Disclaimer:

The information presented in NEMA Standards and guidelines is considered technically sound at the time they are approved for publication. They are not a substitute for a product seller’s or user’s own judgment on the particular product referenced in the Standard or guideline, and NEMA does not undertake to guarantee the performance of any individual manufacturer’s products by this Standard or guide. Thus, NEMA expressly disclaims any responsibility for damages arising from the use, application, or reliance by others on the information contained in these Standards or guidelines.
1. Use of This Publication

This publication serves as a guide that represents the consensus of National Electrical Manufacturers Association (NEMA) Member companies and is not intended to override the recommendations of the specific equipment manufacturer. These guidelines provide information on how to evaluate electrical equipment that has been exposed to earthquakes (refer to other NEMA electrical equipment evaluations guides for water, fire, and heat damage caused by secondary effects of earthquake damage). This guide is designed for use by suppliers, installers, inspectors, and users of electrical products. Where additional information is required, it is recommended that the specific electrical equipment manufacturers be consulted. The evaluation of electrical equipment should be conducted by qualified personnel.

Electrical equipment and their associated distribution systems exposed to damaging earthquakes can be extremely hazardous if reenergized without performing a proper evaluation and taking necessary actions. Reductions in the integrity of electrical equipment due to physical damage to insulation integrity, connections, shock hazard protection, or operability of active components can affect the ability of the equipment to perform its intended function. Damage to electrical equipment can also result from external impacts from falling building debris or failures of external systems, which will affect the integrity and performance of the electrical equipment and associated distribution systems.

Post-earthquake risk for damage can continue for periods from hours to years due to the uncertainties associated with follow-on earthquake sequences. Damaging event earthquake sequences take the form of a possible foreshock, mainshock event, and aftershocks or additional earthquakes classified as a triggered event. Follow-on earthquake damaging ground motions from weaker but closer events can be far more damaging than a more distant precursor event. Time frames between the follow-on shock events can range from hours to months.

Due to the ongoing risk of aftershocks or follow-on secondary triggered earthquakes, inspections shall be coordinated with the appropriate authority having jurisdiction (AHJ), and in no circumstances should a building, structure, or area that has been identified and marked as “UNSAFE” by authorities be entered. See Applied Technology Council (ATC) -20, Procedures for Postearthquake Safety Evaluation of Buildings & Addendum for additional information on earthquake damage placards commonly used.

Damage from earthquake-induced ground failure and tsunami is beyond the scope of this guide.

Earthquake damage to electrical equipment and associated distribution systems is typically due to the following (refer to Section 6 for additional guidance):

1. Shaking (acceleration demand) of rigidly anchored (bolted, welded) equipment. Failure is most often associated with the equipment anchorage, which is either missing, incorrectly chosen, or poorly installed. The connected path between the point of attachment to the equipment to a building’s structural system is referred to as the “seismic restraint load path,” and it must remain intact for the equipment to retain the manufacturer’s seismic qualification.

   Evaluation of the proper design and adequacy of the seismic restraint load path is beyond the scope of this guide and requires the services of a registered design professional recognized by the AHJ as being competent in the design of seismic restraints and structural systems evaluation.

2. Flexibly attached equipment (mounted on vibration isolators), distribution systems (conduit, cable tray) or equipment that is rigidly mounted but can exhibit a flexible response to the earthquake shaking, resulting in impact damage from hitting walls or other distribution systems.
3. Suspended electrical devices and lighting that is free to move laterally and not properly tethered to prevent impact damage.

4. Displacement demands imposed on electrical distribution systems rigidly attached to points spanning structural systems that will be moving at different relative rates dimensionally in response to the earthquake. Typical building-induced displacement demands are:

   4.1. “Interstory drift,” which is expressed as a percent of the horizontal displacement for a given vertical elevation (from floor to floor).

   4.2. Distribution systems crossing gaps in the building structural system for expansion or seismic isolation must be able to accommodate these displacement demands by flexing without damage.

   4.3. “Base isolated buildings,” which can have dramatic differential movement across the separation boundary between the ground-referenced attachment of the base isolator to its point of attachment to the building structural load-bearing system. All utilities, cabling, etc. must have provisions to absorb the building-specific horizontal displacements across the base isolation gap as prescribed by the structural engineer of record for the building base isolation system design.

