen Interior Pipes.



5.3.5.2. Boiling Water and Cloth. Consider thawing pipes by wrapping burlap or other cloth over the frozen section and pouring boiling water over the wrappings, thus transmitting heat to the frozen pipe. When internal freezing is due to failure of the heating plant, repair the heating plant; maintain a high temperature in the building until the pipes thaw.

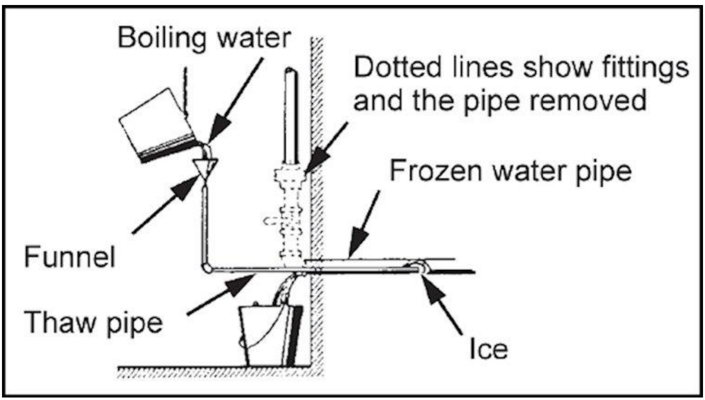
5.3.5.3. Boiling Water and Thaw Pipe. Follow the steps in **Table 5.3** and use the illustration in **Figure 5.13** to thaw frozen exterior pipes. In some cases, a small pump may be an option to clear a piece of pipe. However, excessive pump pressure can cause a backup; therefore, carefully monitor this procedure.

5.3.5.4. Steam Thawing. Steam thawing is often a common option for use on fire hydrants. In steam thawing, workers connect one end of a hose to a boiler, insert the other end into the hydrant through a disconnected fitting, and then gradually advance the hose as the steam melts the ice.

Table 5.3. Steps to Thaw Frozen Underground Pipes.

Pipe Thawing Procedures	
Step 1	Remove the pipe fittings.
Step 2	Insert small thaw pipe or tube into the frozen pipe as shown in Figure 5.13.
Step 3	Add an elbow and a piece of vertical pipe to outer end of the thaw pipe.
Step 4	Place a bucket under the opening to the frozen pipe.
Step 5	Insert a funnel into the open end of the vertical pipe.
Step 6	Pour boiling water into the funnel and, as the ice melts, push the thaw pipe forward.
Step 7	After the flow starts, withdraw the pipe quickly. Allow the flow to continue until the thaw pipe is completely withdrawn and cleared of ice.

Figure 5.13. Thawing Frozen Exterior Pipes.



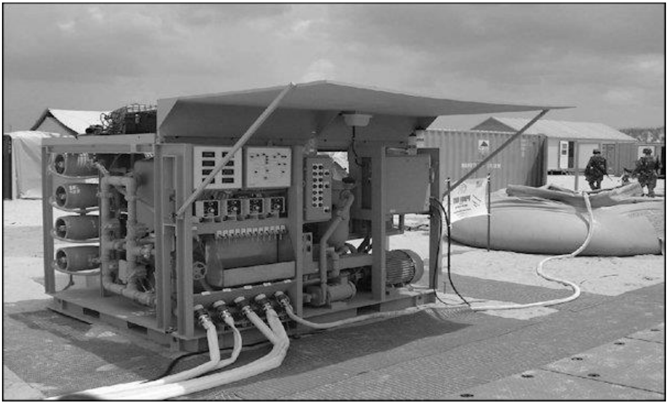
5.3.6. Disinfecting the Piping System. After making repairs to water supply pipes, clean and disinfect plumbing pipes and other parts of a water supply system carrying drinking water before use. Flush the system to remove dirt, waste, and surface water. Disinfect each unit with a chemical such as a solution of hypochlorite or chlorine according to established disinfection standards and procedures. Normally, there is little danger of contamination, and disinfection is not required if leaks or breaks are repaired with clamping devices while the mains remain full of pressurized water.

5.4. Water Treatment System. The expedient restoration of water treatment capabilities may consist of repairs to an existing treatment plant or the installation of portable water treatment units. The importance of restoring the water treatment facility will depend upon the quality of the installation water source following an emergency. If the source is relatively free of contaminants, treatment plant repairs or setting up of portable treatment equipment may be of less importance than other installation repairs. If water treatment is necessary and the treatment plant is beyond repair, or the installation does not possess a treatment facility, it may be necessary to use expedient water treatment equipment. The most common expedient water treatment system available to CE forces is the Reverse Osmosis Water Purification Unit (ROWPU).

5.4.1. The ROWPU purifies water by forcing water under high pressure through a series of membranes to eliminate impurities. The ROWPU can remove dissolved minerals from water. Although ROWPUs come in several sizes, the AF primarily uses the 1500-Gallons per Hour (GPH) unit shown in **Figure 5.14**. Extreme high and low temperatures of the feed water source will reduce the production capability of the ROWPU.

5.4.2. Disinfection treatment is accomplished only after the water processes through the membrane filter elements since chlorine causes acute damage to the filter elements. For specific information on ROWPU operations and procedures, refer to T.O. 40W4-20-1.

Figure 5.14. 1500-GPH ROWPU.



5.5. Water Storage System. The water storage system on an air base or beddown location may consist of underground or open reservoirs; large, fixed storage tanks, or temporary storage facilities. The most severe damage to the storage system could be a rupture causing loss of the stored water. Another consideration is sabotage by clandestine groups. Whenever possible, water storage facilities should be postured well within the secure area of the base or beddown setting. Ruptures or other damage to existing storage facilities can be sealed from the inside using rubber patches, epoxy, or wooden dowels if the holes are small.

5.5.1. When the base's conventional water storage facilities are damaged, or additional storage space is required, swimming pools and similar watertight facilities make excellent alternate reservoirs. Other expedient water storage alternatives include flexible bladders (**Figure 5.15**), ranging in size up to a 50,000-gallon capacity, portable water tanks, water distribution trucks, water trailers, 5- and 10-gallon igloo water coolers, and 55-gallon drums.

5.5.2. An aboveground reservoir can be constructed using sandbags or earthen berms lined with plastic sheeting to make it watertight. In addition, bear in mind that a considerable amount of water is stored within the distribution system pipelines themselves. For example, a 6-inch pipeline, two miles long contains approximately 16,000 gallons when full. Using shutoff valves to quickly isolate undamaged sections of the distribution system could mean substantial amounts of water saved within the pipes for future use.

Figure 5.15. Temporary Water Storage Bladders.

5.6. Wastewater (Sewage) Systems. Improper disposal of sewage in the aftermath of a disaster or enemy attack will compound base recovery problems. If the sewage enters a water supply, an outbreak of intestinal diseases such as typhoid, cholera, dysentery, and diarrhea, is almost certain to occur. To prevent such outbreaks, CE forces may have to repair damage to existing sewer systems as well as provide temporary sanitation facilities. The priority of these repairs will be based on an estimate of potential hazard to the installation population. Basic classification, operation, and repair of sewage systems is addressed below:

5.6.1. Classification of Air Base Sewage. Sewage may be divided into several classifications according to its source. These classifications will decide the immediate need for sewer rehabilitation. The two primary types of sewage on most installations are domestic sewage and storm sewage.

5.6.1.1. Domestic Sewage. Domestic sewage is the waste from toilets, lavatories, urinals, bathtubs, showers, laundries, and kitchens. Proper disposal of this type of sewage should receive first consideration in expedient repair operations.

5.6.1.2. Storm Sewage. Storm sewage is the inflow of surface runoff during or immediately following a storm or heavy rain. Disposal of storm sewage following a disaster is not a high priority unless it hinders base operations or endangers lives by flooding critical areas. Since storm sewers are designed to catch runoff whether it is natural or manmade, they will also catch and collect toxic chemicals introduced accidentally or on purpose. For this reason, civil engineers should be prepared to establish blocking points at critical locations to prevent the spread of hazardous materials. Storm sewers may be blocked using commercially available plugs or sandbags.

5.6.2. Sewage System Operation. The major components of the sewage system consist of facilities for collecting, pumping, treating, and disposing of sewage. The basic collecting system consists of a series of branch, lateral, main, and trunk sewers leading from various installation structures. Raw sewage moves through the collection system to a central point for treatment and eventual disposal. At any point along the system where gravity is not sufficient to move the sewage, a pump or lift station may be required. Sewage treatment plants vary in complexity according to the characteristics of the influent and the degree of treatment required prior to discharge. Effluent standards, set by national and local regulations, determine the degree of treatment.

5.6.3. Anticipated Sewer Damage. Common problems with the sewage system during typical disasters such as floods and hurricanes are complete inundation of the system by excessive amounts of water and blockage of parts of the system by debris. In the extreme, earthquakes or enemy attacks can cause complete destruction of treatment plants and lift stations as well as ruptures of sewage lines. Damage sustained during hostile attacks will probably be collateral in nature since the sewage system is not normally a preplanned target. Specific damage could consist of the following:

5.6.3.1. Sewers. Deliberate demolition to sewers by an enemy is usually limited to junction manholes or large mains. Stoppages caused by debris being blown and washed into sewers can be expected.

5.6.3.2. Pumping Stations. During conflict, attackers may target pumping stations because they are key points, are more accessible, and are most difficult to repair. However, they are not likely to be damaged seriously by bombs or artillery fire since they offer a relatively small target. Disastrous flooding during either tropical storms or tornados can also prove consequential.

5.6.3.3. Treatment Units. Treatment units may be damaged during a conflict by the demolition of machinery and other key equipment. However, they are not normally high-value targets due to their small size and the ability to achieve effective treatment results by other means.

5.6.3.4. Cesspools and Septic Tanks. Damage to cesspools and septic tanks from sabotage or bombing is relatively unimportant. Destruction of a cesspool or septic tank would affect only one or a small number of properties. Their wide dispersal provides a large measure of safety.

5.6.4. Effect of Damage. Human wastes must be properly disposed of in order to protect personnel. If sewage enters a water supply, an epidemic outbreak of intestinal diseases such as typhoid, cholera, dysentery, and diarrhea is almost certain to follow. Existing sewer systems may have to be rehabilitated to prevent such mission-impacting outbreaks.

5.6.5. Expedient Repair Procedures. Expedient sewer repairs should consist only of the minimum work required to prevent the outbreak of disease. For example, if the ruptured sewer line results in sewage leakage into an occupied area and does not threaten water sources, repairs can be delayed until emergency conditions subside. When damage is too widespread for expedient repair, civil engineers must resort to proven field sanitation methods. Development of temporary latrine facilities is addressed in Volume 1 of this publication series. The rehabilitation of a sewage disposal system requires the following actions.

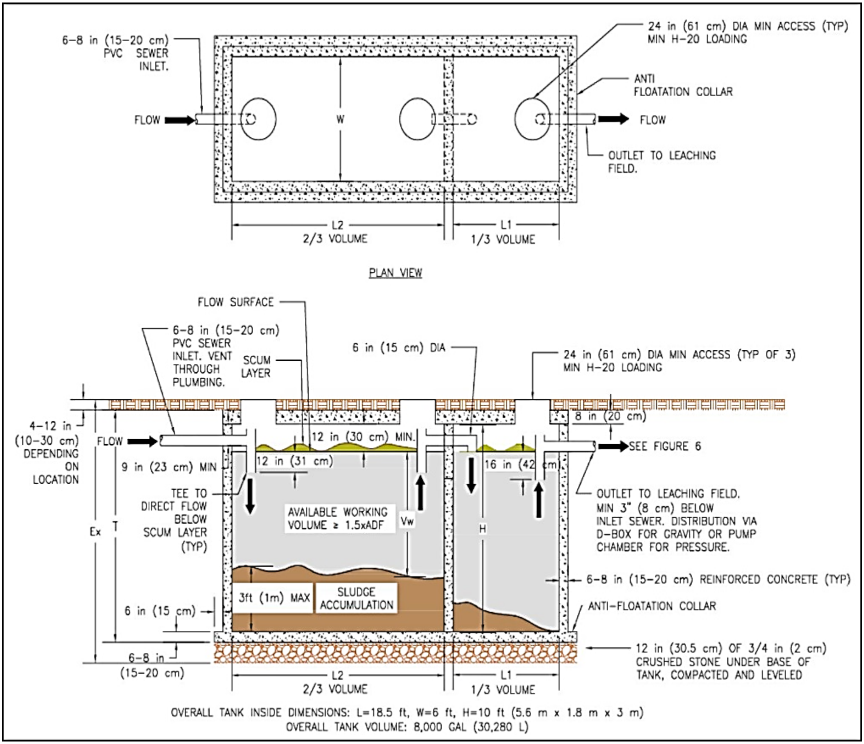
5.6.5.1. Sewers. Sewer lines are the most essential item in a sewage disposal system. If the situation is critical, service can be restored temporarily by pumping from an upstream manhole, around the damaged section, and into a downstream manhole. If the sewer is completely stopped or badly damaged, an open channel can be built. Where storm and sanitary sewers are separate, it may be possible to divert sanitary sewage through a storm sewer to a suitable outlet.

5.6.5.2. Pumping Stations. When sewage pumping stations cannot be repaired expeditiously using available replacement parts or parts cannibalized from other stations, use portable pumps as a substituted. If pumps are not available, consider rerouting past the lift station with pipe or open channels using gravity flow.

5.6.5.3. Treatment Plants. It may be necessary to bypass severely damaged treatment plants. Settling and digestion tanks and filters can usually be repaired with standard construction materials. Sludge beds are practically indestructible. Machinery must be repaired by cannibalization or improvised methods. If compressed air is used in an activated sludge process, replacement of air compressors is difficult at best. However, the activated sludge plants can be operated as sedimentation or septic tanks. Such treatment, together with chlorination, provides a reasonable degree of purification. Further information about expedient septic systems is available in Volume 1 of this publication series.

5.6.5.4. Septic Tanks. Septic tank systems (**Figure 5.16**) are used to treat and dispose of wastewater from buildings where it is not feasible to provide a community wastewater collection and treatment system. A septic tank speeds up the decay of raw sewage. It may be made of concrete, stone, fiberglass, or brick (lumber is used when other materials are not available), in box-section form, and it should be watertight. The septic tank should have a manhole and cover to give access for cleaning and repair and must be designed to hold 70 percent of the peak water demand of that facility for 24 hours and not less than 16 hours. Contingency rapid repair of a septic tank would normally be low priority since other options are usually available. However, if a septic tank is severely damaged and totally inoperable and other prudent options are not available, an expedient-type septic tank can be constructed using procedures provided in Volume 1 of this publication series. Otherwise, expedient repairs would probably be limited to unclogging pipes, pumping out tanks, and improving or expanding drain fields.

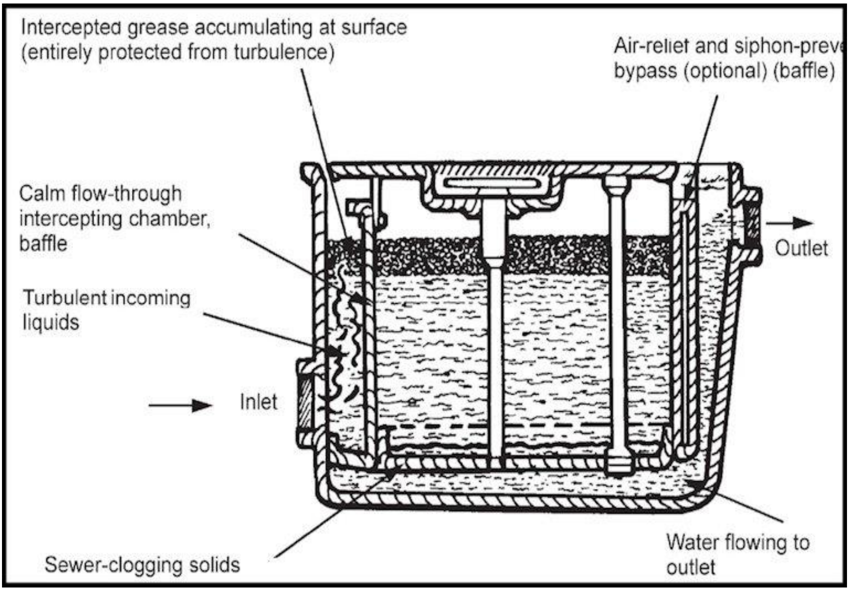
Figure 5.16. Typical Septic Tank Details.



5.6.5.5. Grease Traps. Grease traps come in countless shapes and sizes, but their operation is basically the same. Just as the name suggests, a grease trap catches grease (animal fats and oils) from kitchen wastewater. Although there are many different models, grease traps are typically set in the flow line of the building's sewer system to catch grease and fats from kitchen and scullery sinks, preventing clogs in the waste pipes. Expedient repair of grease traps is usually limited to unclogging inlet pipes and repairing or replacing damaged traps. Service personnel should be trained to perform routine cleaning and maintenance of grease traps installed in their area(s). **Figure 5.17** provides a layout of a typical grease trap.

5.6.5.6. Additional details on water supply and wastewater systems repair procedures can be obtained from UFC 3-230-02 and UFC 3-240-01, *Wastewater Collection*.

Figure 5.17. Grease Trap Layout.



5.7. Pipes and Fittings. Pipes and fittings for plumbing systems are classified into four basic groups: cast-iron soil pipe and fittings, galvanized steel/iron pipe and fittings, copper tubing and fittings, and plastic pipe. Listed in **Table 5.4** and addressed in the following paragraphs are the characteristics and uses of pipes and fittings in a plumbing system. See **Attachment 4** for sizes and metric equivalents.

5.7.1. Cast-Iron Soil Pipe and Fittings. Cast iron is available in two different wall thicknesses or weights: service weight and extra-heavy weight. Use cast-iron soil pipes for sewers, drains, stacks, and vents in a waste system. Service weight is for general household use and is adequate for most military construction. Use extra-heavy weight where liquids may corrode the pipe or where greater strength is needed for tall stacks or under roadways.

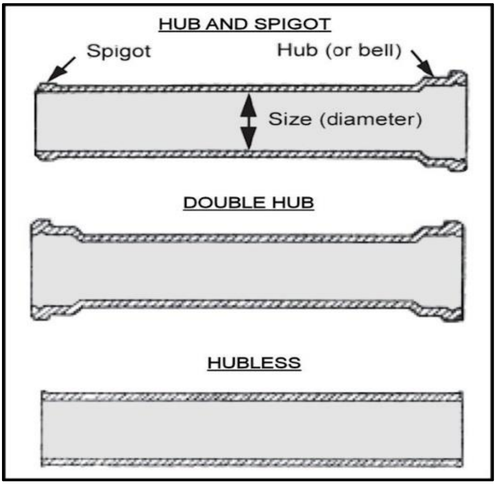
Table 5.4. Pipe Characteristics and Uses.

Type of Pipe	Rigid	Flexible	System	
			Water	Waste
Cast-iron soil pipe:				
Hub and spigot	●			●
Double hub	●			●
Hubless	●			●
Galvanized-steel/iron pipe	●		●	●
Copper tubing:				
K (Thick wall)	●			
L (Medium wall)	●	●	●	
M (Thin wall)	●	●	●	
DWV	●		●	●
Plastic pipe:				
PB (cold water lines)			●	
PE			●	
PVC	●	●	●	●
CPVC (cold and hot water system)	●	●	●	
ABS	●			●

5.7.1.1. Types. As listed in **Table 5.4** and illustrated in **Figure 5.18**, this pipe is manufactured in three different types. The hub-and-spigot pipe comes in lengths up to 10 feet and ranging in diameter from 2 to 15 inches. Whereas the double-hub pipe comes in 5-foot lengths ranging in diameter from 2 to 15 inches. Hubless pipe comes in 10-foot lengths ranging in diameter from 1-1/2 to 8 inches.

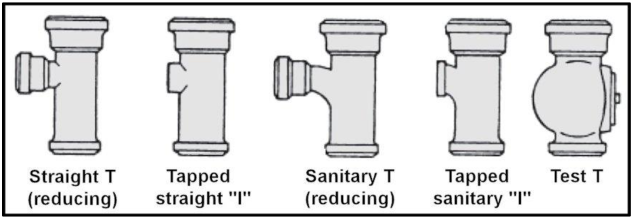
5.7.1.2. Fittings. The major types of fittings used for cast-iron pipe are Tees, Y-branches, bends, and traps. These fittings are used for connecting hub-and-spigot or hubless cast-iron pipes.

Figure 5.18. Cast-Iron Pipes.



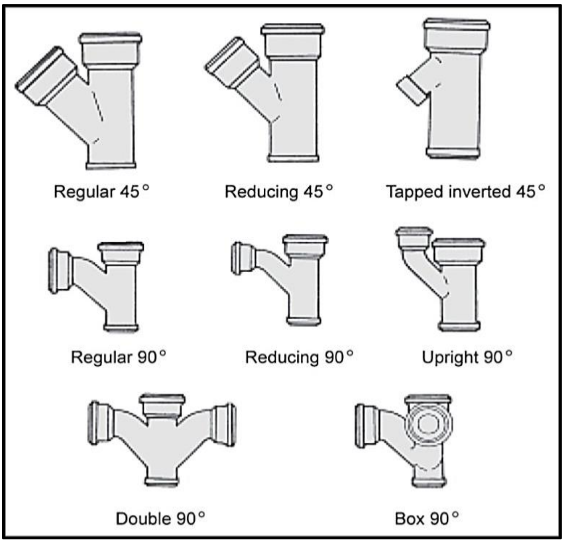
5.7.1.2.1. Sanitary Tees are designed to carry drainage and straight Tees are used for vent lines (**Figure 5.19**). Use a tapped Tee, either sanitary or straight, to connect threaded-pipe branch drains or vent lines. Use a test Tee for testing a newly installed waste system for leaks.

Figure 5.19. Cast-Iron Tees (Ts).



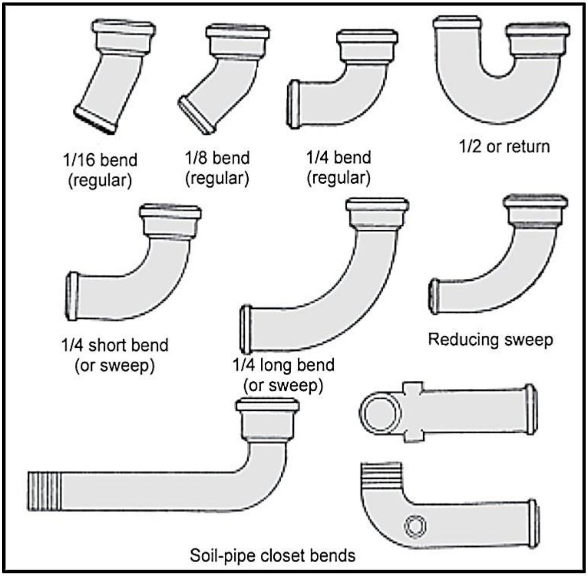
5.7.1.2.2. Y-branches can join one or more sanitary sewer branches or connect a branch to a main line. This design allows a smoother change in flow direction. The most common Y-branches are the 45- and 90-degree types (**Figure 5.20**).

Figure 5.20. Cast-Iron 45- and 90-Degree Y Branches.



5.7.1.2.3. Bends are used to change the direction of a cast-iron pipeline. The degree of direction change is given as a common math fraction. Bends are designated in fractions of 1/16, 1/8, 1/6, 1/5, 1/4, and 1/2 as they change the direction of 22 1/2, 45, 60, 72, 90, and 180 degrees, respectively. These bends can be regular, short sweep, or long sweep (**Figure 5.21**).

Figure 5.21. Cast-Iron Bends.



5.7.1.2.4. Every plumber knows a trap provides a water seal, which keeps sewer gases from entering a building through a waste outlet. The most common type is a P-trap. The P-trap is used in a partition to connect a drain to a waste branch. A running trap is used in a building's drain line when the local plumbing codes require that the building drain be trapped. **Figure 5.22** illustrates four general types of cast-iron soil pipe traps.

5.7.1.2.5. Other cast iron fittings include the offset, increaser, cleanout, tucker coupling, and sewer thimble (**Figure 5.23**). Except for the tucker fitting, they are usable on all types of pipes.

Figure 5.22. Cast-Iron Traps.

