B-D or D-F will see a uniform load in the z direction of 11.5 lb/ft (170 N/m). Segment F-G runs diagonally in the horizontal plane between the x and z directions. Therefore, the projected length of the pipe run is less than the total length of the run, and the F-G segment will see less than the full wind load of 11.5 lb/ft. The actual load can be calculated as

$$\frac{Wl}{L} = \frac{11.5(20)}{\sqrt{20^2 + 20^2}} = 8.1 \text{ lb/ft}$$

$$= \frac{170(6.1)}{\sqrt{6.1^2 + 6.1^2}} = 120 \text{ N/m}$$

where W = wind loading, lb/ft (N/m)

l = projected length, perpendicular to wind direction, ft (m)

L = actual length, ft (m)

This loading is applied to the F-G segment shown in Fig. 5.11 only in the z direction.

The loadings on the supports can be determined by using a method similar to the weight-balancing method. This system can be broken into two segments, as shown in Fig. 5.12, with loads shown at their points of action.

For segment A-E, the equilibrium equations may be used to determine the loads on the restraints. Taking a summation of moments about point A, we get

$$\Sigma M_x = 0$$
$$0 = 20E - (230)(10)$$
$$E = 115 \text{ lb}$$

or

$$0 = 6.1E - (1037)(3.05)$$
$$E = 519 \text{ N}$$

and

$$\Sigma M_z = 0$$
$$0 = 115(45) - 230(45) - 518(22.5) + 15C$$
$$C = 1122 \text{ lb}$$

or

$$0 = 519(13.8) - 1037(13.8) - 2346(6.9) + 4.6C$$
$$C = 5073 \text{ N}$$

and

$$\Sigma F_x = 115 + 1122 - 230 - 518 + A = 0$$
$$A = -489 \text{ lb}$$

or

$$\Sigma F_x = 519 + 5073 - 1037 - 2346 + A = 0$$
$$A = -2209 \text{ N}$$

For segment E-H:

$$\Sigma M_z = 35H - 229(25) - 172.5(17.5) = 0$$
$$H = 250.5 \text{ lb (882 N)}$$
$$\Sigma F_z = 250.5 - 229 - 172.5 + E = 0$$
$$E = 201 \text{ lb (894 N)}$$

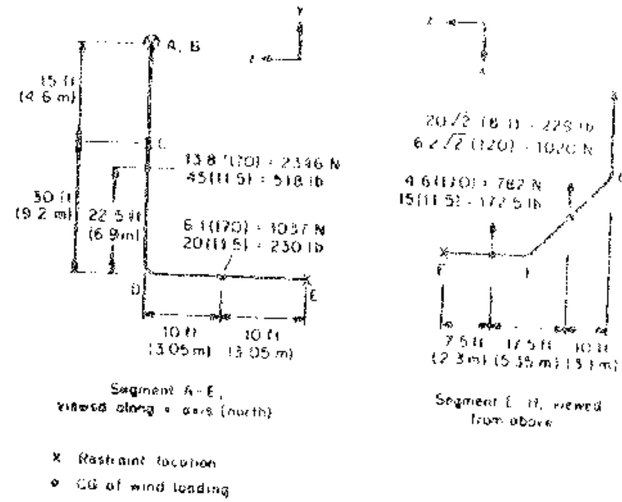

Figure 5.12 Example of wind loading calculation

The total load on the restraint at E is the sum of the load from each side, or

$$E_{tot} = 115 + 201 = 316 \text{ lb}$$
$$= 519 + 894 = 1413 \text{ N}$$

5.3.2 Occasional loads—relief valve discharge

Relief valves are used in piping systems to provide an outlet on those occasions when pressure builds up beyond that desired for safe operation. When the pressure setting is reached, the valve opens, allowing sufficient fluid to escape from the piping system to lower the pressure. This permits a controlled discharge of fluid as a means of preventing pressure vessel ruptures.

When a relief valve discharges, the fluid initiates a jet force, which is transferred through the piping system. This force must be resisted by pipe supports if the pipe is not capable of resisting the load internally. The magnitude of the jet force is usually provided by the valve manufacturer. If this value is not known, it may be calculated fairly easily for those cases where the valve vents to the atmosphere. If the fluid discharged flows through a closed system to a vessel, transient flow conditions may develop which make the valve force difficult to calculate.