   4.4. Distribution systems spanning different structures, such as from a mechanical building to the main building, communications tower to the building, utility substation to the building for which the structures have different dynamic motions in response to the strong earthquake ground shaking.

5. External debris damage. Depending on the nature of the debris, damage to equipment or essential distribution systems interconnections may range from light damage to destruction by falling building cladding, etc. Particulate airborne debris may block equipment ventilation provisions essential for cooling or contaminate insulators and degrade insulation integrity.

   Aftershocks present a life safety issue due to heavy falling building debris. The evaluation of aftershock threat from degraded building structural and nonstructural systems can only be assessed by a registered design professional recognized by the appropriate AHJ to be competent in earthquake structural engineering.

6. Multiple hazards can exist as a result of secondary effects of earthquake damage such as water from damaged sprinkler nozzles, leaking hazardous and flammable gases and chemicals from damaged process piping.

Even in buildings that have been evaluated as safe to reoccupy and appear to have light (if any) apparent observable visible damage, hidden damage can result in the failure of the building envelope watertight protection features. Such damage can allow storm-driven rain and ponding water to infiltrate the building and find its way into the electrical systems through any number of paths and can only be detected by a thorough inspection. If water infiltration is suspected or detected consult the NEMA document, Evaluating Water-Damaged Electrical Equipment, available on the NEMA website at www.nema.org.

Distributors of electrical equipment should not supply any inventory that has been subjected to earthquake damage. This can lead to the continued use of damaged equipment, creating a hazard to individuals or property.
2. Contact the Manufacturer

Working knowledge of electrical systems and the equipment in question is required to evaluate damage due to earthquakes. The original manufacturer of the equipment should be contacted if any questions arise or specific recommendations are needed. In many cases of significant damage, a replacement will be necessary.

NEMA Member companies are committed to safety. For specific contacts within these manufacturing firms, call or write:

National Electrical Manufacturers Association
1300 North 17th Street, Suite 900
Rosslyn, Virginia 22209
Telephone: (703) 841-3200

2.1 Consult the Authority Having Jurisdiction

When considering the replacement or reconditioning of earthquake-damaged electrical equipment, the authority having jurisdiction should be consulted to obtain additional rules and other guidance information impacting the installation. This may include licensing, permitting, and inspection requirements or other rules outlined in the locally adopted codes and Standards. Where public safety is primary, the authority having jurisdiction may be a Federal, State, local, or other regional department or individual such as fire chief; fire marshal; chief of a fire prevention bureau; labor department, or health department; building official; electrical inspector; or others having statutory authority. For insurance purposes, an insurance inspection department, rating bureau, or other insurance company representative may be the authority having jurisdiction. In many circumstances, the property owner or his or her designated agent assumes the role of the authority having jurisdiction; at government installations, the commanding officer or departmental official may be the authority having jurisdiction. During declared Federal or State emergencies, the Federal Emergency Management Agency (FEMA) may assume the role of authority having jurisdiction.

3. Electrical Equipment Replacement and Reconditioning Requirements

Section 4 provides information regarding requirements and recommendations associated with replacing or reconditioning various categories of electrical equipment that have been subjected to damage because of an earthquake event.

After consultation with the manufacturer, some larger types of electrical equipment may be reconditioned by properly trained personnel. The potential to recondition the equipment may vary with the nature of the electrical function, the degree of earthquake damage, the age of the equipment, and the physical damage. Attempts to recondition equipment without consulting the manufacturer can result in additional hazards due to hidden or obscured damage. Further equipment damage may occur due to improper reconditioning techniques.

Users are encouraged to reference the NEMA Policy on Reconditioned Electrical Equipment. Reconditioned equipment shall also comply with the marking requirements identified in the National Electrical Code® (NEC).
4. The Hazards Associated with Specific Types of Electrical Equipment

4.1 Electrical Distribution Equipment

Electrical distribution equipment usually involves switches and low-voltage protective components such as molded-case circuit breakers and fuses within assemblies such as enclosures, panelboards, and switchboards. These assemblies can be connected to electrical distribution systems using various wiring methods.