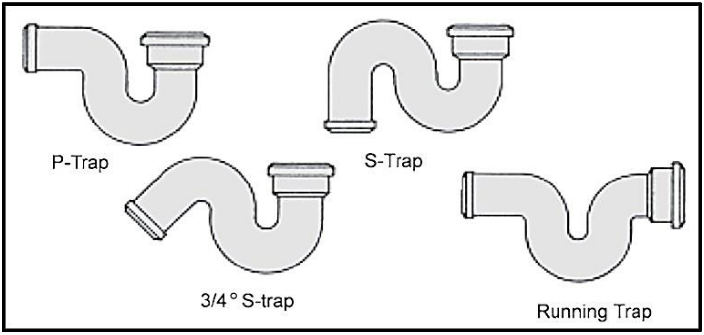
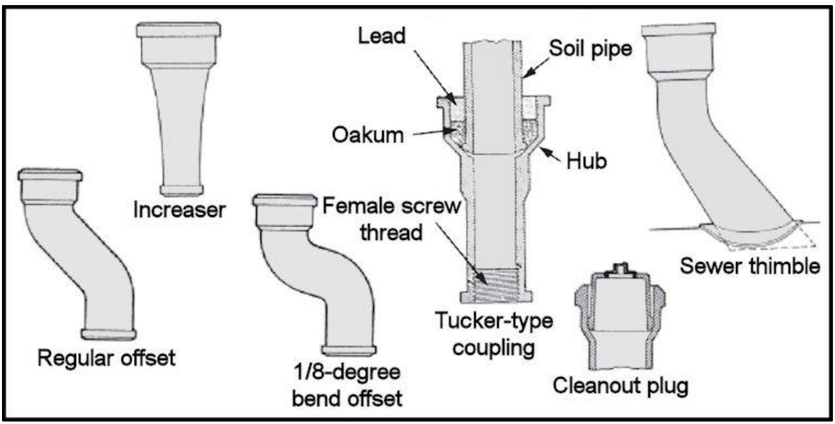


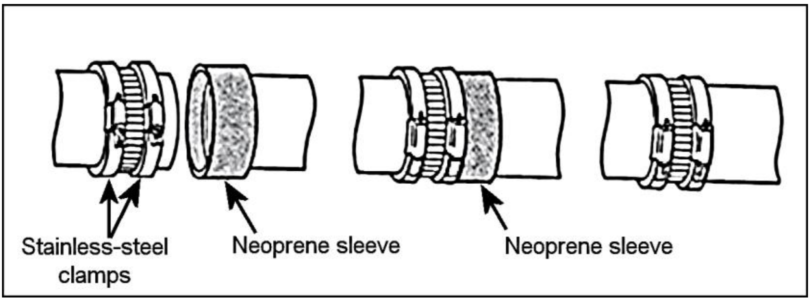
Figure 5.23. Cast-Iron Fittings.



5.7.1.2.6. Make a Hubless joint cast iron pipe repair with a neoprene sleeve and a stainless steel clamp. To make the Hubless joint, use the illustration in **Figure 5.24** and the following procedures:

- Remove the neoprene sleeve from the stainless-steel clamp.
- Slide the sleeve on the end of one pipe or fitting until it is firmly against the collar inside the sleeve.
- Slide the clamp on the other pipe.
- Slide the pipe end into the sleeve until it is firmly against the collar inside the sleeve.
- Center the clamp over the sleeve and tighten with a screwdriver or wrench.

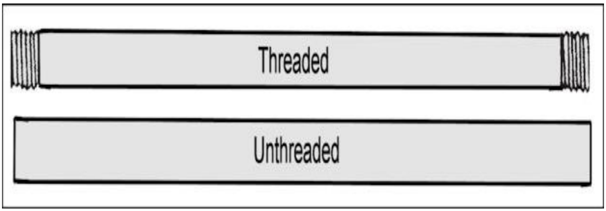
Figure 5.24. Expedient Hubless Joint for Cast-Iron Pipe.



5.7.1.3. Legacy Systems. Legacy systems containing cast-iron pressure pipes (also called corporation), were sometimes used for water supply mains. They may be hub-and-spigot pattern or have flanged ends for bolting connections. Fittings similar to those for cast-iron soil pipe are available. **Note:** Although cast-iron pressure pipes are seldom used today, work crews may encounter these pipes when making repairs to legacy systems.

5.7.2. Galvanized-Steel/Iron Pipes. Galvanized-steel/iron pipe is an option for hot- and cold-water supply distribution, certain drainage applications, and vent installations. This pipe comes in three strengths: (1) standard, (2) extra strong and (3) double extra strong. The definitions Schedule 40 and Schedule 80 also describe pipe strengths. Schedule 40 standard is most commonly used in plumbing. Pipe diameter sizes (nominal pipe sizes) are 1/8 inch to 12 inches, also referred to as iron-pipe size. The pipe comes in 21-foot lengths, threaded or unthreaded (**Figure 5.25**). Galvanized pipe should be stored in a dry place. If the pipe ends are threaded, they must be protected from damage.

Figure 5.25. Galvanized-Steel/Iron Pipe.



5.7.2.1. Fittings and Uses. Galvanized pipe fittings (**Figure 5.26**) are classified as either ordinary (standard) or drainage (recessed). Ordinary fittings are used for water service and venting. They range in size from 3/8-inch to 6 inches. Drainage fittings are used in waste systems. They have threads at a slight angle so that horizontal drainage pipe will slope about 1/4- inch per foot. They range in size from 1-1/4 to 12 inches.

5.7.2.1.1. Use tees (**Figure 5.27**) when a pipe run branches at a 90-degree angle. The required tee size is determined by the through section or run, and the outlet.

5.7.2.1.2. Use elbows (**Figure 5.28**) to change the direction of a pipeline. They come in a variety of sizes and patterns. The most common elbow are 90- and 45-degree angle. Either type can be a standard or a reducing elbow. The size of an elbow is given first by the larger opening and then by the smaller opening.

Figure 5.26. Ordinary and Drainage Pipe Fittings.

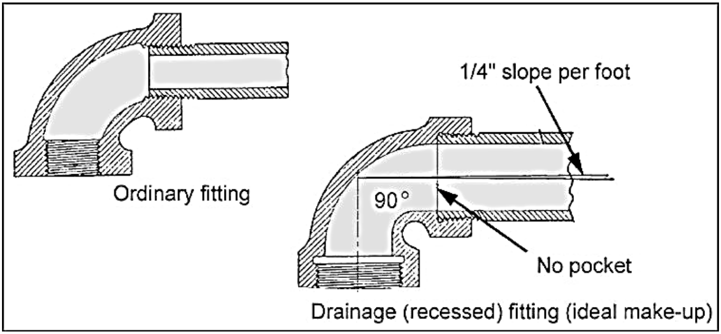


Figure 5.27. Tees (Ts).

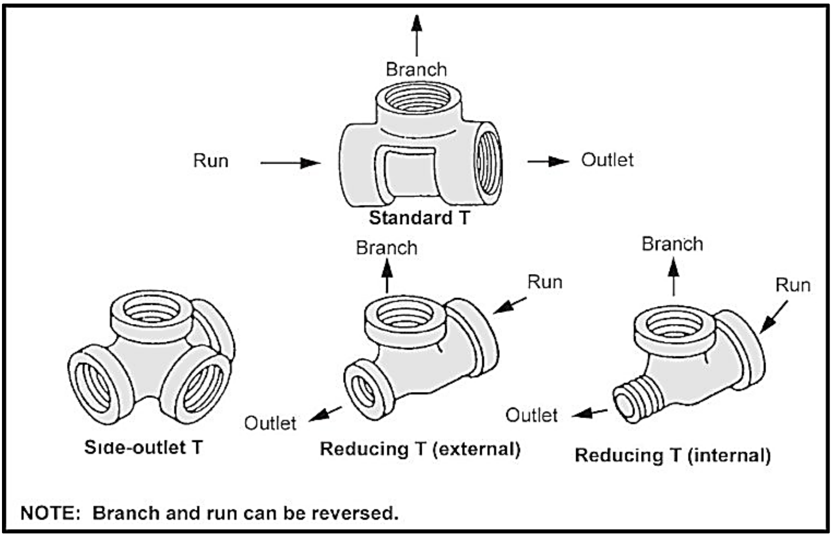
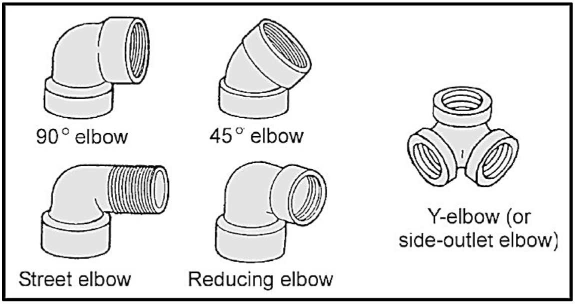
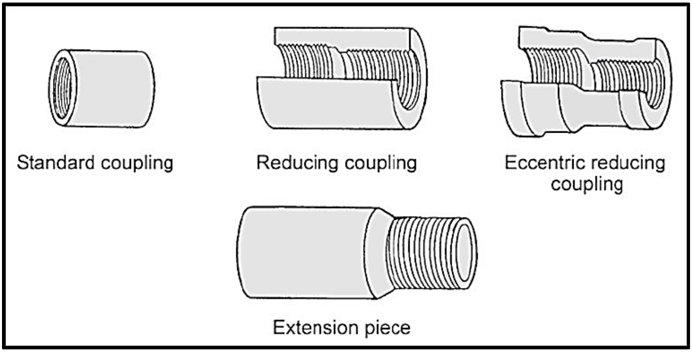


Figure 5.28. Elbows (Ls).



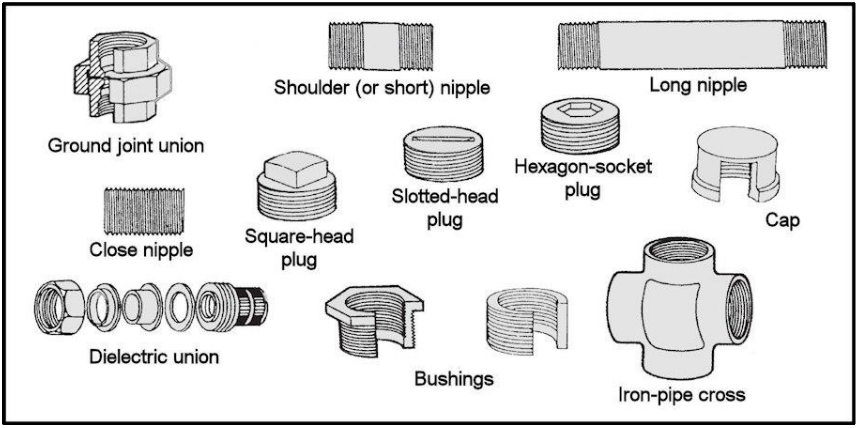
5.7.2.1.3. Use couplings (**Figure 5.29**) to connect two lengths of pipe. A standard or ordinary coupling connects pipes of the same size. A reducing coupling and an eccentric reducing coupling connects pipes of different sizes.

Figure 5.29. Couplings and Extension.



5.7.2.1.4. Other fittings include unions, nipples, plugs, caps, bushings and crosses (**Figure 5.30**). Use unions to join the ends of two pipes that can be turned or disconnected. Nipples are used to make an extension from a fitting or to join two fittings together. Nipples are pieces of pipe 12 inches or less in length and threaded on each end. Plugs and caps are for sealing off openings in other fittings or pipe ends. Cross fittings join two different pipelines in the same plane, making them perpendicular to each other. Crosses can also be side-outlet and reducing. Lastly, bushings are used to reduce a fitting outlet or to connect a pipe to a larger outlet.

Figure 5.30. Other Types of Pipe Fittings.

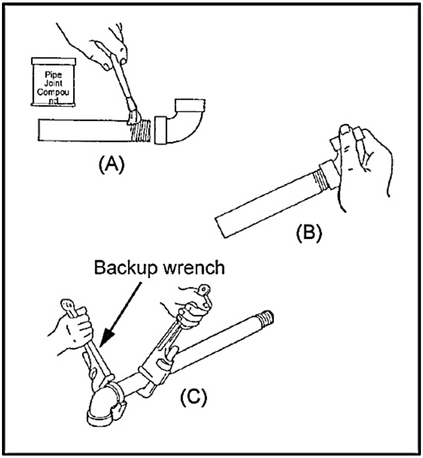


5.7.2.2. Joining Threaded Pipe. Fittings are normally screwed to the pipe after it is threaded, while the pipe is still in the vise. This ensures a good fit. The assembled pipe and fittings should then be screwed into the proper place in the installation. See procedures below and **Figure 5.31** for joining steps:

- Check the fitting threads for cleanliness and damage. If necessary, clean with a wire brush or replace.
- Repeat above procedure for the pipe threads.
- Apply pipe-joint compound or Teflon tape to the pipe threads only (A).
- Screw the fitting on, hand tight (B).

- Tighten the fitting using two pipe wrenches, one on the fitting (backup wrench) and the other on the pipe (C), provided no vise is available. The backup wrench keeps the fitting from turning.

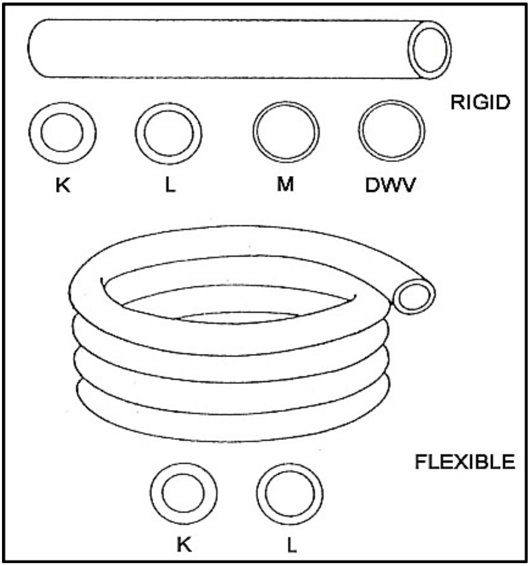
Figure 5.31. Joining Threaded Pipe.



5.7.3. Copper Tubing and Fittings. Copper tubing is lightweight, easily joined, and corrosion resistant. It can be rigid or flexible, and classified by its wall thickness. Copper tubing is used for hot- and cold-water supply systems, certain drainage applications, and venting. While system designers generally select the type of copper tubing required, they consider various plumbing and mechanical codes in their decision-making process. This section only relates to water and wastewater systems.

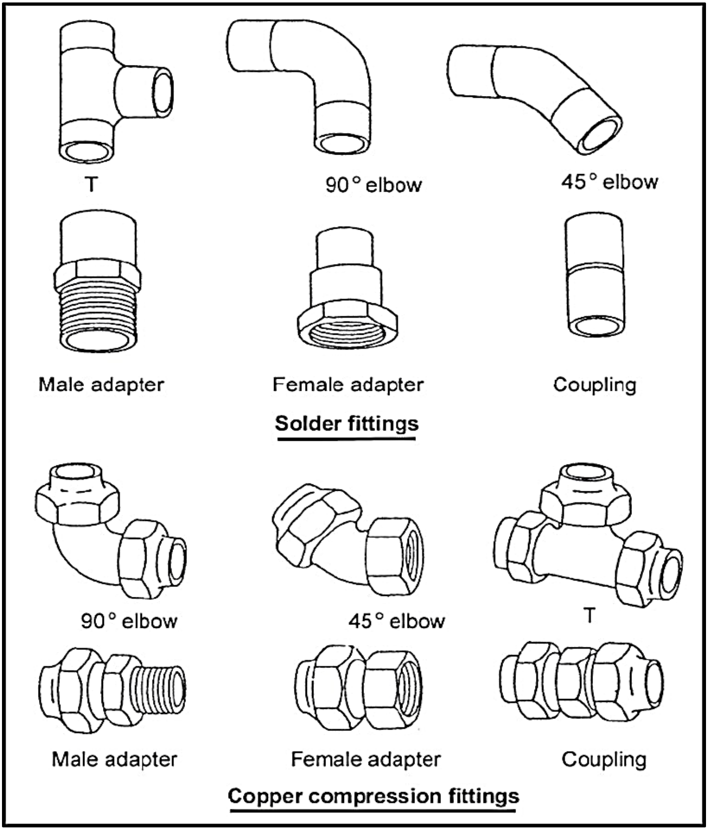
5.7.3.1. Types. Types of copper tubing include K, L, M, and DWV (**Figure 5.32**). Type “K” is a thick-walled, rigid or flexible copper tubing available in 20-foot lengths or 100-foot coils. Diameter sizes range from 1/4-inch to 12 inches. Type “L” is a medium-walled, rigid or flexible copper tubing available in 20-foot lengths or 100-foot coils. Diameter sizes are the same as K. Type “M” is a thinwalled, rigid copper tubing available in 20-foot lengths. Diameter sizes are the same as K and L. The DWV (drain-waste-vent) is available in 20-foot lengths with diameter sizes ranging from 1-1/4 to 8 inches. While K, L, and M copper tubing is used on various water service and distribution systems, DWV copper tubing is used for building drains, waste and vent lines, and sewers.

Figure 5.32. Copper Tubing.



5.7.3.2. Fittings. Fittings for copper tubing can be solder, flared, or compressed (**Figure 5.33**). Soldered fittings can be used with either rigid or flexible copper tubing. The fitting sizes are similar to galvanized steel/iron fittings. Sizes are identified in the same manner. Flared fittings are used with flexible copper tubing that has flared ends. Fitting sizes range from 3/8-inch to 3 inches in diameter. DWV fittings are similar to cast-iron fittings of the solder type.

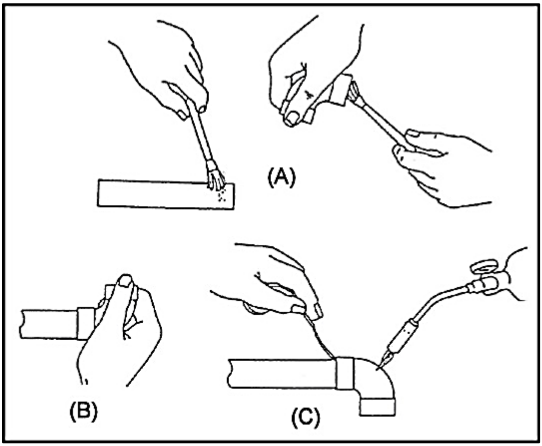
Figure 5.33. Copper Tubing Solder and Compression Fittings.



5.7.3.3. Joining Copper Tubing. The three primary methods of joining copper tubing are solder, flared joint and mechanical compression. **Note:** Other advanced joining methods and techniques likely unavailable at contingency locations are purposely omitted.

5.7.3.3.1. Soldered joints are used to connect rigid copper tubing. The following tools and materials are needed: a heating torch, 95-5 (95 percent tin and 5 percent aluminum) nonacid solder, soldering flux, and Emery cloth or steel wool. Review **Figure 5.34** and the following steps when making a soldered joint:

Figure 5.34. Soldering Copper Tubing Joints.

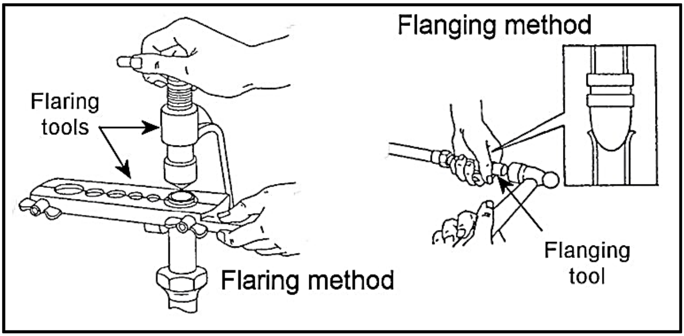


- Inspect the end of the copper tubing to be sure it is round, free of burrs, and cut square.
- Clean the end of the tubing and the inside of the fitting to a bright shine with emery cloth or fine steel wool.
- Apply a thin coat of flux to the shined end of the tubing and fitting (A).
- Push the fitting onto the tubing and give it a quarter turn to spread the flux evenly (B).
- Heat the connection with a torch, applying the flame on the fitting (C).
- When the flux is bubbling, apply the solder to the joint; the solder will flow into and completely around the joint.
- Clean the joint using a clean rag.

5.7.3.3.2. A flared joint is used with flexible copper tubing. Make the flare on the end of the tubing with a flaring or flanging tool. Review the procedures below and illustration in **Figure 5.35** when flaring or flanging flexible copper tubing:

- Inspect the end of the tubing to ensure it is free of burrs and is cut square.
- Remove the flange nut from the fitting and slide its unthreaded end onto the tubing first.
- Flare the end of the tubing with either a flaring tool or a flanging tool.

Figure 5.35. Flaring and Flanging Flexible Copper Tubing.

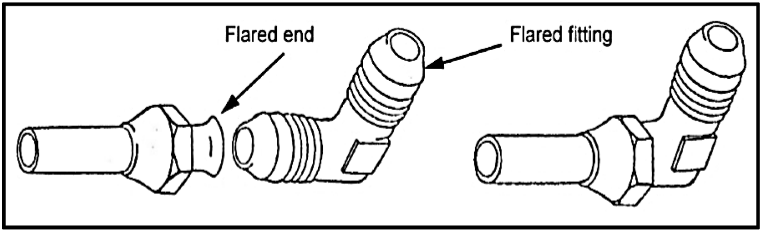


5.7.3.3.2.1. For the flaring tool, loosen the wing nuts on the flaring tool and place the tubing in the correct size hole. Make the tubing's end even with the tool's surface. Then tighten the wing nuts. Finally, turn the yoke cone down into the tubing until the flare fills the beveled pad of the hole.

5.7.3.3.2.2. For the flanging tool method, hold the flanging tool on the end of the tubing so that it is centered and straight. Then, using a hammer, tap the flanging tool until the flare fills the recess in the flanging nut.

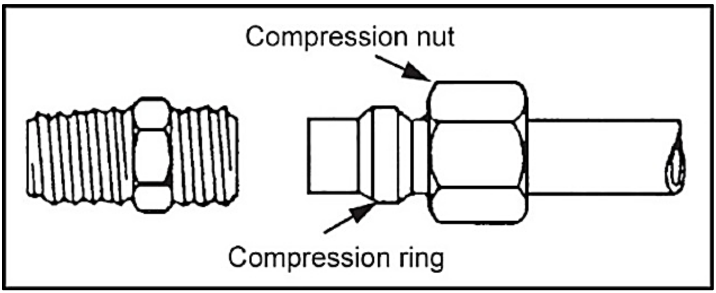
5.7.3.3.2.3. Slide the flare/compression nut up to the flared end and screw it on the fitting hand tight, then tighten the flare/compression nut (**Figure 5.36**).

Figure 5.36. Copper Tubing Flared Fitting.



5.7.3.3.3. A mechanical-compression joint is used to connect a fixture's water supply tubing to the shutoff valves. Review **Figure 5.37** and the following procedures when making mechanical-compression joints for copper tubing.

Figure 5.37. Mechanical-Compression Joint.



- Cut or bend the tubing to the required length.
- Slide the compression nut onto the tubing.
- Slide the compression ring onto the tubing.
- Screw the compression nut onto the fitting by hand.
- Tighten the nut. The ring compresses to form a sealed leak proof joint.

5.7.4. Plastic Pipe and Fittings. Plastic piping is lightweight and rigid or flexible (similar to copper tubing) and is easily joined with corrosion-resistant fittings. Applicable for water or waste systems, plastic piping is usable for hot- or cold-water piping and for drain, waste, and vent piping.

5.7.4.1. Types of Pipes. Generally, we classify plastic pipes by the acronym for the type of material from which it is made.

5.7.4.1.1. Polyvinyl Chloride (PVC) pipe is usually white and used only for cold-water pipelines, sanitary drainage, and venting. It comes in 10- and 20-foot lengths. Diameter sizes range from 1/2 inch to 6 inches.

5.7.4.1.2. Chlorinated PVC (CPVC) pipe is light or cream color and has a higher temperature resistance than standard PVC. Used primarily for hot-water pipelines but can also be used for cold-water lines. It comes in 10-foot lengths. Diameter sizes are 1/2 inch and 3/4 inch.

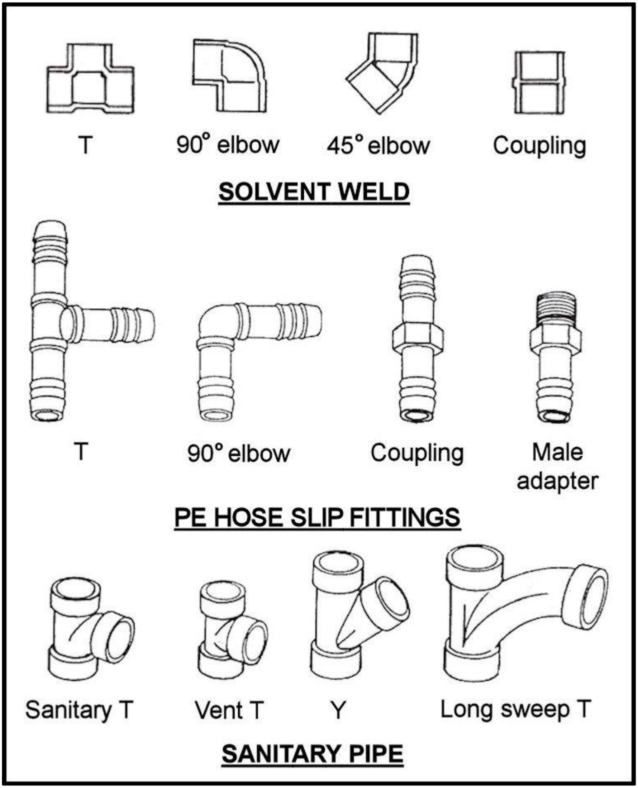
5.7.4.1.3. Acrylonitrile-Butadiene-Styrene (ABS) pipe is black or gray and used for above- and below-ground sanitary drainage and venting. It comes in 10- and 20-foot lengths. Diameter sizes range from 1-1/4 to 6 inches.