For a relief valve venting to the atmosphere, the ANSI B31.1 piping code recommends that the discharge force as shown in Fig. 5.13 be calculated as follows:

$$F = \text{DLF}\left(\frac{MV}{32.2} + PA\right) \quad \text{(USCS)} \qquad (5.12)$$

$$F = \text{DLF}\left(MV + \frac{PA}{1 \times 10^6}\right) \quad \text{(SI)}$$

where F = discharge force, lb (N)

DLF = dynamic load factor (dimensionless, see below)

M = mass flow rate from valve × 1.11, lbm/s (kg/s)

V = fluid exit velocity (see below), ft/s (m/s)

P = static gauge pressure at discharge (see below), psi (N/m²)

A = discharge flow area, in² (mm²)

Also

$$V = \sqrt{\frac{(50{,}113)(h_o - a)}{2b - 1}} \quad \text{(USCS)}$$

$$V = \sqrt{\frac{(2.0085)\,(h_o - a)}{2b - 1}} \quad \text{(SI)}$$

where h_o = stagnation enthalpy of pipe fluid, Btu/lbm (J/kg), and a and b are as follows:

Steam condition	a Btu/lbm	a J/kg	b (dimensionless)
Wet, <90% quality	291	676,411	11
Saturated, >90% quality	823	1,910,183	4.33
Superheated	831	1,928,751	4.33

And

$$P = \frac{M}{A}\,\frac{b - 1}{b}\,\sqrt{\frac{48.33\,(h_o - a)}{2b - 1}} - P_A$$

$$P = \frac{M}{A}\,\frac{b - 1}{b}\,\sqrt{\frac{(1.995 \times 10^{?})\,(h_o - a)}{2b - 1}} - P_A$$

where all terms are as before except P_A = atmospheric pressure, psi (N/m²).

The dynamic load factor (DLF) is used to account for the increased load caused by the sudden application of the discharge force. This factor will vary between 1.1 and 2.0, depending on the rigidity of the valve installation and the opening time of the valve. If the piping system is relatively rigidly restrained, the DLF may be calculated by first finding the natural period of vibration of the valve installation:

$$T = 0.1846\,\sqrt{\frac{WH^3}{EI}} \quad \text{(USCS)} \qquad (5.13)$$

$$T = 114.59\,\sqrt{\frac{WH^3}{EI}} \quad \text{(SI)}$$

where W = mass of safety valve installation, lbm (kg)

H = distance from run pipe to center of outlet pipe, in (mm)

E = pipe material modulus of elasticity at design temperature, psi (N/m²)

I = moment of inertia of inlet pipe, in⁴ (mm⁴)

Next find the ratio of the valve opening t_o to the period T calculated above. For the ratio t_o/T, a DLF can be found from data published in piping codes or structural dynamics texts. A hypothetical DLF curve is shown in Fig. 5.14 for instructional purposes only.

Once the relief valve discharge force has been determined, the load can be distributed to adjacent supports by modeling the pipe segment (and its restraints) as a simple beam.

Problem 5.4 Given a relief valve discharge force of 1500 lb (6675 N) (as specified by the valve manufacturer, including DLF) and the configuration shown in Fig. 5.15, the run pipe at the tee is subjected to the force as well as (due to the 2-ft

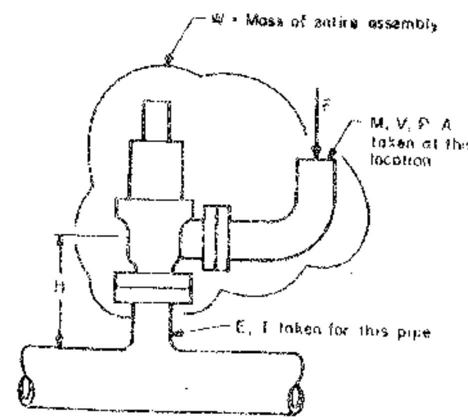

Figure 5.13 Relief valve discharge load calculation.