Distribution assemblies contain protective components together with the necessary support structures, buswork, wiring, electromechanical (or electronic) relays, and meters. The protective components are critical to the safe operation of distribution circuits. Their ability to protect these circuits can be adversely affected by earthquakes.

Replace distribution equipment that has sustained impact damage from falling building debris or loose building contents (tool carts, etc.). Distribution equipment that was never anchored or incurs anchorage failure can experience displacements and mechanical shocks much more extreme than it was seismically qualified for as it responds in a violent and unconstrained manner during the earthquake. These dynamic demands can damage internal assemblies and buswork, causing connections to fail and resulting in structural distortions that can preclude the safe operation of the equipment. Contact the manufacturer.

4.2 Motor Control Equipment

Motor circuits include motor control devices such as motor starters and contactors, which—together with overcurrent protection components such as overload relays, circuit breakers, and fuses—are often assembled into motor control panels and motor control centers, as well as individual enclosures. Motor control centers contain both control and protective components, together with support structures, buswork, and wiring.

The protective components are critical to the safe operation of motor circuits, and their ability to protect these circuits could be compromised by damage to the equipment’s structural system. Consult with the manufacturer before attempting to recondition the equipment.

4.2.1 Adjustable Speed Drives

Adjustable speed drives generally contain electronic components. See Section 4.11 for information on equipment with electronic components. For other components of an adjustable speed drive, the ability to recondition those components will depend on the type of component involved and the extent of the damage. The manufacturer of the drive must be consulted before any attempt to recondition the equipment.

4.2.2 Motor Control Centers

Motor control centers contain many different components, including fuses, circuit breakers, controllers, overload relays, and adjustable speed drives, as well as buswork, insulators, and enclosures. Many of these components are covered in other parts of this document and should be referenced for additional information.

For the buswork and structural assembly, exposure to earthquakes can cause damage to the equipment’s structural system, buswork, and insulation. For these assemblies, contact the manufacturer before further action is taken.

In all cases, attention must be paid to the thorough inspection of physical damage, as well as to the cleaning and testing of insulators and insulation material, and to the integrity of the seismic anchorage and restraints. Consult with the manufacturer before any attempt to recondition the equipment.
4.3 Power Equipment

Power equipment includes low-voltage or medium-voltage protective devices within an overall switchgear assembly. The assembly may also contain, for example, cabling, buswork with appropriate insulators, current transformers, electromechanical or electronic relays, and metering. Reliable operation of the protective devices is vital to system safety. Similarly, the functionality of electronic protective relays and meters can be impaired. See Section 4.11 for additional information on electronic components.

In all cases, attention must be paid to the thorough inspection of physical damage, as well as to the cleaning and testing of insulators and insulation material, and to the integrity of the seismic anchorage and restraints.

The power equipment can be expected to contain additional electronic units such as solid-state relays. These units can be vital to the correct functioning of the protective device, and great care is needed in the verification of their functionality. The manufacturer shall also be contacted for the specific testing required for sophisticated electronic equipment containing, for example, microprocessors.

The overall power equipment assembly (switchboard or switchgear) may be able to be reconditioned, provided careful steps provided by the manufacturer are followed and testing of the equipment before applying power. Areas of concern are the maintenance of the dielectric properties of insulation and the integrity of the seismic anchorage and restraints.

In the field application of medium-voltage equipment, standoff insulators can be subjected to a flexible response to the earthquake shaking. Such insulators must be inspected for damage and tested in accordance with the manufacturer’s recommendations and replaced if appropriate.

4.4 Transformers

Exposure of transformers to earthquakes can cause damage to the transformer core and winding and should be inspected for any evidence of damage. Consult with the manufacturer for proper adjustment of the core mounting frame to the enclosure frame and seismic installation instructions.

During an earthquake building debris can become airborne and may be deposited inside a ventilated transformer. The ability of the transformer to perform its intended function in a safe manner can also be impaired by such debris blocking ventilation channels or degrading the dielectric integrity of the insulation.

Although periodic dielectric tests are not recommended due to the severe stress such tests impose on the insulation, Institute of Electrical and Electronics Engineers (IEEE) Standards C57.12.91 and C.57.12.90 provide a guideline for field evaluation. Where field dielectric tests are required, low-frequency applied-voltage and induced-voltage tests should be used. The test voltage may depend on the specific application of the transformer under test. However, the test voltage stress should never exceed the normal operating stress; it is preferred to contact the manufacturer to define the proper test voltage in the field.