5.7.4.1.4. Polybutylene (PB) pipe is black or dark gray and used for cold-water lines. It is available in coils of 100 feet or more. Diameter sizes range from 3/4 inch to 2 inches. PB pipe is costly, requires special fittings, and is not in wide use.

5.7.4.1.5. Polyethylene (PE) tubing is black and often used for low-pressure cold-water lines and sprinkler systems. It comes in coils of 100 feet. Diameter sizes range from 3/4 inch to 2 inches.

5.7.4.2. Pipe Fittings. There are numerous types of plastic pipe fittings available commercially and through normal logistic channels. See **Figure 5.38** for examples. The sizes for PVC and CPVC pipe fittings are similar to steel and copper fittings.

Figure 5.38. Typical Plastic Pipe Fittings.

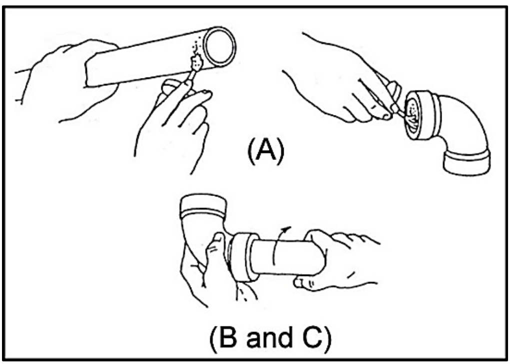


5.7.5. Joining Plastic Pipes. The most common methods for joining PVC and CPVC pipes and fittings are solvent cements, threading, and compression couplings. PE hose fittings used in cold-water sprinkler system piping are usually the insertable type. **Note:** Other joining methods and techniques likely unavailable at contingency locations are purposely omitted.

5.7.5.1. The solvent-cement weld joint is made by using a cleaning primer and solvent cement on the pipe and fitting. Solvent cement consists of a plastic filler (same material for each type of plastic pipe) dissolved in a mixture of solvents. Use the appropriate solvent cement for the type of pipe being used. The solvent cement melts the plastic of the pipe and the fitting to weld them together. Since solvent cement sets fast, a plastic pipe joint is completed quickly (**Figure 5.39**). Use the following steps to join plastic pipe with solvent cement:

- Inspect the pipe end for burrs and the fitting for cracks.
- Clean the pipe and the inside of the fitting with an authorized cleaning primer, using a clean rag.
- Coat the outside of the pipe end and the inside of the fitting with solvent cement (A).
- Push the pipe as quickly as possible into the fitting as far as it will go; a small bead of cement will be visible (B).
- Give the fitting a quarter turn to spread the solvent cement evenly (C).
- Hold the joint connection for about 30 seconds to be sure it is solidly set.
- Wipe off all excess cement.

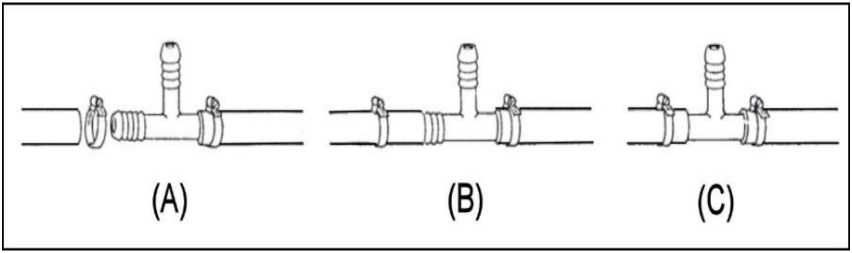
Figure 5.39. Cementing Rigid Plastic Pipe Joint.



5.7.5.2. For flexible plastic piping (i.e., PE tubing), make the insert fitting joint by sliding and clamping the pipe onto the insert fitting as addressed below and illustrated in **Figure 5.40**.

- Slide a clamp over the flexible pipe (A).
- Push the pipe onto the insert fitting to the last serration (B).
- Slide clamp over the pipe and tighten the clamp with a screwdriver (C).

Figure 5.40. Inserting Flexible Plastic Pipe Joint.



5.7.6. Joining Dissimilar Materials. During expedient repair, the goal is delivery. As such, the piping used depends upon the sizes that the pumps will accommodate and the type of piping materials available. **Figure 5.41** and **Figure 5.42** illustrate a few ways to accomplish pipe connections when working with dissimilar materials. In addition to the clamps and couplings shown in the illustrations, dielectric unions and transition fittings are also used to connect dissimilar pipe materials (**Figure 5.43**).

5.7.6.1. Dielectric unions are used to connect dissimilar-metal, water supply pipes to prevent electrolysis (corrosion). This type of union is common when connecting galvanized steel/iron pipe to copper pipe.

5.7.6.2. Transition fittings are common options for connecting joints between plastic and metallic pipes.

Figure 5.41. Joints for Dissimilar Materials (1 of 2).

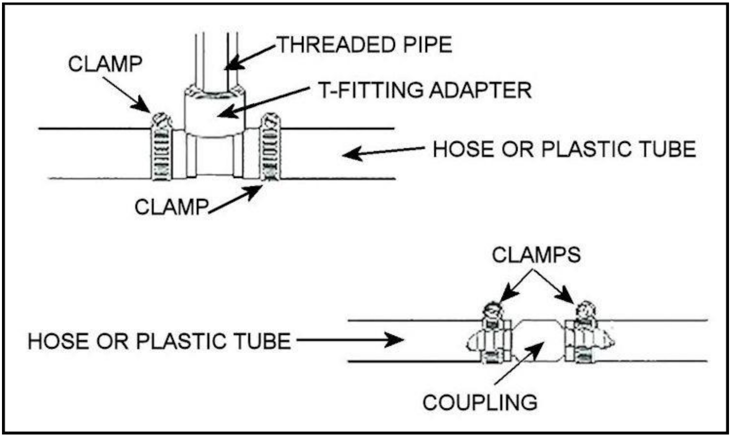


Figure 5.42. Joints for Dissimilar Materials (2 of 2).

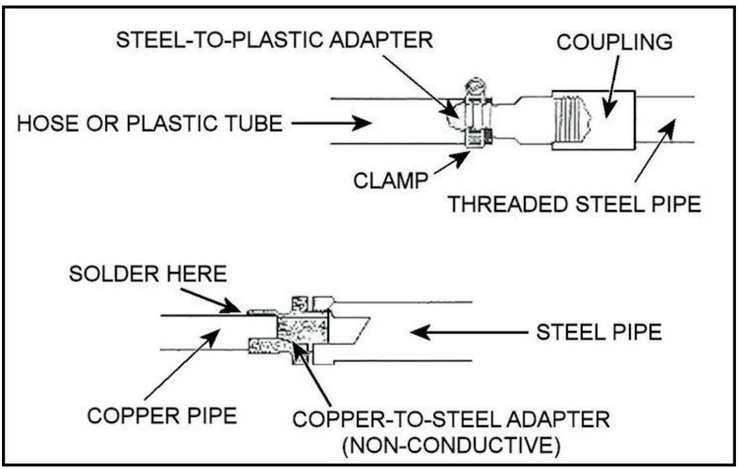
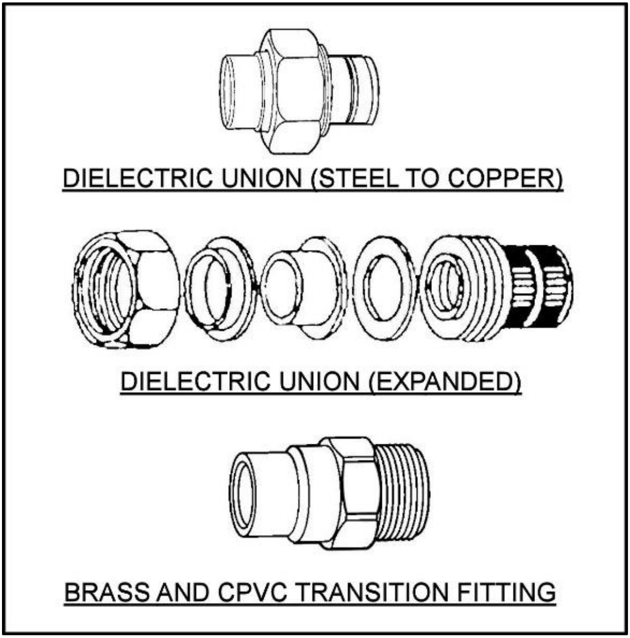


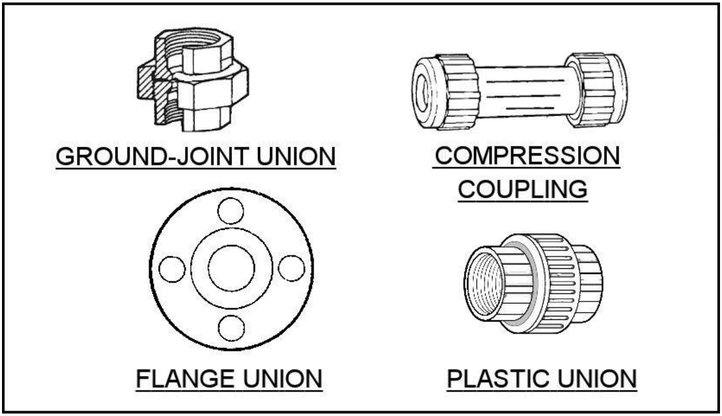
Figure 5.43. Dielectric Union and Transition Fitting.



5.7.7. Unions and Compression Couplings. Additional options for making pipe connections include ground-joint unions, flange unions, plastic unions and compression couplings (**Figure 5.44**). The pipe unions are for joining the ends of two pipes that can be turned or disconnected. Compression couplings are mechanical joints designed to connect two pipe ends quickly. They are available for both metal and plastic pipes. Below is a brief description for making pipe connections using these fittings.

5.7.7.1. A ground union has three distinct parts: a shoulder piece with female threads; a thread piece with female and male threads; and a ring (or collar) with an inside flange that matches the shoulder of the shoulder piece and a female thread that matches the male thread of the thread piece. The pipes are screwed to the thread and shoulder pieces. They are drawn together by the collar, making a gastight and watertight joint.

Figure 5.44. Unions and Fittings.



5.7.7.2. The flange union has two parts, each with a female thread, and screwed to the pipes to be joined. Nuts and bolts pull the flanges together. A gasket between the flanges makes a gastight and watertight joint. Plain-faced flanges may have male and female faces or tongue and groove faces. Regardless of the type of repair performed, flush and disinfect the affected pipe section when the repairs are completed.

5.7.7.3. The compression coupler shown in **Figure 5.44** is for plastic pipe repairs. It allows quick joint connections without the use of solder, solvent cement, glues, and other adhesives. Typically, no tools are required for installation. The coupling slips over the pipe ends and is hand tighten. Compression couplings can be used as a single union to connect two pipe ends or to repair longer, damaged pipe sections by using two couplings with a section of replacement pipe.

5.7.8. Other Types of Pipes and Fittings.

5.7.8.1. Bituminous-Fiber. Bituminous-fiber pipe, often called “Orangeburg,” is used underground to install house-to-sewer and house-to-septic-tank waste lines and storm drainage lines to dry wells. Perforated pipe is used for septic tank disposal fields and for footing drains and other subsurface drainage. It is lightweight, easily joined, and corrosion resistant. This pipe may be a plain or perforated type. Both plain and perforated pipe comes in 5- and 8-foot lengths. The plain pipe ends are tapered 2 degrees from a 1/16-inch shoulder. Diameter sizes range from 2 to 8 inches.

5.7.8.2. Concrete. Concrete pipe is used underground for sanitary and storm drainage pipelines. This pipe is made with cement and sand. Cement pipe is supplied in two grades: non-reinforced and reinforced with wire or steel bars. This pipe comes in various lengths and diameters.

5.7.8.3. Vitrified-Clay. Vitrified-clay pipe (terra cotta) is used underground for sanitary and storm drainage pipelines outside of buildings. This pipe has hub-and-spigot ends in lengths of 2, 2 1/2, and 3 feet. Diameter sizes range from 4 to 42 inches. Clay pipe fittings are similar to cast-iron soil pipe fittings.

Chapter 6

GAS AND LIQUID FUELS SYSTEM REPAIR

6.1. Overview. Overseas military bases often have gas and liquid fuels facilities designed to permit continuous operation using emergency or temporary measures should one or more components of the receiving or dispensing system is loss from enemy action or other factors. This chapter briefly addresses expedient repair of base natural gas and petroleum fuel systems.

6.2. General Information. Our ability to make expedient repairs to land-based gas and liquid fuel facilities and systems helps ensure emergency operation under adverse and demanding conditions.

6.2.1. Natural gas systems usually receive gas via pipeline from local distribution companies to a central regulating and metering station on or near the installation. From there, follow-on gas distribution is through a base piping network to the end users. Some bases use smaller, stand-alone liquefied petroleum gas, or compressed natural gas tank systems for specific fueling needs around the base. Expedient repair of those systems is beyond the scope of this publication and therefore only receive cursory mention in this chapter. Personnel should refer to AFMAN 32-1067, *Water and Fuel Systems*, for additional design, and operation and maintenance (O&M) information for natural gas systems.

6.2.2. Base petroleum fuel systems (liquid fuels) often include receiving and dispensing facilities, aboveground and/or underground storage tanks, ground vehicle fueling and aircraft fueling facilities, and a base pipeline distribution network. These systems provide receiving, storage, and distribution for products such as motor gasoline (Mogas), diesel, aviation fuels, and other commonly used fuels. The distribution network for natural gas and petroleum fuel are the most widespread component of base fuel systems and is where work crews will likely perform most expedient repairs. Repairs to other components such as pump facilities and bulk storage tanks are mostly beyond the scope of expedient repair.

6.2.3. Some gas and fuels distribution components are very similar to previously addressed water distribution components. However, repairing gas and fuel systems present additional environmental and safety hazards not present in repairing water systems. The potential existence of volatile liquids and vapors capable of producing fires, explosions, or contamination of aviation fuel are key concerns. These liquids and vapors are also toxic to the human body.

6.2.4. Personnel should follow local contingency spill plans when responding to breaks in gas and fuel distribution lines. Ensure leaks/releases are reported to the proper authorities if they exceed applicable reportable quantity thresholds. It may be possible to capture gases in confined and enclosed spaces and remove standing volatile liquids using established spill response and cleanup protocols. Only emergency and cleanup personnel should be in the threat area when mitigating the fuel hazard (cleaned up, diluted, evaporated, or absorbed). These workers should avoid any action that could provide an ignition source for fuel vapors. They should also use approved respiratory protection and appropriate monitors or detectors to check for hazardous or toxic vapors.

6.2.5. When making expedient repairs to gas and liquid fuels systems, determine:

- If the damaged line is vital to mission support.
- Repair priority if there is damage to more than one line.
- If the distribution line can be shut-off, plugged, and abandoned.
- If fire suppression, fuel removal, debris removal, and ordnance disposal is necessary.
- If the damaged component should be replaced with a temporary system.
- What safety issues need to be addressed.
- What personnel, tools, and equipment are necessary to perform repairs.

6.3. Natural Gas Distribution Systems. Units should rapidly respond to damaged natural gas systems to prevent and contain potential accidents (**Figure 6.1**). The most expedient method of handling gas system leaks is to shut off the gas supply at main feeder points. Selective system isolation is usually a good option until time and resources permit making the necessary permanent repairs.

6.3.1. Emergency Cut-Off Procedures. If it is not possible to shut the gas off using the existing valves, gas main bags or flow stoppers may be required. Gas main bags are plugs with a bladder inside and a synthetic fiber casing that workers insert into a gas main and inflate until they fill the pipe and halt the gas flow. To seal a main with a gas main bag, insert the inflatable device through a hole in the main (a hole created by damage, removal of a riser, or access port). Inflate the bag through a piece of attached tubing until it fills the pipe and stops the gas flow. To use a gas stopper, squeeze the stopper frame together and inserted it into the hole in the gas main. After the stopper is in the pipe, use the wire levers attached to the frame to restore its circular shape. Then, adjust the gas stopper to shut off the gas flow. In larger mains, it may be safer to use both bag and stopper.

Figure 6.1. Ruptured Natural Gas Line Fire.

6.3.2. Expedient Repairs of Natural Gas Distribution Systems. As mentioned earlier, it is best to simply cut off gas systems and make permanent repairs later when the emergency has subsided. However, certain conditions may call for some immediate expedient repairs to prevent danger to personnel or to provide limited gas service.

6.3.2.1. Venting of Gas Accumulations. After shutting off the main gas supply, immediately check buildings and other areas for the presence of dangerous gas accumulations. The presence of gas should be detected using special gas detection devices such as a combustible gas indicator. Individuals cannot depend on their sense of smell to detect leaks because gas can lose its odor while traveling through the ground. Be sure to vent any gas accumulations to the outside to reduce the potential for asphyxiation or explosion.

6.3.2.2. Repair of Broken or Punctured Gas Lines. There may be conditions following an emergency when gas must be available to certain facilities for essential operations. For example, the dining hall may have no alternate method of preparing food for the recovery force, or the hospital may need hot water for crucial medical services and have no other source of energy for water heaters. During periods of cold weather, gas may be the only source of heat for certain mission-critical installation facilities. Under any of these conditions, leaking or ruptured gas lines may require patching. If the leak is small and involves low-pressure gas pipes, workers may use a sealant in conjunction with a pressure mold to close the opening. The sealant should be a product that does not break down in the presence of natural gas. Consider using various mechanical clamps to repair larger leaks and pipe breaks.

6.3.2.3. Replacing Gas Lines. Refer to UFC 3-430-05, *Natural Gas and Liquefied Petroleum Gas (LPG) Distribution Pipelines*, for specific design requirements for natural gas distribution systems. Consider the following precautions when replacing distribution line sections:

6.3.2.3.1. Do not install distribution system lines under a building.

6.3.2.3.2. Do not lay lines in the same trench with other utilities to preclude the possibility of leaking gas following along or collecting in other conduits and creating an explosion hazard.

6.3.2.3.3. For the same reason as above, gas lines should be above other utilities whenever they cross, if practicable.

6.3.2.3.4. Avoid laying gas lines under paved streets or in other locations subject to heavy traffic whenever practicably avoidable. Whenever it is necessary to locate gas lines in such locations, protect the lines with a suitable casing or by burying to a depth to provide at least 2 feet of cover over the top of the pipe.

6.3.2.3.5. Maintain sufficient clearance between plastic mains and any steam, hot water, power lines, or other source of heat, to avoid temperatures in excess of 140 degrees Fahrenheit for thermoplastics or 150 degrees Fahrenheit for thermo-setting epoxy resin pipe.

6.3.2.4. Safety. The potential for asphyxiation or explosion during encounters with gas leaks makes it imperative that repair crews exercise extreme caution. Personnel should not enter confined areas with high gas accumulations unless they are equipped with self-contained breathing apparatus. Do not use open flame from cutting torches, cigarette lighters, or similar devices in a gaseous environment. Additionally, repair crews must be careful not to generate sparks near a gas leak. A good rule of thumb is not to enter any area where the mixture of air and gas is at or approaches the lower explosive limit. Taking a few extra minutes to ventilate the area will greatly reduce the danger to personnel. Additional safety precautions include:

- Remove the pressure from all the lines before working on them.
- Never smoke in areas where crews are installing or repairing gas piping; it is not permissible.
- Never use matches to test for gas leaks.
- Locate the meter and the riser pipes some distance from electric meters, switches, fuses, and other equipment.
- Install adequate pressure-relief valves on air compressors.
- Test all replaced line for leaks with appropriate procedures prior to returning to service.

6.3.2.5. Leak Detection Measures. Natural gas can be detected using special gas detection devices (**Figure 6.2**). There are also other methods to detect gas leaks—

like heavy insect activity (swarming), hissing sound, unusual improvement or deterioration in surrounding vegetation, and odor.

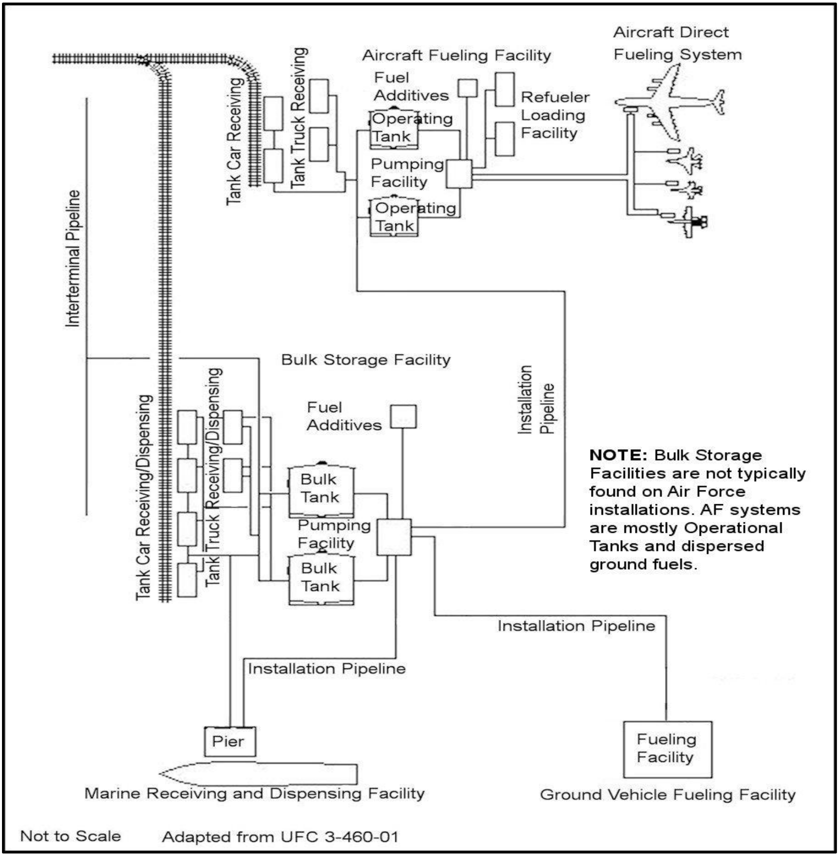
Figure 6.2. Common Gas Leak Detection Devices.

6.3.2.5.1. Although natural gas is odorless, gas companies and DOD plants inject odor additives into the system to warn the public and aid in leak identification. These additives produce a rotten egg or sulfur odor when released into the air. However, be aware that a lack of odor is not a reliable indicator of the absence of a gas leak. The odor of the gas could be filtered out as the gas passes through certain soils, or the odor may be modified by other vapors within a sewer system. Therefore, reports of gas leaks should be investigated using leak detection devices such as a Combustible Gas Indicator or Flame Ionization Detector. Refer to the manufacturer's operating manual for specific leak detector operation.

6.3.2.5.2. Another effective way to pinpoint the location of small leaks on exposed lines involves using a spray bottle of soapy water. The soapy liquid will bubble when it contacts a leak.

6.4. Petroleum Fuels Systems. An installation's petroleum fuels system is a key utility because its loss or degradation could immediately affect aircraft sortie generation. Normally, bases have liquid fuels products piped directly onto the base or delivered by tank truck, rail car, or barge (**Figure 6.3**). The fuel system has two primary components: storage facilities and distribution systems. Refer to AFMAN 32-1067 and UFC 3-460-01, *Design: Petroleum Fuel Facilities*, for specific design requirements for liquid fuels systems. Refer to UFC 3-460-03, *Operation and Maintenance: Maintenance of Petroleum Systems*, for inspection and testing requirements to keep systems operational.

Figure 6.3. Notional Fuel System Storage and Dispensing Scheme.



6.4.1. Storage Facilities. Most installations have several days of storage capacity for major fuel products. Bulk fuels storage methods vary considerably from installation to installation. At some installations, large, fixed storage tanks are located aboveground (**Figure 6.4**) and underground. Conversely, at many contingency locations, fuel storage is in lower profile, collapsible, fabric tanks (**Figure 6.5**), and sometimes dispersed. As previously addressed, wartime damage to large, fixed storage tanks are not usually expediently repairable. However, engineer forces may be able to accomplish minor repair for superficial damage and berm reconstruction. For collapsible fabric tanks, units will likely patch or replace any damaged tanks.

6.4.2. Distribution System. Fuels distribution includes pumping facilities, pipelines, and dispensing points. The construction of most fixed or land-based fuels distribution systems makes them relatively safe from natural disasters other than flooding. The major damage that the distribution system might receive would more likely result from an enemy attack during wartime. Damage impact may be lessened at installations where the distribution system is interconnected. As a protective measure, most control valves at several overseas locations are located in pits in order to limit their exposure to direct impact during an attack.

6.4.2.1. Pumping Stations. Fuel pumping stations may not be considered primary targets during an enemy attack. However, anticipate some losses to pumping capability from collateral damage, though it is likely the system will retain some capacity to pump fuel.

6.4.2.2. Pipelines. Most fuel pipelines are essentially all welded steel pipe. Some semi-permanent systems use spoolable, steel-reinforced pipeline with bolted connections; some expeditionary systems have hose connections. However, since distribution network piping is the most extensive element of the fuels system, it is more likely this element will experience damage during an attack. The impact of such damage will be less at installations with looped distribution systems.

6.4.2.3. Dispensing Points. Dispensing points range from vehicle fill stands to concrete encased aircraft hydrant refueling systems. The fill stands service fuels tank trucks for refueling aircraft at most locations. Expect damage to fill stands as a collateral effect of weapons detonation. Hydrant refueling systems, however, because of their "hardness," should remain relatively intact.

