piping. This option may be less desirable due to the need for greater maintenance efforts to ensure continued proper function of the flexible connections.

Grooved couplings, ball joints, resilient gasket compression fittings, and other articulating-type connections are used in many piping systems and can serve to increase the overall rotational design capacity of the piping connections. Grooved couplings are classified as either rigid or flexible. Flexible grooved couplings demonstrate limited free rotational capacity. The free rotational capacity is the maximum articulating angle where the connection behaves essentially as a pinned joint with limited or negligible stiffness. The remaining rotational capacity of the connection is associated with conventional joint behavior, and design force demands in the connection are determined by traditional means.

Industry-wide procedures for the determination of coupling flexibility are not currently available; however, guidance may be found in the provisions for fire sprinkler piping, where grooved couplings are classified as either rigid or flexible on the basis of specific requirements on angular movement. In Section 3.5.4 of the 2007 Edition of NFPA 13, *Standard for the Installation of Sprinkler Systems*, flexible couplings are defined as follows:

> A listed coupling or fitting that allows axial displacement, rotation, and at least 1 degree of angular movement of the pipe without inducing harm on the pipe. For pipe diameters of 8-inch (203.2 mm) and larger, the angular movement shall be permitted to be less than 1 degree but not less than 0.5 degrees.

Couplings determined to be flexible on this basis are listed either with FM 1920, Approval Standard for Pipe Couplings and Fittings for Aboveground Fire Protection Systems, or UL 213, Rubber Gasketed Fittings for Fire-Protection Service.

Piping component testing suggests that the ductility capacity of carbon steel threaded and flexible grooved piping component joints ranges between 1.4 and 3.0, implying an effective stress intensification of approximately 2.5. These types of connections have been classified as having limited deformability, and piping systems with these connections have R_p values lower than piping with welded or brazed joints.

The allowable stresses for piping constructed with ductile materials assumed to be materials with high deformability not designed in accordance with an applicable standard or recognized design basis are based on values consistent with structural steel standards for comparable piping materials.

The allowable stresses for piping constructed with low-deformability materials not designed in accordance with an applicable standard or recognized design basis are derived from values consistent with ASME standards for comparable piping materials.

For typical piping materials, pipe stresses are seldom the governing parameter in determining the hanger and brace spacing. Other considerations, such as the capacity of the hanging and bracing connections to the structure, limits on the lateral displacements between bracing to avoid impacts, or the need to limit pipe sag between hangers in order to avoid the pooling of condensing gases may be more likely to govern the design. Nevertheless, seismic span tables, based on limiting stresses and displacements in the pipe, can be a useful adjunct for establishing bracing locations.

Piping systems' service loads of pressure and temperature need also be considered in conjunction with seismic loads. The potential for lower than ambient operating temperatures should be considered in the designation of the piping system materials as having high or low deformability. High deformability may often be assumed for steels, particularly ASME listed materials operating at high temperatures, copper and copper alloys, and aluminum. Low deformability should be assumed for any piping material that exhibits brittle behavior, such as glass, ceramics, and many plastics.

Piping should be designed to accommodate relative displacements between the first rigid piping support and connections to equipment or piping headers often assumed to be anchors. Barring such design, the equipment or header connection could be designed to have sufficient flexibility to avoid failure. The specification of such flexible connections should consider the necessity of connection maintenance.

Where appropriate, a walkdown of the finally installed piping system by an experienced design professional familiar with seismic design is recommended, particularly for piping greater than 6 in. (152.4 mm) nominal pipe size, high-pressure piping, piping operating at higher than ambient temperatures, and piping containing hazardous materials. The need for a walkdown may also be related to the scope, function, and complexity of the piping system as well as the expected performance of the facility. In addition to providing a review of seismic restraint location and attachment, the walkdown verifies that the required separation exists between the piping and nearby structures, equipment, and other piping in the as-built condition.