In addition to the dielectric test, it is preferred that the equipment and major components be suitable for, and certified by, actual seismic testing to meet all applicable seismic requirements of the International Building Code (IBC) Site Classification.
4.5 Conduit, Tubing, Fittings, Outlet Boxes, and Junction Boxes

Steel raceways and all metal parts likely to become energized must have assured continuity and be bonded together and run to a grounding electrode to prevent electric shock. The integrity of all effective ground-fault current return paths should be verified. Earthquake imposed shaking and displacement loads imposed on conduit, tubing, fittings, and outlet and junction boxes may impose damage at their points of attachment or separation. Therefore, metallic components comprising the required electrical safety grounding system must be evaluated to verify the integrity of this safety function.

Conduit, tubing, fittings, and outlet and junction boxes embedded in concrete or masonry may have their mechanical integrity compromised by movement in the building or structure. Earthquake-induced gaps and cracks in concrete structural systems such as shear walls, poured floors, masonry infill walls, and penetrations may create a path for storm-driven water to follow and enter these embedded components at damaged connection points. Such damage can be hidden from visual inspection and difficult to detect and may require successive follow-up inspections after periods of heavy rain and flooding to detect.

The presence of known or unknown corrosive agents in flood water can affect the physical properties of both metallic and nonmetallic materials and the required corrosion protection for electrical equipment, per NEC® 300.6. Therefore, the replacement of outlet boxes and fittings in accordance with the original installation requirements is recommended.

Water penetrating damaged seals may be contaminated with oil, chemicals, sewage, and other debris that could enter the conduit/tubing and prevent a clear path for the replacement of conductors or cables. As part of the inspection process, ensure that the interior of the conduit/tubing is clear. Also, contaminants may affect the physical properties of metallic and nonmetallic materials and the corrosion protection for electrical equipment, as required in NEC® 300.6. Since every situation has unique circumstances, the services of an experienced evaluator should be used. The manufacturer can also be consulted for additional assistance.

4.5.1 Outlet Boxes and Fittings

Metallic and nonmetallic outlet boxes and fittings used indoors in dry locations have not been evaluated for the effects of exposure to conditions described in Section 1.

4.5.2 Conduit and Tubing

Where conduit and tubing has become separated at connection points due to earthquake effects, the insulation integrity of the enclosed wiring should be examined before being repaired. Inspect all conduit and tubing for evidence of impact damage and replace where hidden damage to cables may be possible.

4.6 Wire, Cable, and Flexible Cords

Inspect terminations for evidence of damage where cables are free to sway or stretch between attachment points in response to the earthquake. Also, inspect insulation for damage from impacts or scrapping. Perform insulation integrity and continuity test as appropriate.

4.7 Circuit protection devices, wiring devices, and surge protective devices should be examined for evidence of impact damage from the shaking of their enclosures.

4.8 Cable Tray

Carefully inspect the cable tray system to determine if its mechanical and/or electrical integrity has been compromised. Repair or replace any damaged portions per original installation requirements. Remove all debris from the cable tray. If labels, such as those warning against the use of the cable tray as a walkway, have been damaged, obtain new labels from the manufacturer and apply as required.
4.9 Luminaires (Lighting Fixtures), Ballasts and Light Emitting Diode (LED) Drivers

Inspect fluorescent, high-intensity discharge, incandescent, and LED luminaires for impact damage that may damage internal circuitry, which may prevent the equipment from operating properly. Verify the integrity of the seismic restraints for luminaires.

4.10 Motors

Motors are a rigid body but are susceptible to damage to their wiring terminations or bearing damage if their coupled rotating mechanical loads are damaged.

4.11 Electronic Products, Including Signaling, Protection, Communications Systems, and Industrial Controls

Equipment used in signaling, protection, and communication systems generally contains electronic components that are vulnerable to seismic damage. Since some of these types of installations are classified as life safety systems, it is important that the reliability of those systems be maintained.

Where such systems are damaged, replace components of these systems, or return the equipment to the manufacturer for appropriate repair, recalibration, and testing. Manufacturers of these systems should be contacted for information on specific equipment.