Figure 6.4. Fuels Tank Farm.

Figure 6.5. Collapsible Fabric Tanks at Contingency Location.

6.4.3. Fuels System Repairs. Most base fuels systems have a certain amount of redundancy. If after an attack, part of the fuels system is undamaged, isolation and valving may partially restore fuel service to support the flying mission. For repairs to piping, valves, and other elements of the distribution system, engineers will have to think in terms of expedient repairs similar to water systems and use whatever spare parts and materials currently exist in bench stock or special levels. However, unlike water systems, water and fuels system repair crews will have to be especially concerned with toxicity, flammability, and compatibility issues. The volatile nature of the fuels system contents complicates any damage repairs. Avoid getting jet fuel or gasoline on the skin and clothing; severe chemical burns may result if they remain in contact with the skin. Vapors from all petroleum products constitute fire and explosion hazards and are toxic to the human body. Vapors from petroleum products have caused fires or explosions because the vapors are heavier than air and settle in low places such as tanks or pits. The vapors will remain in these low places indefinitely unless removed by ventilation. Consult AFMAN 91-203, *Air Force Occupational Safety, Fire, and Health Standards*, for methods to eliminate personnel hazards associated with exposure to liquid fuels and vapor concentrations. Water and other foreign materials can contaminate aviation fuels, so exercise care to properly clean and maintain the work area.

6.4.3.1. The Water and Fuels Expedient Repair System (WaFERS) provides the tools, parts, and materials to quickly repair valve and line failures resulting from an attack or disaster. The WaFERS (along with associated instructions and related information) is being fielded and replaces legacy expedient repair systems.

6.4.3.2. Whether work crews use isolation or expedient repair methods, it is critical to perform frequent checks of the system to ensure continued system operability. This includes inspections of isolation points, temporary repairs, and the remaining serviceable portions of the system.

6.4.3.3. Watch for leaks or drips in aboveground pipelines when performing other maintenance tasks. Leaks in underground pipelines is sometimes evident by fuel surfacing on the ground, fuel runoff in the storm drainage system, fuel in underground pits or manholes, dead vegetation, or the continuous odor of fuel in a particular area. For information on permanent repairs to fuels systems, refer to UFC 3-460-03.

Chapter 7

EXPEDIENT ELECTRICAL REPAIRS

7.1. Introduction. After an attack or disaster, power for airfield lighting, navigational aids, communications centers, C2 nodes, medical facilities, and other important activities may need restoration for the installation to resume its operational mission. If the attack or disaster resulted in downed or damaged electrical lines, the repair or isolation of life-threatening electrical hazards should receive high priority. This chapter addresses CE basic considerations and expedient repair for electrical utilities. When expedient electrical repairs become necessary, be sure to adhere to requirements in AFMAN 32-1065 and related safety criteria. Additionally, consider other criteria in UFCs such as UFC 3-520-01, *Interior Electrical Systems*, UFC 3-530-01, *Interior and Exterior Lighting Systems and Controls*, UFC 3-550-01, *Exterior Electrical Power Distribution*, and UFC 3-550-07, *Operation and Maintenance (O&M): Exterior Power Distribution Systems*.

NOTICE

Work on energized electrical equipment is prohibited except in circumstances justified and approved by the BCE or equivalent. (AFMAN 32-1065)

7.2. Safety Considerations. The AF Form 1213, Civil Engineer Energized Electrical Work Permit, is required to authorize the performance of energized work meeting the intent of NFPA 70E and the Air Force Risk Management Framework. Additionally, UFC 3-560-01 identifies additional hazard/risk category classifications for work tasks. Detailed safety procedures for electrical repair operations, including Arc Flash protection are contained in AFMAN 32-1065 and UFC 3-560-01. Arc Flash protection is required for all personnel working on or near exposed energized electrical equipment operating at 50 volts or more.

7.2.1. According to AFMAN 32-1065, supervisors must properly equip and train workers to correctly use and maintain tools and PPE. When ensuring workers properly wear PPE, give special focus to rubber insulating protective equipment (rubber gloves, sleeves, line hoses, hoods, and covers) and hotline tools.

7.2.2. Another essential safety concern is proper system documentation for configuration management and future troubleshooting (i.e., redlining one-line diagrams with changes and dates) after repairs. Expedient repairs resulting in system alterations or modifications can potentially lead to serious safety issues if not properly documented. In accordance with AFMAN 32-1065, supervisors must not authorize or permit alterations or modifications to equipment or protective device settings without adequate engineering guidance and study.

7.2.3. System safety devices help protect personnel and prevent equipment failures (overcurrent, short circuit, surge protection). Failing to maintain, bypassing, or making safety devices inoperative without proper authorization increases risk to life safety and can potentially lead to future system failures.

7.2.3.1. Maintaining surge arresters is especially important to limit overvoltages and bypass the related current surge to a ground system that absorbs most of the energy. An overvoltage condition can result from a fault in the electrical system, a lightning strike, or a surge voltage related to load switching. **Note:** Consider all surge arrester equipment as loaded to full circuit potential, unless positively disconnected from the circuit. Be sure the permanent ground conductor is intact before performing any work.

7.2.3.2. Any improper or inadequate maintenance on overcurrent protective devices can increase opening time of the device, thus increasing incident energy. Where equipment is not properly installed or maintained, PPE selection based on incident energy analysis, or the PPE category method may not provide adequate protection from arc flash hazards.

7.2.4. Bottom line, efforts should emphasize not only repairing the power system, but also restoring it to ensure the safety and security of personnel and the mission.

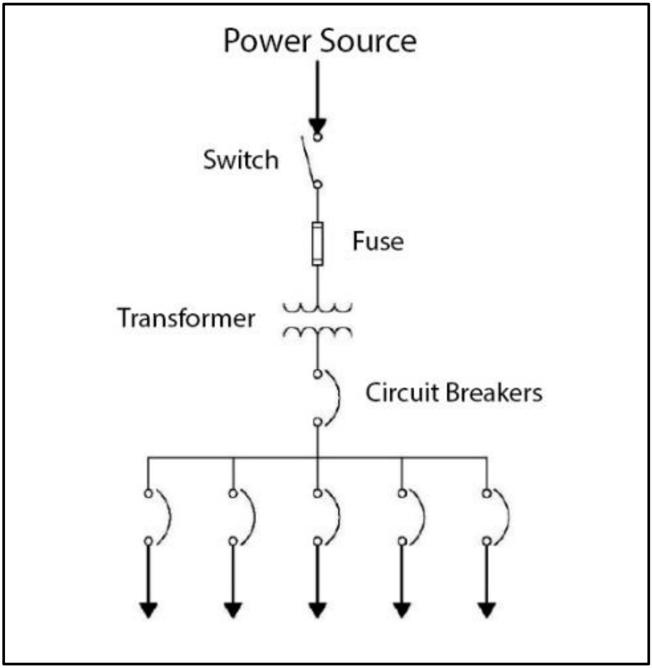
7.3. Components of Electrical System. The electrical system supporting a typical installation consists of three components: production, distribution, and interior wiring. Consider each component in terms of its anticipated damage during a contingency and the expedient repairs needed to mitigate the damage.

7.3.1. Production Systems. At overseas installations, electrical power supply is either by base power plants or by commercial sources. In the Continental United States, a commercial grid most likely provides primary power. If there is an interruption in the commercial source, usually the only alternative is to disconnect the impaired power source from the distribution system and substitute generators to power vital facilities. All mission-essential facilities should have dedicated standby generators with an automatic transfer capability to maintain operations in the event the prime power is lost.

7.3.2. Distribution Systems. The power distribution system may consist of substations, switchgear, and utility lines that are either overhead or underground. Overhead power lines and the associated utility poles are likely to suffer extensive damage during a hurricane, tornado, or enemy attack. An underground system, although better protected from the high winds common to hurricanes and tornadoes, is still vulnerable to the effects of an earthquake, flooding, or enemy munitions. The three basic distribution systems are radial, loop, and network. Any combination of these three systems can exist at most installations.

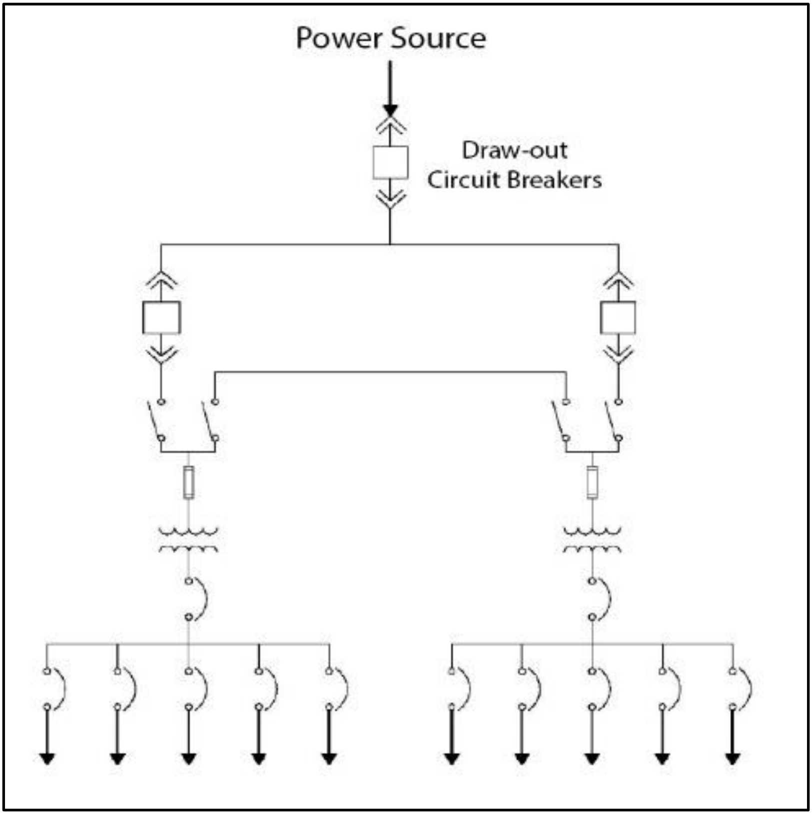
7.3.2.1. Radial System. The radial layout is one in which a mainline is established through the approximate center of an installation and branch lines are run from the mainline to power various facilities. **Figure 7.1** illustrates a basic radial layout. The primary disadvantage of the radial layout is that a break in the mainline from the power source results in a complete loss of power to all branch lines and facilities on the installation. Thus, the radial system is less effective since it is susceptible to extreme weather conditions, war damage, or sabotage. However, since the radial system requires considerably less material, labor, and time to construct, radial systems are often the option used during a contingency beddown.

Figure 7.1. Basic Radial Layout.



7.3.2.2. Loop System. A loop layout supplies power to a facility from more than one direction (**Figure 7.2**). Note that a break in the loop will not cause complete power failure since the base can still distribute power through the other section of the loop. Thus, a loop system has an inherent capability to prevent complete power loss of all facilities. Faults in the circuit can be isolated and repaired without large disruption of service. Also, the loop layout often distributes power with less voltage drop. The primary disadvantage of the loop system is it requires more material and time to construct than radial systems.

Figure 7.2. Basic Loop Layout.



7.3.2.3. Network System. A network system is simply a merger of both the radial and loop systems (**Figure 7.3**). It uses the independent feeder system of the radial system to supply power to distribution transformers while also paralleling the secondary lines used in the loop concept. This configuration capitalizes on the strong individual points of both radial and loop systems, thereby allowing optimum flexibility and efficiency. **Table 7.1** lists basic characteristics of electrical systems.

Figure 7.3. Network Layout.

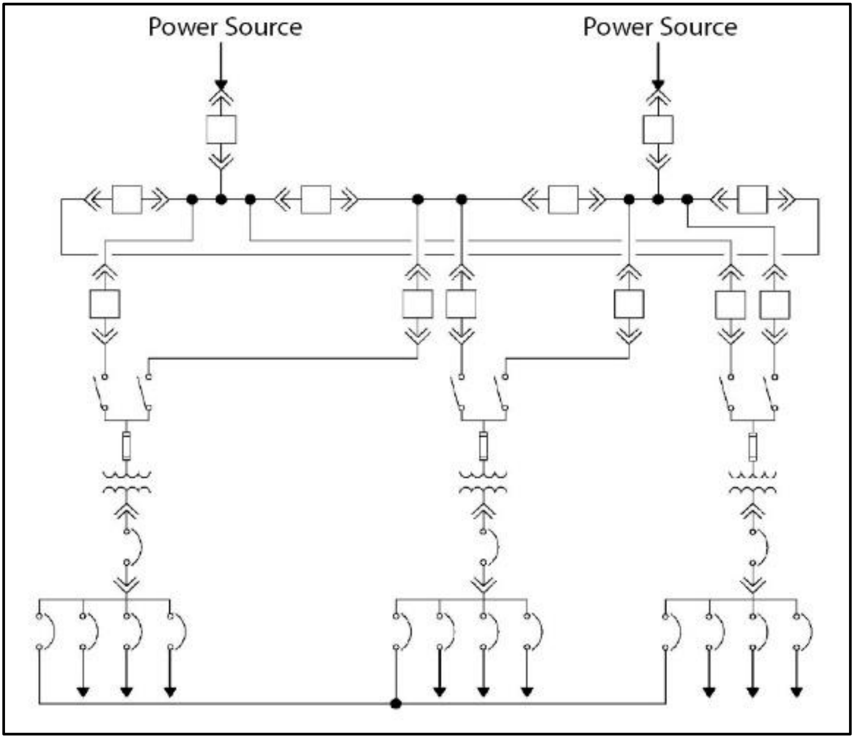
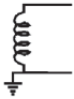
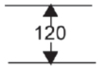
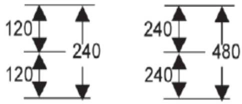
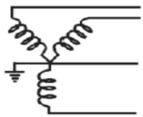
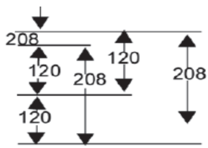
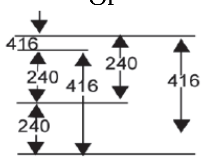
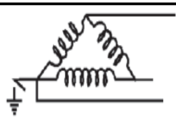
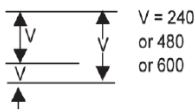
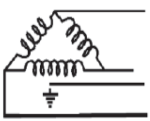
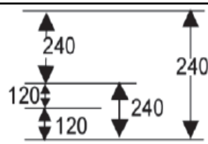


Table 7.1. Characteristics of Electrical Systems.

Type	Wiring Diagram	Voltage	Use
Single-phase, two-wire			Lighting and small, single-phase motors, small loads
Single-phase, three-wire			Local power to small buildings
Three-phase, four-wire		 Or 	Most common system for military secondary distribution
Three-phase, three-wire			Large motor loads, small lighting loads
Three-phase, four-wire			Motor and lighting loads

7.3.3. Interior Wiring. The “third leg” of the electrical system after transmission and distribution is the interior wiring. It generally consists of the wiring, switches, outlets, circuit breakers, and other electrical accessories located within a building after the service entrance interface.

7.4. Repairing Electrical Systems. After an initial damage assessment of the electrical system following an attack or disaster, the next action should be the isolation of those damaged areas presenting life-threatening hazards to personnel or posing a potential for additional property damage. Once initial isolation is accomplished, UCC personnel, using installation utility plans and maps, determine the best way to restore electrical power to vital installation facilities. Typically, work crews accomplished this by rerouting power lines to bypass damaged areas. After damage assessment data is posted to the installation utility maps, the UCC should be able to direct electrical system rerouting quickly using the existing, undamaged circuits. When rerouting around damaged areas, remember the use of non-standard materials may be an option for a provisional or temporary repair until permanent repairs can be accomplished, provided they do not jeopardize safety. If capable of carrying the required loads, consider substituting wires and cables of different sizes or those normally designed for other uses as expedient power lines. Note the use of non-standard materials as a provisional repair and be sure to conduct a regular review of the minimum available shop materials. Strictly adhere to electrical safety requirements outlined in mandatory guidance and ensure proper “phasing” of conductors is accomplished. Additionally, consider salvaging conductors, wire, and other components from unimportant or abandoned facilities.

7.4.1. Power Production Repairs. The extent of damage to an independent power production plant on the installation will vary with the type of emergency that has occurred. Natural disasters, such as hurricanes and tornadoes, are likely to cause structural damage to the plant as well as disrupt the plant’s connections to the distribution system. An enemy attack will probably cause structural damage and disruption of connections to the distribution system. The attack may produce damage to other components of the power system, e.g., demolished control equipment, broken turbine blades, and shattered insulators and bushings. In repairing such damage, take full advantage of bench stocks maintained by each power plant or draw on base supply sources. As a last resort, try cannibalization.

7.4.1.1. Portable generators, as an alternate power source, will probably be in short supply, making it imperative that units properly position and maintain these vital assets. Generators should be limited to providing power to only those facilities that are crucial to base operations. Use AFMAN 32-1062, *Electrical Systems, Power Plants and Generators*, to determine those facilities that are authorized emergency or standby generators.

7.4.1.2. Consider damaged or inoperative generators as a source of spare parts. Reassemble components and parts from several damaged generators to produce one usable machine. Equipment other than disabled generators may serve as a source of repair parts, e.g., salvage injectors from a diesel engine in a destroyed vehicle and may be adaptable to a generator engine. If available, consider using WRM generators if they are compatible with the existing voltages.

7.4.1.3. Since renewable energy sources are becoming more prevalent at contingency locations, consider how Photovoltaic (PV) power generation systems can affect damage repair processes and worker safety.

7.4.1.3.1. Verify that the grid connected renewable has dropped out and isolated prior to working on utility lines. However, this is not necessarily the case for off grid or microgrid/islanded applications. This can cause some degree of a safety risk if the PV system continues to produce power after other distributed resources have been destroyed or drop out for some reason. This will potentially keep lines energizes when they are assumed to be de-energized.

7.4.1.3.2. With the development of microgriding/paralleling base generation sources, and renewable sources that normally drop out upon loss of power, plans should include methods to reestablish the system. These systems can all be unique; in the event of a microgrid, as a part of the design phase, develop or provide an emergency plan for review and system restoration along with monthly, quarterly, and annual testing requirements.

7.4.2. Power Distribution Repairs. Some local municipal utilities or commercial utility companies can perform electrical system repairs via contract; this may not be the situation at some overseas bases or contingency locations. CE expedient repairs to power distribution systems depend on the damage involved and availability of spare parts. Most distribution systems are composed of items such as distribution cables, poles, insulators, capacitors, cross arms, switchgear, and in many cases, transformers. Only a few items within the electrical distribution system lend themselves to repair. Items such as distribution cables, grounding wires, guywires, anchors, service entrances, and occasionally transformers fall into this category. Depending on conditions at the contingency location, distribution cables may be installed overhead, laid on the ground, or buried underground. The method used often relies on the availability of time, materials, and labor. In addition, local threat conditions and degree of system damage may also be factors. The following paragraphs provide a brief review of overhead, on grade, and underground power distribution and repairs. Personnel should consult the National Electrical Safety Code (NESC), Personnel should consult the National Electrical Safety Code (NESC), normally referred to as IEEE C2, and the Accredited Standards Committee (ASC) standards for specific information and requirements.

7.4.2.1. Overhead Conductors. As a temporary repair expedient, BCEs may permit work crews to hang overhead power lines from trees, existing structures, or new poles. In some instances, cutting the damaged line on both sides of the destruction and bridging the area with new cable may be necessary. In any case, work crews should discuss the plan of operation in detail before stringing or removing deenergized conductors and overhead ground wires. Explain the type of equipment used, grounding procedures, crossover methods, safe clearance requirements, and other pertinent operations. Refer to UFC 3-560-01 and UFC 3-550-07 for additional guidance for performing aerial line work.

7.4.2.1.1. Vertical Clearances. **Table 7.2** list general vertical clearances for wires, conductors, and cables above ground. Each clearance has additional variations based on pole position, area location, vehicle height, sag, emergency installation, and other factors.

7.4.2.1.2. Vertical Conductor Spacing. Vertical spacing is the clear distance between conductors, supported on vertical racks or separate brackets. Six-inch minimum spacing is required for spans up to and including 200 feet while 12-inch minimum spacing is required for spans over 250 feet (**Table 7.3**). Always leave a clear space at the top of an electrical pole. This distance is equal to the wire spacing, that is, 6 inches for 200-foot spans and less and 12 inches for spans greater than 200 feet. **Note:** Expediently installed utility poles at initial contingency locations often do not use cross arms and braces. Instead, workers may hang conductors directly on the pole, one above the other.

Table 7.2. Vertical Clearances.

Nature of surface underneath wires, conductors, or cables	Supply cables of 0-750V	Supply cables over 750V	Open supply conductors, over 750V to 22 kV
Railroad tracks (except electrified railroads using overhead trolley conductors	24.0 ft.	24.5 ft.	26.5 ft.
Roads, streets, and other areas subject to truck traffic	16.0 ft.	16.5 ft.	18.5 ft.
Driveways, parking lots, and alleys	16.0 ft.	16.5 ft.	18.5 ft.
Other areas traversed by vehicles (cultivated/grazing lands, industrial areas, commercial sites, etc.)	16.0 ft.	16.5 ft.	18.5 ft.
Spaces/ways subject to pedestrians or restricted traffic only	12.0 ft.	12.5 ft.	14.5 ft.
Source: *NESC IC Rule 232*			

Table 7.3. Vertical Spacing of Conductors.

Span Length (ft.)	Vertical Spacing between Conductors (in.)
0 to 150	4
Over 150 to 200	6
Over 200 to 250	8
Over 250 to 300	12
Exception: The vertical spacing between open wire conductors may be reduced where the conductors are held apart by intermediate spacers, but may not be less than 4 in. Source: *NESC Rule 235*	

7.4.2.2. Wood Utility Poles. Part of the distribution system may include utility or power poles. Workers might need to install wood utility poles to replace war-damaged, storm-damaged, insect-damaged, or decayed poles. Use solid wood poles for electric distribution lines. Do not use laminated wood poles for electric distribution lines. The poles used in a distribution system should consist of a good grade of timber that will last. For example, some pressure-treated species (e.g., Texas Southern Pine) may last 35 to 50 years. Conversely, untreated timber such as soft pine may last only a couple of years and have a useful life of only one season under unfavorable conditions. However, the fact that a pole is in good condition is not proof that it can satisfactorily support the line. Poles must withstand column loadings as well as transverse loads from wind and turns in the line. Natural wood poles and sawn wood structural members, cross arms, and braces should meet the requirements in the NESC and IEEE Standards, and the permitted stress level requirements of American National Standards Institute (ANSI) 05.1-2017, *Wood Poles: Specifications and Dimensions*. **Note:** Concrete or steel poles may be justified for medium-voltage distribution circuits where wood poles do not provide adequate strength, or where climatic conditions cause wood poles to deteriorate rapidly.

7.4.2.2.1. Pole Height. The height of a given utility pole is governed by vertical clearance requirements both above and below the proposed conductors. Near airfields, poles should be kept low, yet high enough to provide adequate clearance over streets and roads. Corner poles, transformer poles, and the like are usually heavier and sometimes higher than line poles.

7.4.2.2.2. Pole Holes. If new poles are to be set adjacent to poles being dismantled, new holes should be dug. Power tools are available for digging, such as power borers or augers, and only qualified personnel must use these tools. Rock cutting drills are generally a safer alternative than the use of explosives, when encountering rock. It may be necessary to dig pole holes by hand if power diggers are unavailable or not usable. Scope the area where poles are to be set and mark all the utilities identified. Take special care when digging close to underground, energized cables and circuits.

7.4.2.2.3. Setting Poles. Crews can set or install the poles by hand, with a crane, or by using a nearby pole as a gin pole. Set the poles according to the ground conditions. Pole-setting depths can vary dependent upon whether the ground is normal firm ground, swampy, or rocky. Ideally, poles should be set deep enough to develop their full bending strength at the ground line. **Table 7.4** lists common setting depths for poles in soil and solid rock. If poles are set on the side of streets, roads, or highways, locate the poles a sufficient distance from the street side of the curb to avoid contact by ordinary vehicles using and located on the traveled way. For a redirectional curb, this horizontal distance should not be less than 6 inches from the street side of the curb.

Table 7.4. Common Pole Setting Depths.

Pole Length[1]	Setting in Soil[1]	Setting in Solid Rock[1,2]
20	4.0	3.0
25	5.0	3.5
30	5.5	3.5
35	6.0	4.0
40	6.0	4.0
45	6.5	4.5
50	7.0	4.5
55	7.5	5.0
60	8.0	5.0

Note 1: All measurements are in feet.

Note 2: Where there is a layer of soil two (2) feet or less in depth over solid rock, increase the hole depth to include depth of soil, but not exceeding the depth specified under "Setting in Soil."

(*Adapted from USDA, Rural Utilities Service [RUS] Bulletin 1728F-804*)

7.4.2.3. Guys (Wires and Anchors). Expedient utility pole repair often involves replacing or resetting guywires and anchors while bracing existing poles or raising new poles. In new work, crews should generally install guys before stringing line wires. In reconstruction work, they should install guys before making any changes in the line wires, while at the same time being careful not to place excessive pull on the pole and wires already in position. Improperly or inadequately guyed power lines will soon begin to sag, degrading the reliability of the line.

7.4.2.3.1. When replacing guy wires, determine the condition of the pole before removing the old guy wire. If the pole is weak, brace it securely before effecting any changes in pole strains. Make sure the guy wire is installed so there is minimal interference with the climbing space on the pole, and guys should clear all energized wires. In some cases, it may be necessary to install a guy hook to prevent the guy from slipping down the pole. Position the hooks so they do not interfere with climbing and cannot be used as steps. Where guys are liable to cut into the surface of a pole, protect the pole by installing a guy plate at the attachment point. Ensure workers well secure the plate to the pole to prevent the possibility of personal injury when climbing up or down the pole.

7.4.2.3.2. When workers install guys near roadways, position them so they do not interfere with street or roadway traffic. Guys located near streets should be equipped with yellow traffic guards (sometimes called "anchor shields"). Any guy wires containing snarls or kinks should not be used for line work, and it is preferable to use guy wires of the correct length to avoid unnecessary splices.

7.4.2.3.3. The type of anchor used in these repairs must provide suitable resistance to uplift and is therefore dependent on the condition of the soil. For most cases, the suitable anchor is an expanding type because most lines are installed in ordinary soils. However, rock, sandy soil, or swamp conditions may prevail. **Figure 7.4** illustrates common anchors utilized in various soil types. **Table 7.5** indicates suitable anchor types based on a range of soils from hard to soft. While the soil descriptions are not an industry standard, manufacturers are familiar with this and other similar classifications.

Figure 7.4. Common Anchors and Details.

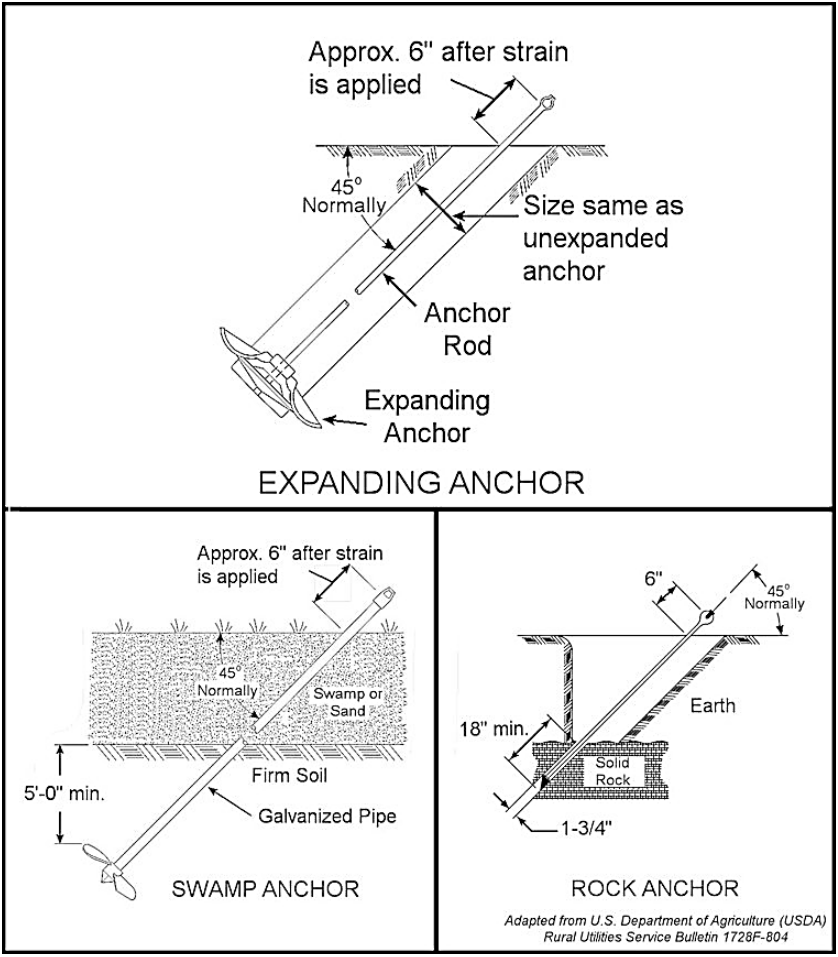


Table 7.5. Anchors Suitable for Various Soils.

<table>
<tr><th>Type of Anchor</th><th>General Soil Type</th><th>No.</th><th>Classification Description</th></tr>
<tr><td rowspan="3">Rock</td><td rowspan="3">Hard</td><td>1</td><td>Solid bedrock</td></tr>
<tr><td>2</td><td>Dense clay; compact gravel; dense fine sand; laminated rock; slate; schist; sandstone</td></tr>
<tr><td>3</td><td>Shale; broken bedrock; hardpan; compact clay-gravel mixtures</td></tr>
<tr><td rowspan="2">Expanding</td><td rowspan="2">Ordinary</td><td>4</td><td>Gravel; compact gravel and sand; claypan</td></tr>
<tr><td>5</td><td>Medium-firm clay; loose sand gravel; compact coarse sand</td></tr>
<tr><td rowspan="3">Swamp or as Suitable</td><td rowspan="3">Soft</td><td>6</td><td>Soft-plastic clay; loose coarse sand; clay silt; compact fine sand</td></tr>
<tr><td>7</td><td>Fill; loose fine sand; wet clays; silt</td></tr>
<tr><td>8</td><td>Swamp; marsh; saturated silt; humus</td></tr>
</table>

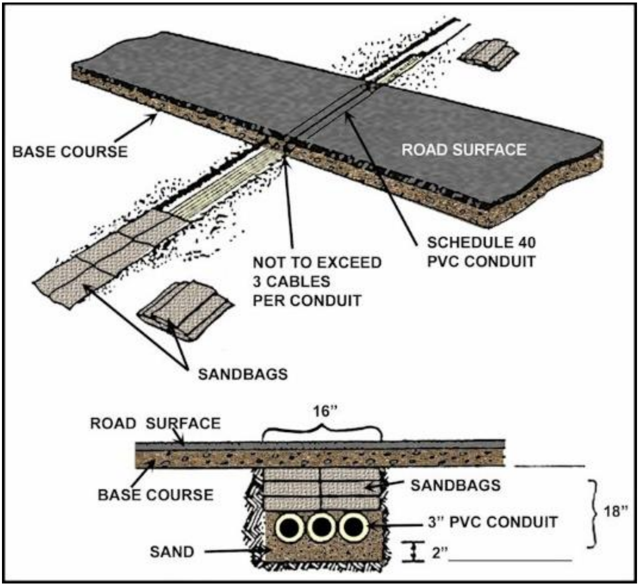
7.4.2.4. Cables Laid on the Ground. During beddown at initial contingency locations, primary and secondary electrical distribution cables are often laid on the ground to save time. At established locations, workers making expedient repairs to existing systems may also lay distribution cables directly on grade. In either situation, the cables should be guarded or otherwise located so they do not unduly obstruct pedestrian or vehicular traffic and are appropriately marked. **Note:** NESC rules indicate power cables operating above 600V to ground must have a continuous metallic shield, sheath, or concentric neutral that is effectively grounded. At a splice or joint, the current path of the metallic shield, sheath, or neutral must be continuous, but need not be concentric.

7.4.2.4.1. Where cables cut across roads or pathways, protect them from mechanical damage using aboveground shielding or route the cables under the roadway. One method to temporarily shield or protect power cables crossing roadways is to use a commercial cable protector as shown in **Figure 7.5**.

Figure 7.5. Commercial Cable Protector across Roadway.

7.4.2.4.2. Another method of crossing roadways is to create a cable raceway under the road using PVC pipe (**Figure 7.6**). Schedule 40 PVC conduit with a diameter of 3 to 4 inches is suitable for expedient raceways under crossings. In applications for which excessively high roadway temperatures are expected, use Schedule 80 PVC if available. For average temperatures over 90 degrees Fahrenheit, the number of cables per raceway should be limited to three to prevent insulation overheating. In addition, the raceway in this application must also have at least 60 percent air space in its section to reduce the possibility of overheating. The cables on both sides of the road are protected from foot traffic by sandbags. If anticipating follow-on road improvements or upgrades, consider running the cables in commercial-grade conduit under roadway or burying the cables deeper.

Figure 7.6. Underground Roadway Crossing.



7.4.2.5. Existing Buried Electrical Cables. Use AF GeoBase Program data layers and area utility maps to help locate existing buried power cables and nearby utilities as accurately as possible. Locate and scope for buried cables along any intended digging areas. Use caution when excavating near or exposing direct-burial electric underground cables. If the depth of all direct-burial cables is known, consider using power-digging equipment for excavating all but the last 12 inches of cover over the cables. Remove the remaining cover using hand-digging tools with fiberglass reinforced plastic handles. Where the depth of direct-burial cables is not known, do not use power-digging equipment, except to break and remove the surface pavement. Workers should refer to UFC 3-560-01 for additional information relating to locating buried electrical cables. Other precautions for direct-burial cables include:

- Do not use probe rods or bars to locate underground cables.
- Avoid damaging cable insulation when uncovering cables.
- Protect all exposed cables against damage in work area using boards or other nonconductive materials.
- Do not stand, sit, kneel, or lean on unprotected cables.

7.4.2.6. Direct-Burial Cables. When time and labor become available, consider burying direct-burial cables previously laid on the ground. Burying the cables can enhance personnel safety, protect the cable from damage, and improve the cable's current-carrying ability. Include the following when planning for cable burial:

- Exposed to the least disturbance practical.
- In as straight a line as practical.
- Allow safe access for construction, inspection, and maintenance.
- Planned trenching or boring path will not interfere with proposed or existing structures.
- Avoids unstable soil such as mud and shifting or corrosive soils.
- Protected from natural hazards.

7.4.2.6.1. Before trenching operations, be sure to scope and mark all appropriate areas showing the exact location of existing utility lines. Ensure the ditching machine has required safety devices and operations are safe and efficient. When possible, excavate trenches in increments that minimize the length of open trenches. Consider removing spoil daily to an area where it is not a safety hazard.

7.4.2.6.2. When trenching for direct-burial cable, the bottom of the trench should be relatively smooth, undisturbed earth; well-tamped earth; or sand. Do not lay cables directly on sharp rocks or in very rocky soil. For excavations in rock or rocky soils, lay the cable on a protective layer of well-tamped backfill. If the soil is very rocky and the area will be trafficked, then a layer of sand or rock- free soil may be necessary as backfill above the cables. As a minimum, the backfill within 4 inches of the cable should be free of materials that could damage the cable. Avoid using machine compaction within 6 inches of the cable. Consider laying down underground warning/marking tape 12 inches or less below grade along the length of the line to alerts workers there is an existing high voltage line, especially at locations where the maps may not be current. Consult the NESC for additional instructions for trenching and other cable burial options.

7.4.2.6.3. The burial depth for direct-buried cables should be adequate to prevent cables from being disturbed or damage by surface digging or usage. The NESC and IEEE Standards provide adequate burial depths for direct-buried cables and conductors (**Table 7.6**). **Exception:** Where conflicts with other underground facilities exist, street and area lighting cables operating at not more than 150V to ground may be buried at a depth not less than 18 inches.

Table 7.6. Direct Burial Cable or Conductor Depths.

Voltage (phase-to-phase)	**Depth of Burial (in)**
0 to 600	24[1]
601 to 50kV	30
Above 50kV	42
Note 1: See exception in paragraph 7.4.2.6.3 above. *(Source: NESC)*	

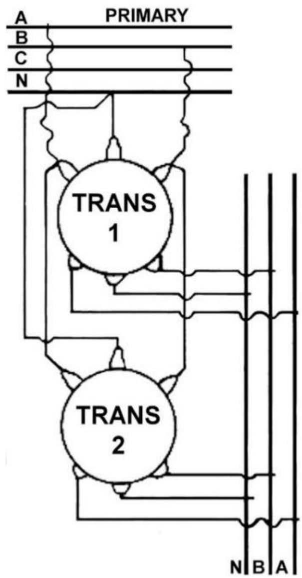
NOTICE

Work on energized electrical equipment is prohibited except in circumstances justified and approved by the BCE or equivalent. (AFMAN 32-1065)

7.4.2.7. Pole-Mounted Power Transformers. If the damage is not too extensive, electricians may be able to repair certain unserviceable or impaired transformers. Cracks or holes in the tank can be patched by welding, provided testing indicates that internal windings have not been compromised. Return the transformers to service after being thoroughly dried and replacing lost or contaminated oil. Keep in mind that oil from damaged transformers must be filtered before being reused and that motor oil is not a satisfactory substitute for transformer use (a transformer requires a highly refined mineral oil free from moisture or other impurities).

7.4.2.7.1. At some contingency locations, there may not be sufficient spare transformers available to provide a one-for-one replacement for damaged units. For example, you may not have a single-phase transformer with the capacity for the required load. In such a case, it may be necessary to parallel two smaller transformers in order to supply the load (**Figure 7.7**). This expedient solution will solve an immediate problem, but it is not cost effective. Replace this transformer configuration when the correct equipment becomes available. **Note:** Ensure the transformer polarities match additive-to-additive or subtractive-to-subtractive.

Figure 7.7. Paralleling Single-Phase Transformers.



7.4.2.7.2. In a situation where three-phase power is needed and one transformer out of the three is damaged, three-phase power can still be provided by making what are commonly called open-delta connections. **Figure 7.8** shows the open-delta connection when a four-wire, three-phase wye primary is involved. **Figure 7.9** illustrates the connections that must be made to achieve the open-delta connection when a three-wire, three-phase delta primary is involved. Regardless of the type of primary involved, these connections are used only for emergencies and should not be constructed as permanent installation. The two transformers used in the open-delta connection will only supply 86.6 percent of their rated capacity. The total capacity of the bank will be only 57.7 percent of the original bank capacity.

Figure 7.8. Open–Delta with Wye Primary.

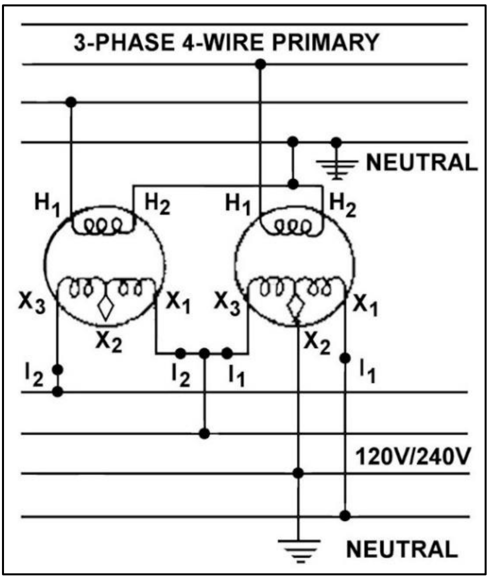
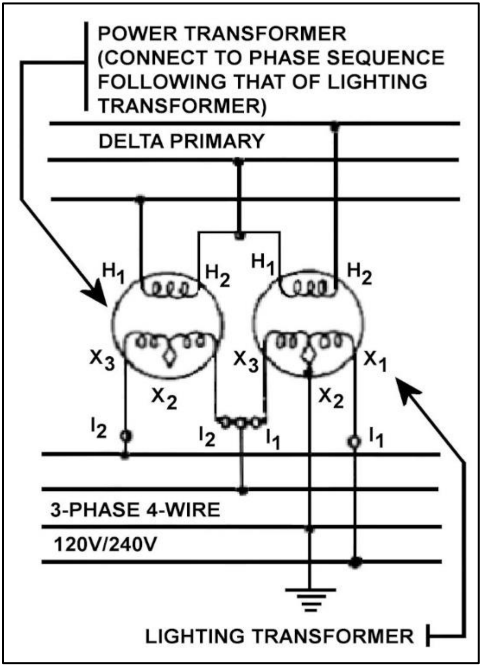


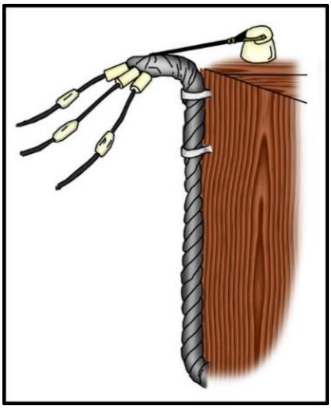
Figure 7.9. Open-Delta with Delta Primary.



7.4.2.8. Service Entrances. During the aftermath of an attack or disaster, it may become necessary to repair or build new service entrances with expedient methods and materials. New installations would be intended as temporary measures only and would be upgraded as the situation stabilizes or used where the location is intended only as a one-time, short-term development. An electrical service entrance is the point at which electrical service enters a facility, it normally consists of a load center with circuit breakers or fuses, and any other equipment located between the load center and service drop (overhead connection). An expedient service entrance can be constructed as follows:

7.4.2.8.1. If only the service entrance cable is available, electrician can make a weather head using PVC pipe to form the downward curve of the weather head. Fasten the PVC to a rigid vertical item like wood framing. Should PVC not be available, plastic electrician's tape can effectively seal moisture out of the cable insulation for the service entrance (**Figure 7.10**). Individually insulated wires can be bundled and wrapped with tape to form a service entrance cable. Should plastic tape not be available, friction tape can be used to wrap the cable; however, if friction tape is used, it should be coated with varnish to render it waterproof before installation.

Figure 7.10. Expedient Weather Head Using Electrician's Tape.



7.4.2.8.2. If load centers are not available, using safety switches (**Figure 7.11**) for service equipment can protect light loads. It may be necessary to bridge one set of contacts inside the switch so that the neutral will be a solid, unbroken circuit. The energized circuits can then be fused to the proper ampacity (current-carrying capacity) through the operating contacts. Keep in mind that this is an emergency situation and that the fuses should be well below the ampacity of the branch circuits installed to protect the insulation of these branch circuits.

Figure 7.11. Safety Switch.

7.4.2.9. Grounding Wires and Rods. Proper grounding of electrical systems is essential to the safe operation of the system. Grounding is accomplished by driving ground rods into the ground and providing a minimum 10 American Wire Gauge (AWG) bare copper wire from the ground rod to the device or system to be grounded. The spacing and depth of ground rods depends upon the resistance to ground to the earth at the site. In the absence of the capability to measure the resistance to ground and determine actual grounding requirements for the site, use a 5/8-inch x 8-foot ground rod driven into the earth or into the permanent ground water level, if known. Electrical continuity is essential in a grounding system; therefore, all connections must be clean and properly bonded. The design and application of grounding to an electrical system should normally be inherent in the system installation and not something that is added later.

7.4.2.10. Tools and Equipment. Generally, the tools, equipment, and materials needed for electrical utility repairs are contained in CE and Basic Expeditionary Airfield Resources UTCs along with their associated Mobility Readiness Spares Packages (MRSP). However, before deploying it is important to contemplate site-specific needs and the availability of on-site assets. If additional materials are needed for early or expedient repairs, consider having arriving personnel bring the materials with them for the anticipated work.

7.4.3. Airfield Lighting Repairs. Airfield lighting can be essential to support aircraft nighttime operations and other periods of decreased visibility. If after an attack or disaster, damage conditions allow use of the permanently installed airfield lighting system, likely some expedient repairs will be necessary. Ideally, as repairs to runway pavement surfaces are under way, concurrent repairs to the airfield lighting system should be proceeding with the intent of having the system operational when the full runway returns into service. Refer to AFMAN 32-1040, *Civil Engineer Airfield Infrastructure Systems*, UFC 3-535-01, *Visual Air Navigation Facilities*, and UFC 3-260-01, *Airfield and Heliport Planning and Design*, for specific information on runway and airfield lighting guidance.

7.4.3.1. Lamps and Fixtures. These items are probably the most vulnerable components of runway lighting systems. Because of their exposed locations, the components can suffer damage from accidents, natural disasters, or airfield attacks. If the fixtures are undamaged, just replace the broken or inoperative lamps. If replacement lamps or fixtures are scarce or unavailable, consider substitute equipment and alternate sources for parts. If, for example, the base has multiple runways, lamps and other components salvaged from one runway may be useful to light another. As a last resort, lamps and fixtures not commonly used in runway lighting systems may be a potential option to accomplish the mission under emergency conditions. If considering these or other unconventional emergency repair options, coordinate with local airfield management and wing safety (flight and ground) authorities before proceeding. **Note:** Remove substitute equipment from service upon installation of approved replacement equipment.

7.4.3.2. Light Emitting Diode (LED) Fixtures. With significant technology advancements in interior and exterior lighting, LED sources and fixtures have rapidly become industry standards and may be potential replacements for defective and quartz-halogen lighting. According to AFMAN 32-1040, LED fixtures are approved for use on Department of the Air Force installations in both enduring and contingency applications with the following exceptions: medium-intensity and high-intensity runway edge lighting, approach lighting, and obstruction lighting. Other conditions may limit or prohibit the use of LED lights and fixtures on the airfield. In any case, the use of LED light fixtures for airfield ramp, apron, alert, or airfield security lighting requires appropriate base level organization coordination. For specific requirements regarding LED fixtures, refer to AFMAN 32-1040 and UFC 3-535-01.

7.4.3.3. Power Supply. An adequate power supply must be available to return a damaged runway lighting system to operation. If the main base power and the air base lighting vault are still operational, the first consideration should be to reconnect or reroute feeder lines from the vault to the nearest source of base power. If the main base power system is not operational, or it is not feasible to reconnect an operational vault to base power, the use of generators is the alternative. Since an operational runway usually has highest priority in base recovery activities, the acquisition of generators should not pose a significant problem. Depending on runway location, connecting the runway lighting system to an off base, commercial power supply might also be a viable option.

7.4.3.4. Cable Connections. It is likely that disruption to parts of the underground cable system will occur during an airfield attack. The most expedient way to repair this type of damage is to use the existing system to the maximum extent by splicing broken cable and looping around the extensive breaks with replacement cable. If the lighting system received extensive damage, or the selected MOS does not lend itself to the use of an existing lighting system, run new cables to support a new lighting system. In either situation, "expedient" is the key word. Avoid devoting extra time to burying cable repairs or new cables unless required for safe aircraft operations. Running the cables above ground expedites repairs and saves considerable time for other critical repair tasks. Accomplish permanent repairs and burying of cables after emergency conditions subside. Remember, it is desirable to use standard runway lighting cable for repairs. However, if necessary, consider any available electrical cable with a voltage and current rating equivalent to that required by the lighting system as a potential substitute.

7.4.3.5. Emergency Airfield Lighting System. While the expedient solution to damaged airfield and runway lighting is usually to repair or replace the damaged parts, if that is not feasible, the use of an emergency airfield lighting system (EALS) may be next best option. Likewise, if a minimum operating strip (MOS) is in use, an EALS installation may be necessary to support night and adverse weather flying requirements. When making repairs to EALS, refer to T.O. 35F5-3-17-1, *Lighting System, Airfield, Emergency A/E82U-2*, for repair procedures.

7.4.4. Interior and Exterior Fluorescent and Incandescent Lighting. When repairing or replacing defective fluorescent and incandescent lighting sources and systems, energy consumption and life cycle costs are usually an important consideration. Refer to UFC 3-530-01 for additional information on interior and exterior lighting systems and controls.

7.4.4.1. Fluorescent Lamp Repairs. Tubes, starters, ballasts, and tube holders (also called sockets) are the components usually involved in the repair of fluorescent lamps. All components are easy to replace, and most repairs are a matter of substitution. Due to improved life cycle costs, consider use and availability of solid-state lighting (SSL), such as LED sources or fixtures as potential replacements. For example, replacing linear fluorescent lamps with linear LED lamps (sometimes referred to as tubular LED (TLED) lamps). **Note:** UFC 3-530-01 only permits LED light source replacements (screw base) for incandescent or compact fluorescent light (CFL) sources.

7.4.4.2. Incandescent Lamp Repairs. Recent developments in light source technology have introduced long life light sources that have four to five times the life of standard incandescent light sources. In lieu of repair, consider replacing defective incandescent lamps with LED retrofits or other energy-efficient light sources. If feasible, also consider replacing defective incandescent or fluorescent lamps in exit lights with compatible LED types where permitted.

7.4.5. Interior Wiring. Expedient repairs to the interior wiring of a structure depend on the extent of damage and the criticality of the facility. If the facility is not critical to current base recovery operations, delay repairs until additional resources are available. For facilities considered essential to base operations, determine the minimum level of required electrical service. Does an entire structure need power or only a small portion of it? What type of equipment will the electrical system of the building be required to support? Will it only need minimum electrical voltage to provide lighting, or are there requirements for specialized voltages to power large air conditioning units, refrigeration units, or specialized systems and equipment? For example, there is no need to devote excessive labor and materials to complete restoration of the base hospital's electrical system if the hospital staff needs only a section of the building and one X-ray machine. In this case, electrical wiring in this section of the building could be restored and a special high-voltage cable could be run to operate the X-ray machine.

7.4.5.1. When making expedient repairs to the interior wiring, use undamaged wiring to the maximum extent possible. This will cut repair time and result in fewer exposed live circuits when the facility returns to operation.

7.4.5.2. As with distribution systems, consider bypassing damaged areas with new wiring to complete a vital circuit. When bypassing damaged areas or running temporary lines into a structure, running wiring across floors and other building surfaces to expedite repairs may be an option. However, if the facility will have a high volume of personnel traffic, tack the wiring to the wall or ceiling to prevent further damage or hazards. It is not necessary to conceal the temporary wiring to present a finished appearance; it only needs to be functional and out of the way of heavy traffic (**Figure 7.12**).