4.12 Batteries

When a wet cell battery is subjected to the shaking effects of an earthquake, caustic liquid electrolytes may be spilled through vents or cracks in its case and must be replaced. All traces of spilled electrolytes must be neutralized and removed.

Groups of connected batteries should be inspected to verify the electrical integrity of the cable or bus at their terminals and be repaired. Battery racks and associated seismic restraints should be inspected for damage and repaired.

4.13 Exposure to Water

In many cases, earthquakes damage building water piping systems. In those cases, electrical equipment can be subjected to water damage. This equipment should be evaluated for damage resulting from water exposure or replaced (see the NEMA Guide Evaluating Water-Damaged Electrical Equipment).

5. Grounding and Bonding

Grounding and bonding connections must have assured continuity to prevent electric shock and system damage. Earthquake imposed shaking, and displacement loads imposed on grounding and bonding points of attachment may degrade their ability to conduct fault current.

Earthquake-induced loads on the building concrete or steel structural systems and foundation may damage embedded grounding and bonding paths. Such damage can be hidden from visual inspection and difficult to detect and may require specialized testing to detect.

Therefore, all grounding and bonding points required for the electrical safety of the grounding system must be evaluated to verify the integrity of this safety function.
6. Seismic Installation Considerations

6.1 Seismic Load Path

The integrity of the equipment attachment and associated seismic restraint of the building load-bearing structural system is the single most significant contributor to the prevention of earthquake damage to essential equipment in critical facilities. That portion of the structural load path from the point of equipment connection to the building load-bearing structural system is termed the “seismic load path” by building design professionals. The seismic restraints transfer earthquake induced loads imposed on the equipment by the strong earthquake shaking to the building load-bearing structural system or limits movement to minimize damaging impacts. The integrity of the seismic load path between the equipment attachment points through the seismic restraints and the building structural system must be evaluated by a registered design professional to ensure continued protection from future events. The most common methods of seismic restraints encountered are rigid, flexible, tethered. Other types or combinations of these are possible but are beyond the scope of this guide.

Refer to the following Federal Emergency Management Agency (FEMA) FEMA publications for additional guidance. All are available for download from the http://www.fema.gov website:

- FEMA E-74 Reducing the Risks of Nonstructural Damage – A Practical Guide
- FEMA 412 Installing Seismic Restraints for Mechanical Equipment
- FEMA 413 Installing Seismic Restraints for Electrical Equipment
- FEMA 414 Installing Seismic Restraints for Duct and Pipe

6.2 Rigid Mounted

Rigid mounted equipment is attached to the building structure through bolted or welded connections. Follow manufacturer’s recommendations for seismic installations and the seismic restraint details provided by a registered design professional.

6.3 Flexibly Mounted

Equipment that can couple vibration loads to the building structure during normal operation is commonly mounted or attached to the building structural system on a flexible element such as a spring or elastomeric pad, also commonly referred to as a “vibration isolator.” The earthquake-induced strong building shaking may allow the equipment to move violently such that significant and damaging impacts occur within the vibration isolation system. To preclude these impacts from destroying the flexible attachment device, elastomeric pads or other damping means are incorporated within the vibration isolation device. The integrity of the equipment attachment points and the vibration isolation device should be verified to prevent damage from future events. Refer to the manufacturer’s seismic mounting instructions for the equipment, vibration isolation device and the seismic restraint details provided by the registered design professional of record.

6.4 Tether Restrained

Tethers in the form of cables or chains may be used to restrain lateral motion to mitigate impact damage for equipment suspended from the ceiling. The integrity of the equipment attachment points and the tether restraints should be verified to prevent damage from future events. Refer to the manufacturer’s seismic installation instructions and the seismic restraint detail provided by the registered design professional of record.
6.5 Drift Sensitive

Electrical equipment with attachment points that span from floor to floor, across building expansion joints or between buildings can be damaged from differential building movements in response to the strong ground shaking from the earthquake. As these attachment points move differently relative to each other, damaging forces can be imposed within the seismic restraints or equipment attachment points from the building structural system. The integrity of the equipment attachment points and the seismic restraint system should be verified to prevent damage from future events. Refer to the manufacturer’s seismic installation instructions and the seismic restraint detail provided by the registered design professional of record.

§