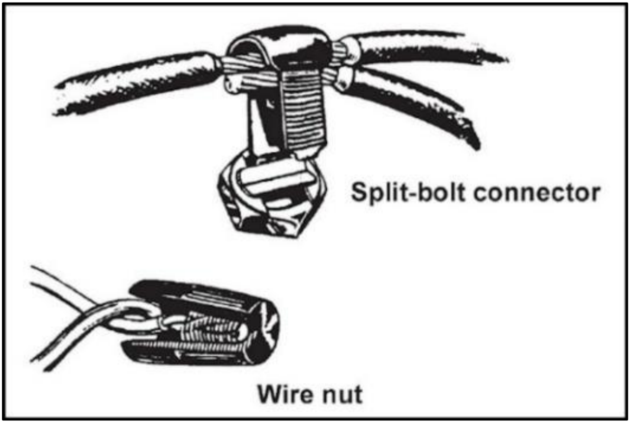
7.4.5.3. The best wiring practice (including open wiring systems) is to run continuous wires from the service box to the outlets. Although spliced wires are permitted (if they are located inside an electrical box), avoid using them whenever possible. If using spliced wires, the spliced wire must be as good a conductor as a continuous wire. **Note:** Never pull splices through conduit. Place splices in appropriate electrical boxes so that the hot wire will not make contact with the grounding system.

Figure 7.12. Installing Temporary Interior Wiring.

7.4.5.3.1. Since heavy wires are difficult to splice, electricians will often use split-bolt connectors for wire joints (**Figure 7.13**). Wire nut connectors are common options for connecting small-gauge and fixture wires. One design consists of a funnel-shaped, metal spring insert molded into a plastic shell; the other type has a removable insert that contains a setscrew to clamp the wires. In either design, the plastic shell screws onto the insert to cover the joint. Follow steps below to connect a wire nut:

- Strip off about 1 inch of insulation from the ends of the wires that you are going to join.
- Twist the stripped ends clockwise at least one and one-half turns.
- Snip 3/8 to 1/2 inch off the twisted wires so that the ends are even.
- Screw the wire nut on clockwise.

Figure 7.13. Solderless Connectors.

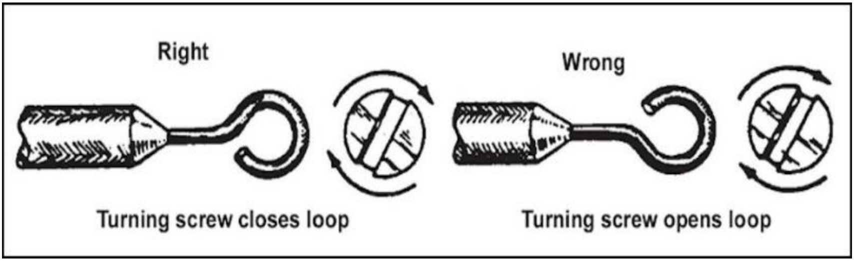


7.4.5.3.2. For temporary or expedient wiring, use plastic electrical tape to insulate splices. On a two-conductor cable, separate the two legs. Secure the tape on one leg, tape the first leg, close the legs together, and tape the wire splice past the end. Adequately cover all bare copper. Apply three layers for voltages up to 600 volts. Half lap the tape (overlap by half the width of the tape) for padded mechanical protection.

7.4.5.4. When attaching a wire to a switch or an electrical device or when splicing a wire to another wire, remove the wire insulation to bare the copper conductor. Make the cut at an angle to the conductor to avoid nicking and weakening the wire. To attach the trimmed wire to the terminal, always insert the wire loop under the terminal screw (**Figure 7.14**), so that tightening the screw tends to close the loop. When correctly inserted, the loop brings the wire insulation ends close to the terminal.

7.4.5.5. After completing wiring repairs evaluate the loading on each phase and balance the loads as well as possible. Failing to keep the loads balanced can quickly generate additional failures. See UFC 3-520-01 for more information when checking and maintaining load balance between phases.

Figure 7.14. Wire Attachment to Terminals.



7.4.5.6. Other important considerations for expedient repair of interior electrical systems is the supply of wiring, switches, and associated hardware needed for repairs. Depending on the extent of damage, base supply sources may not have enough for all repair needs. In these cases, cannibalization and substitution become important. At theater locations, many components will be of foreign manufacture and not readily available through US supply channels, making it imperative that repair crews salvage as much as possible. Structures declared irreparable may contain switches, wiring, and other hardware that is usable to restore electrical services to other structures. Exercise caution to avoid inflicting additional or unnecessary damage during salvage attempts. Salvaged structures may require rehabilitation in the future.

7.4.5.7. The tools an electrician would need for interior wiring include standard items such as pliers, screwdrivers, hammers, wrenches, chisels, hacksaws, files, and drills. **Table 7.7** lists special tools and materials not typically available in a standard took kit.

Table 7.7. Tools for Interior Wiring.

Tool	Purpose
Fuse Puller	Eliminates the danger of pulling/replacing cartridge fuses by hand. Also used for bending fuse clips, adjusting loose cutout clips, and handling live electrical parts. Some have encased circuits and test probes to determine if voltage is present in a circuit.
Masonry Drill	Typically, carbide-tipped drill used for drilling holes in brick or concrete walls to anchor apparatus with expansion screws or allow passage of conduit/cable.
Conduit Threaders, Reamers, and Cutters	Used to thread rigid conduit for installation. The tapered pipe reamer is as a precaution against wire damage. The thin-wall conduit cutter has a tapered-blade attachment for reaming the conduit ends.
Insulation Stripping Tools	Wire strippers (or knives) are for removing wire insulation before making connections; multi-tools to cut and skin wires, attach terminals, gauge wire, and cut small bolts; and cable cutter instead of a hacksaw to remove the armor from electrical conductors at the box entry or when cutting cable to length.
Plastic Electrical Tape	Used for replacing insulation and wire coverings; provides weather resistance and limited mechanical protection to a splice that is already insulated.
Fish Tape	Used to pull wire through conduit. Tape is made of tempered spring steel, is about 1/4-inch wide, and is available in different lengths to suit requirements.
Drop Chain	Used for pulling wire and cable between studs in existing buildings. Consists of small chain links attached to a lead or iron weight; used only to feed through wall openings in a vertical plane.

Tool	Purpose
Ruler and Measuring Tape	Folding ruler and steel measuring tape used for measuring conduit and determine the quantity of material required for each job.
Wire Grip and Splicing Clamp	Wire grips aid in pulling wire through conduit and for pulling open-wire installations tight. Splicing clamps used to twist the wire pairs into a uniform, tight joint when making splices.
Extension Light	Used when normal building lighting is not available; light includes long extension cord.
Wire Code Markers	Used to identify wires and equipment, particularly for wires in complicated wiring circuits, fuse circuit-breaker panels, or junction boxes.
Multimeter	Used for measuring voltage, current, resistance, and continuity.

7.5. Foreign Wiring Systems. Engineers may encounter contingency situations that involve reactivating an established installation in a foreign country. In this case, the facilities on the installation would be intact but possibly requiring renovation or modification. Be cognizant of differences in foreign wiring systems/standards (e.g., color coding, frequencies, and secondary distribution voltages) and how they could influence expedient repair processes. See combatant command guidance for any specific requirements relating to foreign wiring systems.

7.5.1. Foreign Systems Interface. The primary difference between US and foreign wiring systems is some foreign systems are not installed according to standards outlined by the NESC, IEEE, and ASC. This may be due to material shortages, particularly in economically depressed nations, which often have to use materials at hand. The following paragraphs provide additional details regarding material variances and electrical system comparisons.

7.5.1.1. Voltage. The US uses nominal voltages that range from 120 to 240 volts for single-phase alternating current and 208 to 600 volts for three-phase alternating current in low-voltage distribution systems. A considerable number of foreign countries use other voltages, requiring our electrical equipment to be converted, modified, or operated inefficiently when powered by these foreign electrical systems.

7.5.1.2. Frequency. The standard frequency of alternating current distribution in the US is 60 Hertz (Hz). In many foreign lands, 50-cycle frequency generation is common; but the electrician may also encounter frequencies such as 25, 40, 42, and 100 cycles. See **paragraph 7.5.4** for general guidelines for using 60 Hz electrical equipment on 50 Hz power sources. **Attachment 5** lists frequencies and secondary distribution voltages for commercial power systems in various countries. **Note:** This data is subject to change so always verify before beginning work.

7.5.1.3. Materials. The wiring materials commonly used in foreign countries are normally peculiar to the country's manufacturer. The US employs the AWG system, which US installations use. Most foreign wire will differ in size and use. In addition, receptacles, switches, and plugs used in foreign wiring systems are different and normally cannot be mated or used with similar American-manufactured components. Be aware that problems may result when dissimilar materials are used interchangeably in a power-distribution system. The close association of dissimilar metals may cause galvanic corrosion at the joints that eventually destroys the usefulness of the equipment. This is a particular concern when joining aluminum and copper. Newer materials made especially for connection to copper or aluminum with no adverse effects will be appropriately marked. Except in emergency expedient installation, dissimilar metals should never be used together. If using aluminum exclusively in a system, a special joint compound must be applied to all connections or joints to protect against excess surface oxidation. The oxide of an aluminum conductor differs from copper oxide in that it adds a high contact resistance to the wire.

7.5.2. Expedient Procedures Involving Foreign Systems. During contingency operations in a foreign country, the AF may use all or part of the installation electrical system. Though the decision of employment is usually determined by immediate circumstances, the AF will likely use one of the approaches below:

7.5.2.1. Since the electrical components of a foreign and domestic electrical system cannot be interchanged, the decision may be made to use all foreign equipment. The obvious problem in this decision is one of supply. The parts needed may not be readily available.

7.5.2.2. If time is a consequential factor, consideration should be given to the use of standard electrical items made in the US and the modification of plugs or connections so that they may be used in the foreign system. Although this method usually results in decreased operating efficiency, the ease of adaptability and abundance of supplies usually outweigh the reduction in performance.

7.5.3. Different Voltage Effects. Whenever possible, all equipment should be operated at its rated voltage. To expedite foreign system use, items built to operate at standard American voltages may have to function at different voltages. Though such items may not be operated efficiently, their availability for use may be an important military need. Below are some effects of voltage differences on common electrical devices.

7.5.3.1. Lighting Fixtures. When fluorescent lamps are operated at voltages higher than standard, both the lamp and ballast life are shortened. Line voltages below the minimum of the operating ranges of 110-125, 199-216, or 220-250 volts will cause uncertain starting, short lamp life, and reduced lighting efficiency.

7.5.3.2. Motors. Rotating equipment, such as motors and fans, are usually designed to operate with a permissible voltage variation of 10 percent within their prescribed rating. The combined voltage and frequency variation is also limited to 10 percent. Higher voltages give increased torque, increased efficiency, and increased starting temperature. Operating at voltages differing from rated voltages by more than 10 percent may be permitted only in an extreme emergency since the equipment will quickly be damaged or destroyed by such operations.

7.5.4. Different Frequency Effects. Electrical operating items based on resistance characteristics (such as heaters, hot plates, and electric stoves) operate efficiently over all ranges of distribution frequencies used throughout the US and foreign territories. Rotating equipment and items such as lights and transmission or receiving equipment are adversely affected by variations in frequency. Some of the effects of frequency changes on this type of equipment are described below.

7.5.4.1. Resistive Loads. Fluorescent lights rated to operate at a nominal 60-cycle current can be used at 50 cycles, but with a shorter ballast life. At lower than 60-cycle frequencies, a noticeable flicker in the light output can be detected. This is undesirable where painstaking and meticulous work is being performed. Operation at lower frequency is not satisfactory and should be avoided. Incandescent lights, because of their resistance design, will operate satisfactorily at all of the frequencies encountered overseas. However, lamps designed to function at 60 Hz will not burn as brightly at 50 Hz and ovens will not be as hot.

7.5.4.2. Static Induction Devices. Distribution transformers, electric discharge lighting ballasts, series lighting current regulators, and other static inductive equipment induce magnetic energy fields in iron as part of their normal operation. The magnetic flux density is directly proportional to the volts/hertz ratio of the power source. Consequently, the voltage must be reduced proportionally to maintain the volts/hertz ratio at the design point.

7.5.4.3. Transmitting Equipment. All receiving and transmitting equipment, or other items which have transformers included in their wiring, will not operate satisfactorily either below or above their rated line frequency and should be used only in an emergency. In some cases, there may be frequency converters available, particularly in flight line operations, which can be obtained and used when the equipment operation is mission essential.

7.5.4.4. Induction Motors. Induction motors rated for 60 Hz operation will run at about 5/6 of rated speed when connected to a 50 Hz source. Consequently, if a motor is nominally rated to run at 1800 rpm at 60 cycles and is operated at 50 cycles, its output speed will be reduced to approximately 1500 rpm. Motor current varies inversely with both source frequency and voltage. As the 50 Hz source voltage is reduced, motor current heating the winding increases while iron loss heating is decreasing. No amount of voltage reduction can compensate for both heating effects simultaneously. However, induction motors rated at 120V, 60 Hz will operate successfully at about 110V, 50 Hz if the speed reduction can be tolerated. Keep in mind that some motors are built to function at either 50 or 60 cycles. In addition, **Table 7.8** lists current and circuit breaker sizes for alternating current motors.

Table 7.8. Full Current and Circuit Breaker Sizes for AC Motors.

SINGLE-PHASE				
Motor Horse-Power	**118-Volt**		**220-Volt**	
	Current (AMPS)	Circuit Breaker Size (AMPS)	Current (AMPS)	Circuit Breaker Size (AMPS)
1/6	3.34	15	1.67	15
1/4	4.0	15	2.4	15
1/2	7	15	3.5	15
3/4	9.4	25	4.7	15
1	11	25	5.5	15
1 1/2	15.2	25	7.6	25
2	20	50	10	25
3	28	50	14	35
5	46	70	23	50
7 1/2	68	125	34	70
10	86	200	43	70
THREE-PHASE				
Motor Horse-Power	**220-Volt**		**440-Volt**	
	Current (AMPS)	Circuit Breaker Size (AMPS)	Current (AMPS)	Circuit Breaker Size (AMPS)
1/2	2.5	15	1.3	15

3/4	2.8	15	1.4	15
1	3.3	15	1.7	15
1 1/2	4.7	15	2.4	15
2	6	15	3	15
3	9	25	4.5	15
5	15	25	7.5	15
7 1/2	22	50	11	25
10	27	50	14	35
15	38	70	19	50
20	52	125	26	70
25	64	125	32	70
30	77	125	39	70
40	101	200	51	125
50	125	200	63	125
60	149	225	75	125
75	180	400	90	200
100	244	400	123	200

7.5.5. Electric Motor Voltage/Hertz Variation Remedies. Corrective measures for two of the more common major electric motor problems related to voltage and hertz incompatibilities are provided below.

7.5.5.1. Motor Heating Due to Iron Saturation. Motor geometry establishes a design volts/hertz ratio. As addressed earlier, if the motor will be operated at less than designed frequency, then the voltage must be reduced proportionately (5/6) to maintain the volts/hertz ratio at or below the design limit.

7.5.5.2. Reduced Motor Shaft Speed. Shaft speed is a function of source frequency and motor configuration. The coupling to the drive load often involves belts, pulleys, chains, or gears. A change in drive ratios could correct the speed. However, many loads operate adequately at 5/6 of design speed.

7.6. Miscellaneous Reference Material. The following information addresses load-carrying capacity of various wire, load current and circuit breaker sizes for alternating current motors, and common AWG wire sizes, types, and general uses.

7.6.1. Wire Size and Voltage Drop Determination. The selected wire size for a given section of a system is based on the amount of electrical load that it must carry, and the allowable voltage drop. Note the larger the wire size, the greater its capacity and the less resistance it will have, hence, less voltage drop. Consider economy in size determination. **Table 7.9** shows the kilovolts-amperes (kVA) and current-carrying capacities for wires ranging from No. 8 to a 4/0. The largest gauge size is No 4/0. Wires larger than this are classified in size by their circular mil cross-sectional area. One circular mil is the area of a circle with a diameter of 1/1,000 inch. Thus, if a wire has a diameter of 0.1 inch or 100 mil, the cross-sectional area is 100 by 100, or 10,000 circular mils. At overseas contingency locations, metric size wiring is likely used. **Table A4.3** compares AWG or MCM (1,000 circular mils) wire sizes to the nearest metric equivalents.

Table 7.9. kVA Load-Carrying Capacity of Wire.

Wire Size[1] (AWG)[2]	Maximum Amperes	Type of Circuit				
		1Ø 2W 120V (kVA)	1Ø 3W 120/240V (kVA)	3Ø 4W 127/220V (kVA)	1Ø 2W 2,400V (kVA)	3Ø 4W 2,400/4,160V (kVA)[3]
8	75	9	18	29	180	540
6	100	12	24	38	240	720
4	150	18	36	57	360	1,080
2	180	22	44	69	432	1,296
1/0	250	30	60	95	600	1,800
4/0	435	52	104	166	1,044	3,130

Note 1: Overhead wires with weatherproof insulation or bare wires.
Note 2: American Wire Gage.
Note 3: kVA (1,000 volt-amps).

7.6.2. Conductor Types. Conductors used in installation overhead distribution systems are usually copper, although they may be steel, aluminum, or combinations of these metals. **Figure 7.15** and **Figure 7.16** provides information regarding common AWG wire sizes, types, and applications. In addition, **Table 7.10** through **Table 7.13** list the wire sizes for 120-volt, single-phase circuits, number of wires allowable in various conduits, and the wire sizes for 240-volt, single-phase circuits, respectively.

7.6.2.1. Copper Conductors. Copper has high conductivity and is easily spliced. Hard-drawn or medium-hard-drawn copper is desirable for distribution conductors because of its strength. Since heating and cooling reduces the wire's tensile strength from 50,000-psi to 35,000-psi, soldered splices should not be used on hard-drawn copper wire because the hot solder weakens the joints. Splicing sleeves are normally used when making joints.

7.6.2.2. Steel Conductors. Steel wire used as a conductor permits long spans because of its high tensile strength. Steel has about 10 to 15 percent as much conductivity size-for-size as copper, but the short life and low conductivity of steel wire are overcome, to some extent, by the use of copper-clad steel made by welding a copper coating to the steel wire.

7.6.2.3. Primary Distribution. For primary distribution below 5,000 volts, either bare or weatherproof conductors may be used. The ordinary weatherproof covering is not to be considered as insulation, although it does prevent breakdowns on the lower primary voltages caused by conductors swinging together. For all primary distribution over 5,000 volts, bare conductors are ordinarily used.

7.6.2.4. Secondary Distribution. Insulated wires are used for secondary distribution. The insulated wires permits rack-type distribution and closely spaced secondary conductors. No wire smaller than a No. 8 should be used for secondary distribution or for any external transmission of power.

Figure 7.15. Common Wire Sizes, Types, and Uses (1 of 2).

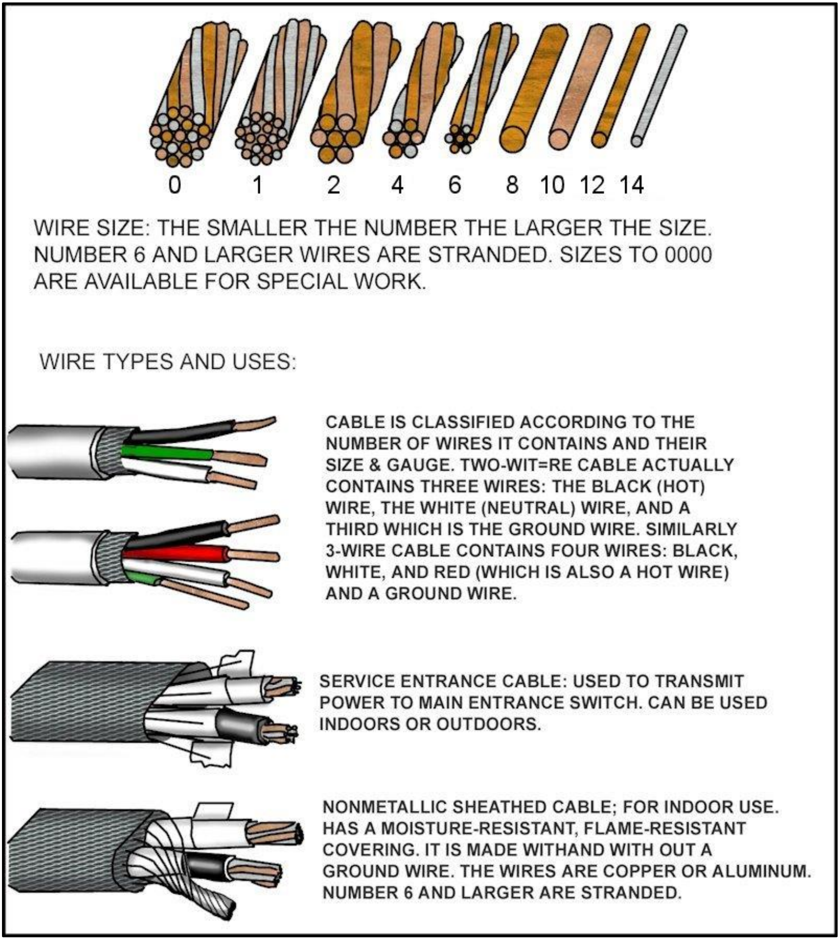


Figure 7.16. Common Wire Sizes, Types, and Uses (2 of 2).

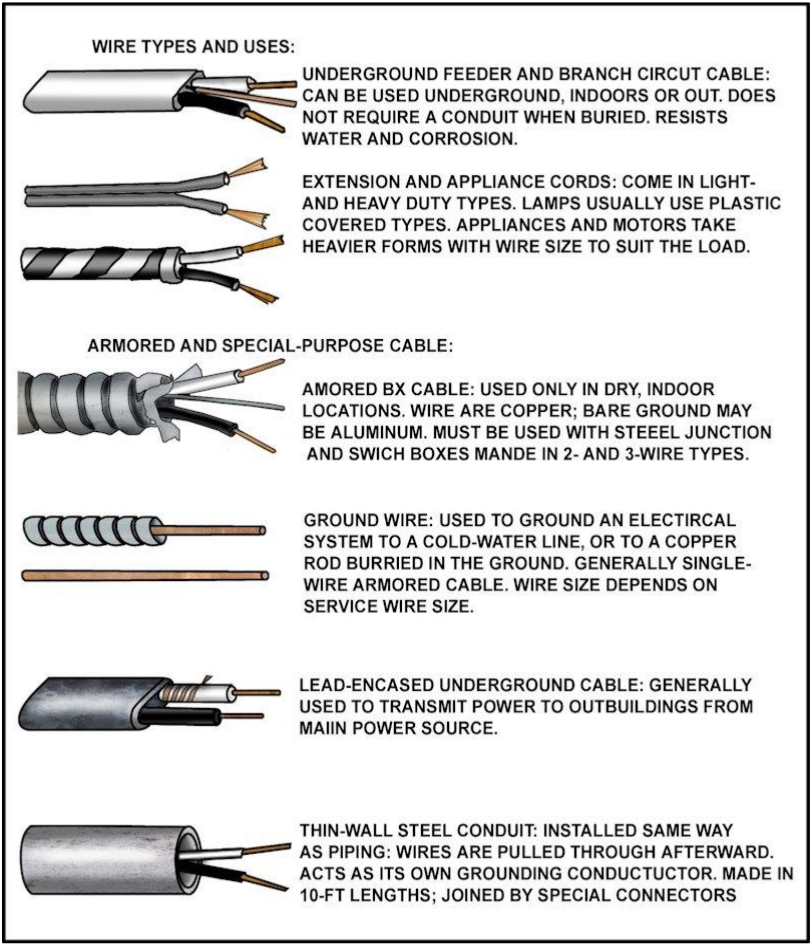


Table 7.10. Wire Sizes for 120-Volt, Single-Phase Circuits.

Load (AMPS)	Minimum Wire Size (AWG)	WIRE SIZE (AWG) Distance One-Way From Supply to Load (Feet)												
		50	**75**	**100**	**125**	**150**	**175**	**200**	**250**	**300**	**350**	**400**	**450**	**500**
15	14	14	12	10	8	6	6	6	6	4	4	4	2	2
20	14	12	10	8	8	6	6	6	4	4	2	2	2	2
25	12	10	8	8	6	6	4	4	4	2	2	2	1	1
30	12	10	8	6	6	4	4	4	2	2	1	1	0	0
35	12	8	6	6	4	4	4	2	2	1	1	0	0	2/0
40	10	8	6	6	4	4	2	2	2	1	0	0	2/0	2/0
45	10	8	6	4	4	2	2	2	1	0	0	2/0	2/0	3/0
50	10	8	6	4	4	2	2	2	1	0	2/0	2/0	3/0	3/0
55	8	6	4	4	2	2	2	1	0	2/0	2/0	3/0	3/0	4/0
60	8	6	4	4	2	2	1	1	0	2/0	3/0	3/0	4/0	4/0
65	8	6	4	2	2	2	1	0	2/0	2/0	3/0	4/0	4/0	
70	8	6	4	2	2	1	1	0	2/0	3/0	3/0	4/0	4/0	
75	6	6	4	2	2	1	0	0	2/0	3/0	4/0	4/0		
80	6	6	4	2	2	1	0	0	2/0	3/0	4/0	4/0		
85	6	4	4	2	1	1	0	2/0	3/0	3/0	4/0			
90	6	4	2	2	1	0	0	2/0	3/0	4/0	4/0			
95	6	4	2	2	1	0	2/0	2/0	3/0	4/0				
100	4	4	2	2	1	0	2/0	2/0	3/0	4/0				

Table 7.11. Minimum Size Conduit for a Given Number of Wires.

Wire Size (AWG)	Number of Wires[1] in Conduit[2]								
	1	2	3	4	5	6	7	8	9
18	1/2	1/2	1/2	1/2	1/2	1/2	1/2	1/2	3/4
16	1/2	1/2	1/2	1/2	1/2	1/2	3/4	3/4	3/4
14	1/2	1/2	1/2	1/2	3/4	3/4	3/4	1	1
12	1/2	1/2	1/2	3/4	3/4	1	1	1	1-1/4
10	1/2	3/4	3/4	3/4	1	1	1-1/4	1-1/4	1-1/4
8	1/2	3/4	1	1	1-1/4	1-1/4	1-3/4	1-3/4	1-3/4
6	1/2	1	1-1/4	1-1/4	1-1/2	1-1/2	2	2	2
4	3/4	1-1/4	1-1/4	1-1/2	2	2	2	2	2-1/2
2	3/4	1-1/4	1-1/2	1-1/2	2	2	2-1/2	2-1/2	2-1/2
1	3/4	1-1/2	1-1/2	2	2	2-1/2	2-1/2	3	3
1/0	1	1-1/2	2	2	2-1/2	2-1/2	3	3	3
2/0	1	2	2	2-1/2	2-1/2	3	3	3	3-1/2
3/0	1	2	2	2-1/2	3	3	3	3-1/2	3-1/2
4/0	1-1/4	2	2-1/2	2-1/2	3	3	3-1/2	3-1/2	4

Note 1: Rubber-covered or weatherproof wire.

Note 2: Conduit sized in inches.

Table 7.12. Wire Sizes for 240-Volt, Single-Phase Circuits (1 of 2).

Load (AMPS)	Minimum Wire Size (AWG)	WIRE SIZE (AWG) – Distance One-Way From Supply to Load (Feet)												
		100	**150**	**200**	**250**	**300**	**350**	**400**	**500**	**600**	**700**	**800**	**900**	**1000**
15	14	14	12	10	8	6	6	6	4	4	4	4	2	2
20	14	12	10	8	8	6	6	6	4	4	2	2	2	2
25	12	10	8	8	6	6	4	4	4	2	2	2	1	1
30	12	10	8	6	6	4	4	4	2	2	1	1	0	0
35	12	8	6	6	4	4	4	2	2	1	1	0	0	2/0
40	10	8	6	6	4	4	2	2	2	1	0	0	2/0	2/0
45	10	8	6	4	4	2	2	2	1	0	0	2/0	2/0	3/0
50	10	8	6	4	4	2	2	2	1	0	2/0	2/0	3/0	3/0
55	8	6	4	4	2	2	2	1	0	2/0	2/0	3/0	3/0	4/0
60	8	6	4	4	2	2	1	1	0	2/0	3/0	3/0	4/0	4/0
65	8	6	4	2	2	2	1	0	2/0	2/0	3/0	4/0	4/0	
70	8	6	4	2	2	1	1	0	2/0	3/0	3/0	4/0	4/0	
75	6	6	4	2	2	1	0	0	2/0	3/0	4/0	4/0		
80	6	6	4	2	2	1	0	0	2/0	3/0	4/0	4/0		
85	6	4	4	2	1	1	0	2/0	3/0	3/0	4/0			
90	6	4	2	2	1	0	0	2/0	3/0	4/0	4/0			
95	6	4	2	2	1	0	2/0	2/0	3/0	4/0				
100	4	4	2	2	1	0	2/0	3/0	3/0	4/0				

Table 7.13. Wire Sizes for 240-Volt, Single-Phase Circuits (2 of 2).

Load (AMPS)	Minimum Wire Size (AWG)	WIRE SIZE (AWG)												
		Distance One-Way From Supply to Load (Feet)												
		100	**150**	**200**	**250**	**300**	**350**	**400**	**500**	**600**	**700**	**800**	**900**	**1000**
125	4	4	2	1	0	2/0	3/0	3/0	4/0					
150	2	2	1	0	2/0	3/0	4/0	4/0						
175	2	2	0	2/0	3/0	4/0	4/0							
200	1	1	0	2/0	3/0	4/0								
225	1/0	1/0	2/0	3/0	4/0									
250	2/0	2/0	2/0	3/0	4/0									
275	3/0	3/0	3/0	4/0										
300	3/0	3/0	3/0	4/0										
325	4/0	4/0	4/0											

Note: Table reflects an approximate 3% voltage drop.

Chapter 8

HEATING, VENTILATION, AND AIR CONDITIONING (HVAC) SYSTEMS REPAIR

8.1. General Information. Effective facility heating and air conditioning enhances personal comfort, but historically, it usually had minimum impact on aircraft sortie generation. However, in today's operating environment, many mission-critical systems and electronics equipment require stringent climate control. For example, some self-contained C2 center operations may find it difficult to function without HVAC support (**Figure 8.1**). In these situations, adequate HVAC systems are imperative to mission accomplishment.

Figure 8.1. Command and Control Center with Climate Control.

8.2. Overview. This chapter briefly reviews expedient HVAC repair options during contingency situations. Repairs may involve working around hazardous materials or require work on and near energized circuits; therefore, only trained technicians may accomplish HVAC system repairs and modifications. Be sure to comply with requirements in AFMAN 32-1065 and other Air Force electrical safety criteria when making repairs.

8.3. Heating Systems Repair. Depending upon weather conditions at the time of a disaster or attack, repairing damage to the heating system can range in importance from critical to insignificant. However, unless the installation is undergoing a period of severe cold, consider delaying repairs to heating systems servicing non-mission-essential facilities by using space heaters and having personnel wear additional clothing. However, if repairs are essential, concentrate on minimum efforts necessary to return some measure of heat to base facilities. It is not necessary to attain pre-disaster comfort levels following an emergency. A partial return of heat can raise temperatures to a level that will allow normal operations if personnel are warmly clothed.

8.3.1. Central Heating Systems Repair. Expedient repairs to central heating systems may involve the production plant or distribution system. For those installations that have a large central heating system, damage following an attack or disaster can be widespread. The feasibility of conducting expedient repairs to the heating system will depend to a great degree upon the amount of damage incurred. For example, if an earthquake or bomb explosion causes a large rupture of the central boiler, it is unlikely that expedient repair techniques will suffice. On the other hand, a break in one of the pipes leading from the boiler could probably be expediently repaired. Fortunately, the inherent strength of materials used to contain the pressure within the system also serves to protect the system from external damage.

8.3.1.1. Production Plant Repairs. In some situations, units will need to delay expedient repair of heat production plants pending structural and/or electrical support. It may be necessary to shore damaged walls to prevent structural collapse or restore electrical utility service power to control and monitoring devices. From a mechanical perspective, crews may need to repair or replace broken pipes, bypass damaged automatic controls with manual ones, or cannibalize inoperable plant components in order to get some boilers back in operation. As stated earlier, however, if a plant’s boilers have sustained significant damage, the production plant is probably beyond immediate repair.

8.3.1.2. Distribution System Repairs. The high heat and pressure associated with most heating systems preclude the use of many expedient repair methods and materials used to correct damage to water distribution systems. It is not safe to attempt to patch or weld pipe or fittings. Pipe replacement and welding are the most common repair techniques used to correct distribution system problems. Welding of high-pressure vessels is a specialized technique and requires substantial experience; only an American Society of Mechanical Engineers certified welder should attempt it. In overseas areas, expect to encounter older systems containing components no longer in production. Repair parts for these facilities may have to be custom fabricated or cannibalized from other systems. Most locations, however, should have an emergency stock of heating system materials. Tap this source as much as possible.

8.3.2. Individual Systems Repair. Installations without a central heating system generally feature individual building systems. The great advantages of these independent units are that damage is limited to the system that supports a single building and general repair concepts are, for the most part, universally applicable. The basic question then becomes whether or not to repair.

8.3.2.1. If the weather permits, or the facility is not critical to the base mission, delay repairs until emergency conditions are essentially over. Another quick alternative when extensive repairs are required is to move personnel into a nearby building with a working heating system.

8.3.2.2. Expedient repairs to an individual heating unit are generally less complex than repairs on a large central system. Damage is confined and easy to determine since the independent system does not involve a dispersed network. Components are smaller, making it easier for repair crews to install replacements. In addition, spare parts may be more readily available from base supply and local vendors. Furthermore, since there often are many facilities containing similar individual heating systems, there are more opportunities for cannibalization of parts from low-priority buildings. If the damage is limited to the system's ducting, consider placing temporary flexible ducts to correct the problem. **Figure 8.2** shows examples of flexible ducting.

Figure 8.2. Typical Flexible HVAC Ducting.

8.3.3. Alternative Heating Sources. If attempts to repair existing heating systems fail, temporary heating sources can provide support for mission-essential facilities. Remember, however, alternate heat sources can be dangerous and require frequent checks and servicing. As time permits, repair damaged systems using existing stocks or cannibalized materials, thereby freeing portable heaters for use elsewhere.

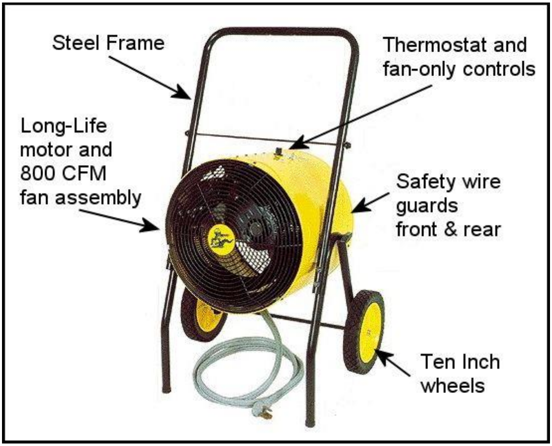
8.3.3.1. Fuel-fired and Propane Space Heaters. Various types of space heaters provide an alternative to central or individual heating systems. Fuel-fired heaters (**Figure 8.3**) may be an option in large open buildings if the odor is not objectionable and explosive vapors are not present. The propane heater on the right of the figure delivers 8,000 to 24,000 BTU of portable, infrared heat from a common 20-lb propane cylinder. Several variations are readily available on the open market, including larger units designed to meet higher heating demands. In general, open flame heaters are dangerous, especially the unvented type. If they are used the catalytic types are the safest.

Figure 8.3. Typical Portable Fuel-Fired and Propane Heaters.

8.3.3.2. Electric Space Heaters. Electric heaters (**Figure 8.4**) provide a safer alternative to open flame units provided temporary wiring and power sources can handle the extra load. Space heaters may be available from various sources, including routine supply channels or local vendors. Some units may have portable shop heaters that may be reassigned to critical facilities. Heating units are also in Basic Expeditionary Airfield Resources assets.

8.3.3.3. Cart-Type Ducted Heaters. Cart-type ducted heaters provide an excellent alternate heat source because combustion stays outside the structure being heated. The units may be available from organizations on base, such as aerospace ground equipment or communications squadrons, after requirements for aircraft sorties and other vital operations have been met.

Figure 8.4. Industrial Portable Electric Heater.



8.3.3.4. Improvised Heaters. The use of improvised heaters should be avoided, except in cases of extreme cold and where no other alternative exists. The primary dangers inherent with improvised heating systems are the possibility for asphyxiation and fire hazard potential. Caution must be taken to ensure that dangerous fumes are vented during combustion and any open flame is properly contained. One of the most common improvised heaters consists of a 55-gallon drum converted for use as a burner coupled with makeshift sheet metal ducting to vent fumes to the outside. Remember, improvised heaters do not completely contain combustion vapors. Therefore, even with vents to the outside, makeshift heaters should never be used in totally enclosed areas.

8.4. AC System Repairs. Generally, AC systems are more vulnerable than their heating counterparts are. Several critical components of the climate control system are usually located externally to the facility they serve and therefore are more susceptible to damage. Typical AC repairs tend to be labor intensive and usually take a considerable amount of time. Like heating systems, AC support is highly dependent on a reliable electric supply. In addition to being time intensive, it is common to have many unit and system variations present on a typical installation or base. These factors make developing an expedient repair strategy and standardized repair kit to satisfy all potential needs both cost prohibitive and nearly impossible. If system rejuvenation is plausible and parts are not available in a standardized repair kit, consider obtaining needed parts from similar units that support less critical functions. Normally, if expedient AC is required after an attack or natural disaster, portable units are the ideal way to go until time and resources allow permanent repairs. Several BTU variations are available that support AC requirements ranging from small area units to large package configurations used for cooling entire buildings. **Figure 8.5** is an example of a trailer-mounted portable AC unit.

Figure 8.5. Trailer-Mounted Portable AC Unit.

8.4.1. Visual Check. A careful visual inspection of the AC system is often all that it takes to find the cause of the problem. This could include broken belts, obstructed condenser air passages, a loose clutch, loose or broken mounting brackets, disconnected or broken wires, and refrigerant leaks. However, refrigerant leaks are especially problematic because, whether large or small, the leak will eventually empty the system of its charge and cause faulty operation.

8.4.2. Refrigerant Leaks. Refrigerants are a key component of any air conditioning (AC) system and require proper handling. Review guidance in AFMAN 32-7002, *Environmental Compliance and Pollution Prevention*, when performing work on any AC system. Expedient AC repairs often involve locating and repairing leaks within the refrigeration system. If, during an emergency, you have mission essential cooling units that are operable except for minor leaks, your first course of action would usually be to charge the unit as a temporary measure and move on to the next issue. However, if the situation allows for a more concerted effort, make permanent repairs to avoid duplication of effort.

8.4.2.1. Methods for testing for leaks vary with the refrigerant used. When conducting leak tests, be certain to check for leaks before the unit is evacuated. Moisture could enter the system through a leak during evacuation or pump-down. Always use the proper recycle/recover equipment when locating and repairing leaks. Some manufacturers recommend using the refrigerant in the system to test for leaks. In such situations, use a sensitive leak detector to help find leaks.

8.4.2.2. Other methods involve applying pressure to the system with an inert gas, such as nitrogen or carbon dioxide. At the start of testing, a positive pressure (greater than atmospheric pressure) of 5 to 30 psi is necessary throughout the circuit. If unable to find leaks, test again at or above the normal condensing pressure for the refrigerant used. When you find and repair a leak, you should recheck the complete unit to confirm the repair and ensure there are no additional refrigerant leaks.

8.4.3. Alternative AC Sources. When expedient repair to an existing central AC system is not feasible, an alternative AC source may be necessary to provide cooling for mission-essential equipment, systems, and facilities. While there are many alternate cooling options available, portable, self-contained, ductless, and field-deployable AC units are likely the most expedient options during contingencies. Self-contained AC systems are generally one of two types: window-mounted or floor-mounted units. They are all-inclusive package units, and commonly configured as a thru-wall unit on exterior walls. These package units are primarily in smaller structures and modular units. Some locations may employ self-contained systems as a temporary, expedient cooling method during contingencies.

8.4.3.1. Window-mounted AC units usually range from 4,000 to 36,000 BTU per hour in capacity. In addition to window installation, workers may install these units in other transoms or directly in the outside walls (commonly called a "through-the-wall" installation). Install these units with a slight downward tilt towards building exterior so the condensate drains to the outside. These units require very little mechanical attention before operation.

8.4.3.2. Floor-mounted AC units range in size from 24,000 to 360,000 BTU per hour. The entire system of this package unit is located in the conditioned space. Like window units, these larger units contain a complete system of refrigeration components. These units normally use either a water-cooled or an air-cooled condenser.

8.4.3.3. Ductless Mini-Split AC System. These systems have an outdoor unit that houses the compressor and condenser and an indoor unit consisting of the evaporator and air handler. In some split-system air conditioners, the indoor unit may also include electric heating coils. An advantage of ductless systems is they avoid the energy losses associated with ductwork of conventional central air systems. This type of unit is often the option at enduring expeditionary locations.

8.4.3.4. Ductless Mini-Split Heat Pumps. Like ductless AC units, these units may be an option when use of distribution ductwork is not feasible. They also have two main components, an outdoor compressor/condenser, and an indoor air-handling unit. These units are easy to install, and generally only require a small hole through the wall for the conduit, which houses the power cable, refrigerant tubing, suction tubing, and condensate drain.

8.4.3.5. Portable Chillers. Generally, chillers cool and circulate water (or water mixture) to provide comfort cooling into buildings and other controlled spaces. These systems deliver conditioned air by pumping chilled water to heat exchangers in air handling or fan-coil units. Units may have air-cooled or water-cooled chiller condensers, and range in size from small units capable of cooling small areas to large units capable cooling entire buildings.

8.4.3.6. Field-Deployable Environmental Control Unit (FDECU). Also considered somewhat self-contained, the FDECU is a packaged, air-to-air heat pump that requires the units be located outside the facility and connection to the facility is through the supply and return ducts. The AF uses this type of unit extensively at contingency locations to cool, heat, dehumidify, filter, and circulate air in portable shelters and containers for personnel and equipment.

8.5. Sizing Portable and Temporary AC Units. AC units are rated by the number of BTU of heat they can remove per hour. Another common rating term for air conditioning size is the "ton," which is 12,000 BTU per hour. As reference in the U.S. Department of Energy (DOE) publication, *Energy-Efficient Air Conditioning*, when sizing AC units, consider the following:

- Size of facility and number of windows.
- Amount of shade on the building's roof, windows, and walls.
- Amount of insulation in the ceiling and walls.
- Extent of outside air leaking into the building.
- Amount of heat generated by building occupants and equipment.

8.5.1. To determine specific AC size requirements, consider using sizing calculations and standards provided by the Air Conditioning Contractors of America (ACCA), at **https://www.acca.org/standards**, and the American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE), at **https://www.ashrae.org/resources--publications/free-resources/choosing-the-right-system-for-your-home**. Keep in mind that an AC's performance, efficiency, durability, and cost depends on properly matching its size to your specific facility or room cooling requirements.

8.5.2. An oversized AC unit does not provide the best cooling; in fact, it will result in the following:

- Higher costs for a unit larger than needed for the facility.
- Larger units cycles on and off more frequently, reducing efficiency.
- Frequent cycling inhibits proper moisture removal from the indoor air, increasing humidity and personal discomfort.
- Frequent cycling also wears out the compressor and electrical parts more rapidly.
- Uses more electricity and increases demands on electrical generation and distribution.

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Attachment 1

GLOSSARY OF REFERENCES AND SUPPORTING INFORMATION

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Prescribed Forms

None

Adopted Forms

DAF Form 847, *Recommendation for Change of Publication*.

AF Form 1213, *Civil Engineer Energized Electrical Work Permit.*

Abbreviations and Acronyms

ABS—Acrylonitrile-Butadiene-Styrene

AC—Air Conditioning

AF—Air Force

AFCEC—Air Force Civil Engineer Center

AFI—Air Force Instruction

AFMAN—Air Force Manual

AFTTP—Air Force Tactics, Techniques, and Procedures

ASC—Accredited Standards Committee

ASTM—American Society of Testing and Materials

AWG—American Wire Gage

BCE—Base Civil Engineer

BE—Bioenvironmental Engineering

BTU—British thermal unit

C2—Command and Control

CE—Civil Engineer

CPVC—Chlorinated Polyvinyl Chloride

DAF—Department of the Air Force

DAFMAN—Department of the Air Force Manual

DOD—Department of Defense

DOE—Department of Energy

EOC—Emergency Operations Center

EPA—Environmental Protection Agency

FDECU—Field-Deployable Environmental Control Unit

GPH—Gallons per Hour

HVAC—Heating, Ventilation and Air Conditioning

Hz—Hertz

IEEE—Institute of Electrical and Electronics Engineers

IPE—Individual Protective Equipment

JP—Joint Publication

kVA—Kilovolts-Amperes

LPG—Liquid Petroleum Gas

NESC—National Electrical Safety Code

NFPA—National Fire Protection Association

O.C.—On Center

OSB—Oriented Strand Board

PB—Polybutylene

PE—Polyethylene

PLP—Plywood Laced Posts

PPE—Personal Protective Equipment

Prime BEEF—Prime Base Engineer Emergency Force

PSI—Pounds Per Square Inch

PV—Photovoltaic

PVC—Polyvinyl Chloride

ROWPU—Reverse Osmosis Water Purification Unit

T.O.—Technical Order

UCC—Unit Control Center

UFC—Unified Facilities Criteria

US—United States

USACE—US Army Corps of Engineers

USAF—United States Air Force

UXO—Unexploded Explosive Ordnance

V—Volts

WaFERS—Water and Fuels Expedient Repair Systems

Office Symbols

AF/A4CX—Air Force Directorate of Civil Engineers, Readiness Division
AFCEC/COOM—Air Force Civil Engineer Center, Operations Maintenance Branch

Terms

Base—1. A locality from which operations are projected or supported. 2. An area or locality containing installations which provide logistic or other support. 3. Home airfield or home carrier. (JP 4-0)

Basic Expeditionary Airfield Resources (BEAR)—A critical ACS capability. It provides vital equipment and supplies necessary to beddown and support combat forces at expeditionary sites with limited infrastructure and support facilities. As a minimum, each location must have a runway and parking ramp suitable for aircraft operations and a source of water that can be made potable. (AFI 10-210)

Beddown—A location at which a deploying unit operates during a contingency. It is usually, but not always, in the area of responsibility. (AFDA 4-0)

Bitumen or Bituminous—The most common type of asphalt surface placed in the theater of operations.

Boiler—A water heater for generating steam.

Branch—Any part of a plumbing pipe system except risers, mains, or stacks.

British Thermal Unit (BTU)—Measure of heat value. The quantity of heat required to increase the temperature of one pound of water one degree Fahrenheit.

CBRN Defense—Measures taken to minimize or negate the vulnerabilities to, and/or effects of, a chemical, biological, radiological, or nuclear hazard or incident. (JP-3-11)

Condensate—1. (Plumbing) Droplets of water that form on the outside of a cold-water pipe when it is exposed to warm air. Also called condensation. 2. (HVAC) Steam cooled to liquid state and returned to boiler for heating.

Contingency—A situation requiring military operations in response to natural disasters, terrorists, subversives, or as otherwise directed by appropriate authority to protect United States interests. (JP 5-0)

Contingency Location—A non-enduring location outside of the United States that supports and sustains operations during named and unnamed contingencies or other operations as directed by appropriate authority and is categorized by mission life-cycle requirements as initial, temporary, or semi-permanent. (DoDD 3000.10)

Coupling—A fitting with inside threads only, used for connecting two pieces of pipe.

Duct—Pipe, tube, or channel used to convey air, water, gases, or liquids.

Footing—An enlargement at the lower end of a wall, pier, or column that distributes the load.

Fishplates—Metal plates, fastened to each side of a butt splice for support.

Force Beddown—The provision of expedient facilities for troop support to provide a platform for the projection of force. (JP 3-34)

Framing—The rough timber structure of a building, including interior and exterior walls, floor, ceiling, and roof.

GeoBase—Commissioned July 2001, supports the AF CE mission by providing accurate, current, and timely satellite and aerial imagery and map data representing real-world features and conditions for AF installations, ranges and property. GeoBase strives to support AF missions by providing Installation Geospatial Information and Services. Committed and trained personnel as well as advanced information technology infrastructure enable these services. (Air Force Instruction 32-10112)

Grease Trap—A device for solidifying and separating grease from domestic wastes and retaining it so that it may be removed, thus preventing the stoppage of waste pipes.

Half-Lap Joint—Two pieces joined by cutting away half the thickness of each so that they fit flush into each other.

Header—A short joist into which the common joists are framed around or over an opening.

Hostile Act—An attack or other use of force against the United States, United States forces, or other designated persons or property to preclude or impede the mission and/or duties of United States forces, including the recovery of United States personnel or vital United States Government property.

Hub—A bell-shaped end of cast iron pipe; that portion of a pipe, which, for a short distance, is sufficiently enlarged to receive the end of another pipe of the same diameter for the purpose of making a joint.

Hub-and-Spigot Joint—Each length of cast-iron pipe is made with an enlarged (bell or hub) end and a plain (spigot) end. The spigot end of one length fits into the hub end of the next length and is made tight by caulking.

Incident—An occurrence, caused by either human action or natural phenomena, that requires action to prevent or minimize loss of life, or damage, loss of, or other risks to property, information, and/or natural resources. (JP 3-28)

Initial Contingency Location—A locale occupied by a force in immediate response to a contingency operation and characterized by austere infrastructure and limited services with little or no external support except through Service-organic capabilities.

Kilovolt-Ampere (kVA)—An electrical unit, equal to 1000 volt-amperes.

Lower Explosive Limit—The minimum concentration of vapor in air below which propagation of a flame does not occur in the presence of an ignition source. (CFR 29, 1915.11)

Overseas—A geographic area located outside the jurisdiction of the United States, which includes land and associated territorial sea, contiguous zones, and exclusive economic zones of the United States; an area outside the United States (e.g., a foreign country).

Rafters—Beams that slope from the ridge of a roof to the eaves making the main body of the roof's framework.

Roofing—The material put on a roof to make it weatherproof.

Roof Decking—The layer of wood or plywood applied directly to the rafters, under the shingles.

Scab—A short piece of lumber used to splice or prevent movement of two other pieces.

Sewage—Any refuse or waste matter carried off by a sewer.

Solid State Lighting—Light sources that generate light through electro-luminescence rather than filaments or gas discharge. SSL sources include light emitting diodes (LEDs), organic light emitting diodes (OLEDs), and polymer light emitting diodes (PLED). (UFC 3-530-001)

Sheathing—Wallboards or roofing boards; generally applied to narrow boards laid with a space between them, according to the length of a shingle exposed to the weather.

Stitch Bolt—A small bolt placed in a member to prevent enlargement of checks or splits. Stitch bolts should never be used to close a check.

Toenailing—Driving a nail, spike, or brad at an angle into the end of one piece of wood to fasten it to a second piece; avoids having the nails show above the surface.

Top Plate—A piece of lumber supporting the ends of rafters.

Truss—Structural framework of triangular units, used in place of rafters, for supporting loads over long spans

Wye—A three-phase, Y -shaped circuit arrangement.

Attachment 2

CRACK REPAIR USING EPOXY INJECTION METHOD

A2.1. Purpose. To provide guidance on use of epoxy injection to repair cracks in concrete. The following information was extracted from Repair, Evaluation, Maintenance, and Rehabilitation Technical Note CS-MR-3.9, Crack Repair Method: Epoxy Injection.

A2.2. Description. This method can be used to repair cracks as narrow as 0.002 inch. The method generally consists of drilling holes at close intervals along the cracks, in some cases installing entry ports, and injecting the epoxy under pressure. For massive structures, an alternative procedure consists of drilling a series of holes, usually 7/8 inch in diameter that intercepts the crack at several locations. Typically, holes are spaced at 5-foot intervals.

A2.3. Equipment, Tools, and Personnel Requirements. A concrete drill, an epoxy injection system, a means of cleaning holes and cracks, and normal hand tools are required. One man can repair cracks using this method, but a two- or three-man operation is more efficient. Epoxy injection requires personnel with a high degree of skill for satisfactory execution.

A2.4. Applications and Limitations. Epoxy injection has been successfully used in the repair of cracks in buildings, bridges, dams, and other concrete structures. However, unless the cause of cracking is removed, thereby making the crack dormant, it will probably recur, possibly somewhere else in the structure. If the crack is active and the desired is to seal it while allowing continued movement at that location, a sealant or other material that allows the crack to function as a joint must be used. The ambient temperature may also limit application of this method. In the case of delaminated bridge decks, epoxy injection can be an effective intermediate-term repair method. In this case, steps in paragraph A2.5.1, A2.5.2, and A2.5.6 outlined below are omitted. The process is terminated at a specific location when epoxy exits from the crack at some distance from the injection ports. This method does not arrest ongoing corrosion.

A2.5. Step-By-Step Procedure.

A2.5.1. Clean the cracks. The first step is to clean cracks that have been contaminated. Oil, grease, dirt, or fine particles of concrete prevent epoxy penetration and bonding. Preferably, contamination should be removed by flushing with water or some other especially effective solvent. The solvent is then blown out using compressed air, or adequate time is provided for air-drying.

A2.5.2. Seal the surface. Surface cracks should be sealed to keep the epoxy from leaking out before it has gelled. Where the crack face cannot be reached, but where there is backfill, or where a slab-on grade is being repaired, the backfill material or subbase material is often an adequate seal. A surface can be sealed by brushing an epoxy along the surface of the crack and allowing it to harden. If extremely high injection pressures are needed, the crack should be cut out to a depth of 1/2 in. and width of about 3/4 in. in a V-shape, filled with an epoxy, and struck off flush with the surface. If a permanent glossy appearance along the crack is objectionable and if high injection pressure is not required, a strippable plastic may be applied along the crack. When the job is completed, the dry filler can be stripped away to expose the gloss-free surface.

A2.5.3. Install the entry ports. Three methods are in general use:

A2.5.3.1. Drilled holes—fittings inserted. Historically, this method was the first to be used and is often used in conjunction with V-grooving of the cracks. The method entails drilling a hole into the crack, approximately 3/4 inch in diameter and 1/2 to 1 inch below the apex of the V-grooved section, into which a fitting, such as a pipe nipple or tire valve stem, is bonded with an epoxy adhesive. A vacuum chuck and bit are useful in preventing the cracks from being plugged with drilling dust.

A2.5.3.2. Bonded flush fitting. When the cracks are not V-grooved, a method frequently used to provide an entry port is to bond a fitting flush with the concrete face over the crack. This flush fitting has a hat-like cross section with an opening at the top for the adhesive to enter.

A2.5.3.3. Interruption in seal. Another means of providing entry is to omit the seal from a portion of the crack. This method can be used when special gasket devices are available that cover the unsealed portion of the crack and allow injection of the adhesive directly into the crack without leaking.

A2.5.4. Mix the epoxy. This is done by either batch or continuous methods. In batch mixing, the adhesive components are premixed according to the manufacturer's instructions, usually with the use of a mechanical stirrer, like a paint-mixing paddle. Care must be taken to mix only the amount of adhesive that can be used prior to commencement of gelling of the material. When the adhesive material begins to gel, its flow characteristics begin to change, and pressure injection becomes more and more difficult. In the continuous mixing system, the two liquid adhesive components pass through metering and driving pumps prior to passing through an automatic mixing head. The continuous mixing system allows the use of fast-setting adhesives that have a short working life.

A2.5.5. Inject the epoxy.

A2.5.5.1. Hydraulic pumps, paint pressure pots, or air-actuated caulking guns can be used. The pressure used for injection must be carefully selected. Increased pressure often does little to accelerate the rate of injection. In fact, the use of excessive pressure can propagate the existing cracks, causing additional damage.

A2.5.5.2. If the crack is vertical; the injection process should begin with pumping epoxy into the entry port at the lowest elevation until the epoxy level reaches the entry port above. The lower injection port is then capped, and the process is repeated at successively higher ports until the crack has been completely filled and all ports have been capped.

A2.5.5.3. For horizontal cracks, injection should proceed from one end of the crack to the other in the same manner. The crack is full if the pressure can be maintained. If the pressure cannot be maintained, the epoxy is still flowing into unfilled portions or leaking out of the crack.

A2.5.6. Remove the surface seal. After the injected epoxy has cured, the surface seal should be removed by grinding or other means, as appropriate. Fittings and holes at entry ports should be painted with an epoxy-patching compound.

A2.6. Environmental Considerations. Reasonable caution should guide the preparation, repair, and cleanup phases of any crack repair activities involving potentially hazardous and toxic chemical substances. Manufacturer's recommendations to protect occupational health and environmental quality should be carefully followed. In instances where the effects of a chemical substance on occupational health or environmental quality are unknown, chemical substances should be treated as potentially hazardous and toxic materials.

A2.7. Reference. Additional information is available in Army Engineer Manual (EM) 1110-2-2002, *Evaluation and Repair of Concrete Structures*, at: **http://www.publications.usace.army.mil/USACEPublications/EngineerManuals.aspx**

Attachment 3

ENGINEER REACHBACK AND OTHER USEFUL LINKS

Table A3.1. Useful Organizational and Product Links.

Organization and Products Links
Air Force Civil Engineer Center (AFCEC): **https://www.afcec.af.mil/**
CE DASH (AFCEC Technical Support Portal): **https://usaf.dps.mil/teams/CEDASH/scripts/homepage/home.aspx**
CE Playbooks: **https://www.ceplaybooks.com.**
DAF Publications and Forms: **https://www.e-publishing.af.mil/**
My Learning (Learning Management System): **https://lms-jets.cce.af.mil/moodle/login/index.php**
AF Design Guides (AFDG): **https://www.wbdg.org/ffc/af-afcec**
Whole Building Design Guide (WBDG): **https://www.wbdg.org/**
US Army Corp of Engineers Official Publications, **http://www.publications.usace.army.mil/Home.aspx**
Unified Facilities Criteria (UFC): **https://www.wbdg.org/ffc/dod/unified-facilities-criteria-ufc**
Unified Facilities Guide Specifications (UFGS): **https://www.wbdg.org/ffc/dod/unified-facilities-guide-specifications-ufgs**
USACE Reachback Operations Center (UROC): **https://uroc.usace.army.mil**
USACE Protective Design Center: **https://intelshare.intelink.gov/sites/pdc/SitePages/Home.aspx**
Army Publications and Forms: **https://armypubs.army.mil/**
Navy Doctrine Library System: **https://doctrine.navy.mil/**
DOD Issuances: **https://www.esd.whs.mil/DD/DoD-Issuances/**
Joint Publications: **https://jdeis.js.mil/my.policy**
Armed Forces Pest Management Board: **https://www.acq.osd.mil/eie/afpmb/**

Attachment 4

WEIGHTS, MEASURES, AND CONVERSIONS

A4.1. The following tables list conversions for various sizes, weights, and other measurements. **Note:** Nominal sizes do not reflect actual dimensions, but rather an industry standard that loosely equates to the product's size.

Table A4.1. Nominal Pipe Sizes and Metric Equivalents.

Inches	Mm	Inches	mm
1/8	6	8	200
3/16	7	10	250
1/4	8	12	300
3/8	10	14	350
1/2	15	16	400
5/8	18	18	450
3/4	20	20	500
1	25	24	600
1-1/4	32	28	700
1-1/2	40	30	750
2	50	32	800
2-1/2	65	36	900
3	80	40	1000
3/1/2	90	44	1100
4	100	48	1200
4-1/2	115	52	1300
5	125	56	1400
6	150	60	1500

Table A4.2. Nominal Electrical Conduit Sizes.

Inches	Mm	Inches	mm
1/2	16	2-1/2	63
3/4	21	3	78
1	27	3-1/2	91
1-1/4	35	4	103
1-1/2	41	5	129
2	53	6	155
Source: Adapted from GSA Metric Design Guide			

Table A4.3. Metric Equivalents to AWG.

AWG[1] or MCM		Diameter		Nearest Metric Sized Wire Equivalent[2]
Size	No. of Wires	Inches	Millimeters	Sq. Millimeters (mm^2)
14	Solid	0.064	1.63	2.5 (larger)
12	Solid	0.080	2.05	4.0 (larger)
10	Solid	0.102	2.59	6.0 (larger)
8	Solid	0.129	3.27	10 (larger)
6	7	0.184	4.67	16 (larger)
4	7	0.232	5.89	25 (larger)
3	7	0.260	6.60	25 (smaller)
2	7	0.292	7.41	35 (larger)
1	19	0.332	8.42	50 (larger)
1/0	19	0.373	9.46	50 (smaller)
2/0	19	0.418	10.6	70 (larger)

AWG[1] or MCM		Diameter		Nearest Metric Sized Wire Equivalent[2]
3/0	19	0.470	11.9	70 (smaller)
4/0	19	0.528	13.3	95 (smaller)
250	37	0.575	14.6	120 (smaller)
300	37	0.630	16.0	150 (smaller)
350	37	0.681	17.3	185 (larger)
400	37	0.728	18.5	185 (smaller)
500	37	0.814	20.6	240 (smaller)
600	61	0.893	22.7	300 (smaller)
Note 1: The most common AWG wire sizes used in interior wiring are 14, 12, and 10; and they are usually of solid construction. Note 2: Size rounded up (larger) or down (smaller) to the nearest equivalent mm^2-sized wire.				

Table A4.4. Weight Conversions.

When You Know:	You Can Find:	If You Multiply By:
Ounces	Grams	28.35
Grams	Ounces	0.035
Pounds	Kilograms	0.453
Kilograms	Pounds	2.204
Short Tons (2000 lbs.)	Metric Tons	0.907
Metric Tons	Short Tons (2000 lbs.)	1.102

Table A4.5. Length Conversions.

When You Know:	You Can Find:	If You Multiply By:
Inches	Millimeters	25.4
Inches	Centimeters	2.54
Feet	Centimeters	30.48
Feet	Meters	0.304
Yards	Centimeters	91.44
Yards	Meters	0.914
Miles	Kilometers	1.609
Miles	Meters	1609
Millimeters	Inches	0.039
Centimeters	Inches	0.393
Centimeters	Feet	0.0328
Meters	Feet	3.28
Centimeters	Yards	0.0109
Meters	Yards	1.093
Meters	Miles	0.000621
Kilometers	Miles	0.621
Meters	Nautical Miles	0.000539
Nautical Miles	Meters	1852

Table A4.6. Area Conversions.

When You Know:	You Can Find:	If You Multiply By:
Square Inches	Square Centimeters	6.452
Square Inches	Square Meters	0.0006
Square Feet	Square Centimeters	929
Square Feet	Square Meters	0.0929
Square Yards	Square Centimeters	8,360
Square Yards	Square Meters	0.836
Square Miles	Square Kilometers	2.589
Square Centimeters	Square Inches	0.155
Square Meters	Square Inches	1550
Square Centimeters	Square Feet	0.001
Square Meters	Square Feet	10.8
Square Centimeters	Square Yards	0.00012
Square Meters	Square Yards	1.195
Square Kilometers	Square Miles	0.386

Table A4.7. Temperature Conversions.

When You Know:	You Can Find:	If You Multiply By:
º Fahrenheit	º Celsius	Subtract 32 then multiply by 5/9
º Celsius	º Fahrenheit	Multiply by 9/5 then add 32
º Celsius	Kelvins	Add 273.15º

Table A4.8. Volume Conversions.

When You Know:	You Can Find:	If You Multiply By:
Ounces (Liquid)	Milliliters	29.57
Cups	Liters	0.236
Pints (Liquid)	Liters	0.473
Pints (Dry)	Liters	0.550
Quarts (Liquid)	Liters	0.946
Quarts (Dry)	Liters	1.101
Gallons (Liquid)	Liters	3.785
Gallons (Dry)	Liters	4.404
Milliliters	Ounces (Liquid)	0.034
Liters	Cups	4.226
Liters	Pints (Liquid)	2.113
Liters	Pints (Dry)	1.816
Liters	Quarts (Liquid)	1.056
Liters	Quarts (Dry)	0.908
Liters	Gallons (Liquid)	0.264
Liters	Gallons (Dry)	0.227
Cubic Feet	Cubic Meters	0.028
Cubic Yards	Cubic Meters	0.764
Cubic Meters	Cubic Feet	35.31
Cubic Meters	Cubic Yards	1.307

Attachment 5

COUNTRY VOLTAGES AND FREQUENCIES

A5.1. The following table lists secondary electrical distribution voltages and frequencies for various countries. This data is subject to change so always verify before beginning work.

Table A5.1. Voltages and Frequencies.

Country	Frequency (Hertz)	Single Phase	Three Phase
Abu Dhabi	50 Hz	230	400
Afghanistan	50 Hz	220	380
	50 Hz	127	220
Australia	50 Hz	240/415	415
Austria	50 Hz	230	400
Azerbaijan	50 Hz	220	
Bahamas	60 Hz	120/208	208
	60 Hz	120/240	240
Bahrain	50 Hz	230/400	400
Bangladesh	50 Hz	220/440	440
Barbados	50 Hz	115/230	230
	50 Hz	115/200	200
Belarus	50 Hz	220/380	380
Belgium	50 Hz	220/380	380
Belize	60 Hz	110-220	220
	60 Hz	220-440	440
Benin	50 Hz	220/380	380

Country	Frequency (Hertz)	Single Phase	Three Phase
Bermuda	60 Hz	120/240	240
	60 Hz	120/208	208
Bolivia	50 Hz	110/220	220
	50 Hz	115/230	230
	50 Hz	220	380
	50 Hz	230/400	400
Bosnia-Herzegovina	50 Hz	220	
Botswana	50 Hz	231/400	400
Brazil	60 Hz	127/220	220
	60 Hz	220/380	380
	60 Hz	115/230	230
	60 Hz	125/216	216
	60 Hz	120/240	240
	60 Hz	110/220	220
	50 Hz	127/220	220
British Virgin Islands	60 Hz	110/208	208
Brunei	50 Hz	240	415
Bulgaria	50 Hz	220	380
Burundi	50 Hz	220	380
Cambodia	50 Hz	220/380	380
Cameroon	50 Hz	220/380	380
Canada	60 Hz	120/240	240
Cape Verde	50 Hz	220/380	380
Cayman Islands	60 Hz	120	240

Country	Frequency (Hertz)	Single Phase	Three Phase
Central African Republic	50 Hz	220	380
Chad	50 Hz	220	380
Channel Islands (UK Dep.)	50 Hz	230	400
	50 Hz	240	415
Chile	50 Hz	220/380	380
China	50 Hz	220/380	380
Colombia	60 Hz	110/220	220
Comoros	50 Hz	220	
Congo	50 Hz	220	380
Cook Island	50 HZ	240	
Costa Rica	60 Hz	120/240	240
Croatia	50 Hz	220	380
Cuba	60 Hz	115	
Cyprus	50 Hz	240	415
Czech Republic	50 Hz	220/380	380
Denmark	50 Hz	220/380	380
Djibouti	50 Hz	220	380
Dominica	50 Hz	230	400
Dominican Republic	60 Hz	110/220	220
Ecuador	60 Hz	120/208	208
Egypt	50 Hz	220	380
El Salvador	60 Hz	115/230	230
Equatorial Guinea	50 Hz	220	
Eritrea	50 Hz	220	380

Country	Frequency (Hertz)	Single Phase	Three Phase
Estonia	50 Hz	220/380	380
Ethiopia	50 Hz	220	380
Falkland Islands	50 Hz	240	
Fiji	50 Hz	240/415	415
Finland	50 Hz	230/400	400
France	50 Hz	220	380
	50 Hz	127	220
	50 Hz	115	200
French Guiana	50 Hz	220	380
Gabon	50 Hz	220	380
Gambia	50 Hz	220	380
Georgia	50 Hz	220	380
Germany	50 Hz	220	380
Ghana	50 Hz	240	415
Gibraltar	50 Hz	240	415
Greece	50 Hz	220	380
Greenland	50 Hz	220/380	380
Grenada	50 Hz	230	400
Guadeloupe	50 Hz	220	380
Guam	60 Hz	110/220	220
	60 Hz	120/208	208
Guatemala	60 Hz	120/240	240
Guinea	50 Hz	220	380
Guinea-Bissau	50 Hz	220/380	380

Country	Frequency (Hertz)	Single Phase	Three Phase
Guyana	60 Hz	110/220	220
Haiti	60 Hz	110/220	220
Honduras	60 Hz	110	220
Hong Kong	50 Hz	220/380	380
Hungary	50 Hz	220/380	380
Iceland	50 Hz	220/380	380
India	50 Hz	220	380
	50 Hz	230	400
Indonesia	50 Hz	220	380
	50 Hz	127	220
Iran	50 Hz	220/380	380
Iraq	50 Hz	220	380
Ireland	50 Hz	220	380
Israel	50 Hz	230	400
Italy	50 Hz	127	220
	50 Hz	220	380
Ivory Coast	50 Hz	220	380
Jamaica	50 Hz	110/220	220
Japan	60 Hz	100	200
	50 Hz	100	200
Jordan	50 Hz	220/380	380
Kazakhstan	50 Hz	220	380
Kenya	50 Hz	240	415
Korea, North	60 Hz	220	

Country	Frequency (Hertz)	Single Phase	Three Phase
Korea, South	60 Hz	220	380
	60 Hz	100/200	200
	60 Hz	105/210	
Kuwait	50 Hz	240	415
Kyrgyzstan	50 Hz	220	
Laos	50 Hz	220	380
Latvia	50 Hz	220	
Lebanon	50 Hz	220	380
	50 Hz	110	190
Lesotho	50 Hz	220	380
Liberia	60 Hz	120/240	240
	60 Hz	120/208	208
Libya	50 Hz	230	400
	50 Hz	127	220
Lithuania	50 Hz	220	
Luxembourg	50 Hz	230	400
	50 Hz	220	380
Macao	50 Hz	220/380	380
Macedonia	50 Hz	220	380
Madagascar	50 Hz	127/220	220
	50 Hz	220/380	380
Malawi	50 Hz	230	400
Malaysia	50 Hz	240	415
Maldives	50 Hz	230	400

Country	Frequency (Hertz)	Single Phase	Three Phase
Mali	50 Hz	220	380
Malta	50 Hz	240	415
Martinique	50 Hz	220	
Mauritania	50 Hz	220	380
Mauritius	50 Hz	230	400
Mexico	60 Hz	127/220	220
Moldova	50 Hz	220	
Mongolia	50 Hz	220	
Montenegro	50 Hz	220	
Montserrat	60 Hz	230	400
Morocco	50 Hz	127	220
	50 Hz	220	380
Mozambique	50 Hz	220	380
Myanmar	50 Hz	230	400
Namibia	50 Hz	220	380
Nepal	50 Hz	220	380
Netherlands	50 Hz	220/380	380
Netherlands Antilles	60 Hz	115/230	
	60 Hz	120/208	208
	50 Hz	127/220	220
	50 Hz	220/380	380
New Caledonia	50 Hz	220	
New Zealand	50 Hz	230/400	400
Nicaragua	60 Hz	120/240	240

Country	Frequency (Hertz)	Single Phase	Three Phase
Niger	50 Hz	220	380
Nigeria	50 Hz	230	415
Norway	50 Hz	230	400
Okinawa (Japan)	60 Hz	100/200	
	60 Hz	120/240	
Oman	50 Hz	240	415
Pakistan	50 Hz	230	400
	50 Hz	220	380
Palau	60 Hz	120	240
Panama	60 Hz	110/220	220
	60 Hz	120/240	240
	60 Hz	115/230	230
	60 Hz	120/208	208
Papua New Guinea	50 Hz	240	415
Paraguay	50 Hz	220	380
Peru	60 Hz	110	220
	50 Hz	220	380
Philippines	60 Hz	110/220	220
	60 Hz	115/230	230
Poland	50 Hz	220	380
Portugal	50 Hz	220/380	380
Puerto Rico	60 Hz	120/240	240
Qatar	50 Hz	240/415	415
Romania	50 Hz	220/380	380

Country	Frequency (Hertz)	Single Phase	Three Phase
Russia	50 Hz	220/380	380
Rwanda	50 Hz	220	380
Saint Kitts-Nevis	60 Hz	230	
Saint Lucia	50 Hz	240	
Samoa	50 Hz	230/400	400
Saudi Arabia	60 Hz	127	200
	50 Hz	220	380
Scotland (UK)	50 Hz	240	415
Senegal	50 Hz	127/220	220
Serbia	50 Hz	220	380
Seychelles	50 Hz	240	
Sierra Leone	50 Hz	230	400
Singapore	50 Hz	230	400
Slovakia	50 Hz	220	380
Solomon Islands	50 Hz	240	
Somalia	50 Hz	110	220
	50 Hz	220	380
	50 Hz	220	440
South Africa	50 Hz	220	380
	50 Hz	230	400
	50 Hz	240	415
	50 Hz	250	433
Spain	50 Hz	220/380	380
	50 Hz	127/220	220

Country	Frequency (Hertz)	Single Phase	Three Phase
Sri Lanka	50 Hz	230	400
St. Vincent and the Grenadines	50 Hz	230	400
Sudan	50 Hz	240	415
Suriname	50 Hz	127/220	220
	60 Hz	115/230	230
Swaziland	50 Hz	230	400
Sweden	50 Hz	220/380	380
	50 Hz	230/400	400
Switzerland	50 Hz	220/380	380
Syria	50 Hz	220	
Tahiti	60 Hz	127/220	220
Taiwan	60 Hz	110/220	220
Tajikistan	50 Hz	220	380
Tanzania	50 Hz	230/400	400
Thailand	50 Hz	220/380	380
Togo	50 Hz	127	220
	50 Hz	220	380
Tonga	50 Hz	240	415
Trinidad and Tobago	60 Hz	115/230	230
	60 Hz	230/400	400
Tunisia	50 Hz	220	380
	50 Hz	127	220
Turkey	50 Hz	220/380	380
Turkmenistan	50 Hz	220	380

Country	**Frequency (Hertz)**	**Single Phase**	**Three Phase**
U.S. Virgin Islands	60 Hz	120/240	240
Uganda	50 Hz	240	415
Ukraine	50 Hz	220	380
United Arab Emirates	50 Hz	220	380
United Kingdom (England)	50 Hz	240	415
	50 Hz	240	480
United States	60 Hz	110/220	220
	60 Hz	120/240	208
	60 Hz	120/240	240
	60 Hz		460
Uruguay	50 Hz	220	380
Uzbekistan	50 Hz	220	380
Vanuatu	50 Hz	220	
Venezuela	60 Hz	120/240	240
	60 Hz	110/220	220
Vietnam	50 Hz	220	380
	50 Hz	127	220
	50 Hz	120	208
Yemen	50 Hz	220	380
	50 Hz	230	400
Zambia	50 Hz	220	380
Zimbabwe	50 Hz	220/380	380
	50 Hz	230/400	400