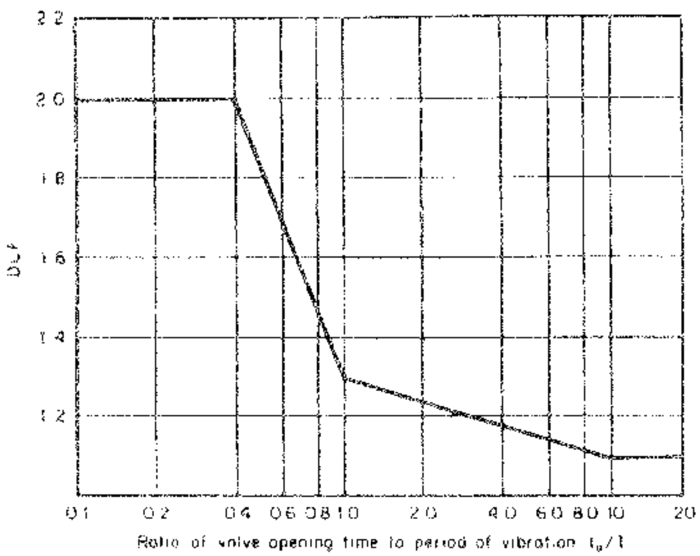

Figure 5.14 Hypothetical dynamic load factor.

(0.6-m) moment arm) a moment of 3000 ft·lb (4072 m·N). The resulting reactions at the restraints can be estimated as

$$F_a = \frac{1500(3)}{17+3} + \frac{3000}{20} = 375 \text{ lb}$$

$$F_b = \frac{1500(17)}{17+3} - \frac{3000}{20} = 1125 \text{ lb}$$

or

$$F_a = \frac{6675(0.92)}{5.19+0.92} + \frac{4072}{6.11} = 1672 \text{ N}$$

$$F_b = \frac{6675(5.19)}{5.19+0.92} - \frac{4072}{6.11} = 5003 \text{ N}$$

5.3.3 Occasional loads—seismic

Safety-related piping in nuclear power plants as well as nonnuclear piping in areas where earthquakes are prevalent must usually be designed to withstand seismic loadings.

Earthquake design criteria begin with an estimate of the earthquake potential in an area or region. This earthquake potential is partially based on the known history of previous earthquake activity in the area and is usually determined through a literature search that notes the intensity and the date on which a seismic event may have occurred. The literature

search usually consists of a review of reports from old records such as newspapers, journals, etc., and is used to try to estimate the intensity of past earthquakes.

Since seismographs and other instruments capable of measuring earthquake intensity have not been available throughout most of history, the estimations of earthquake intensity must be based on a correlation between reported observations of people witnessing the earthquake and reports of earthquakes of known intensities. An example is shown in Fig. 5.16 which details the expected observations during earthquakes of varying intensity on the modified Mercalli scale.

By performing a search for previous reports and using the data in written documents to estimate the intensity of past earthquakes, a history of a populated location can be assembled and used to help predict further earthquakes in the region. Once the particulars of the earthquake (i.e.,

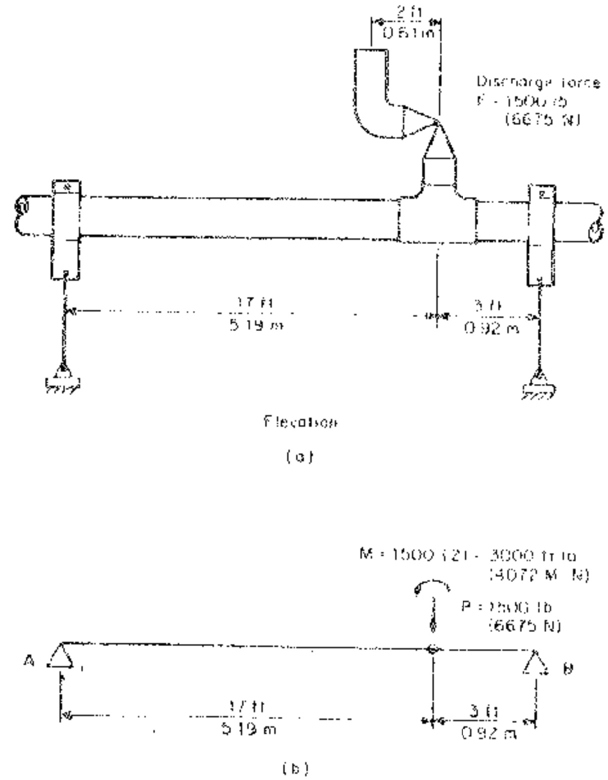

Figure 5.15 Relief valve discharge load distribution: (a) physical configuration; (b) mathematical model

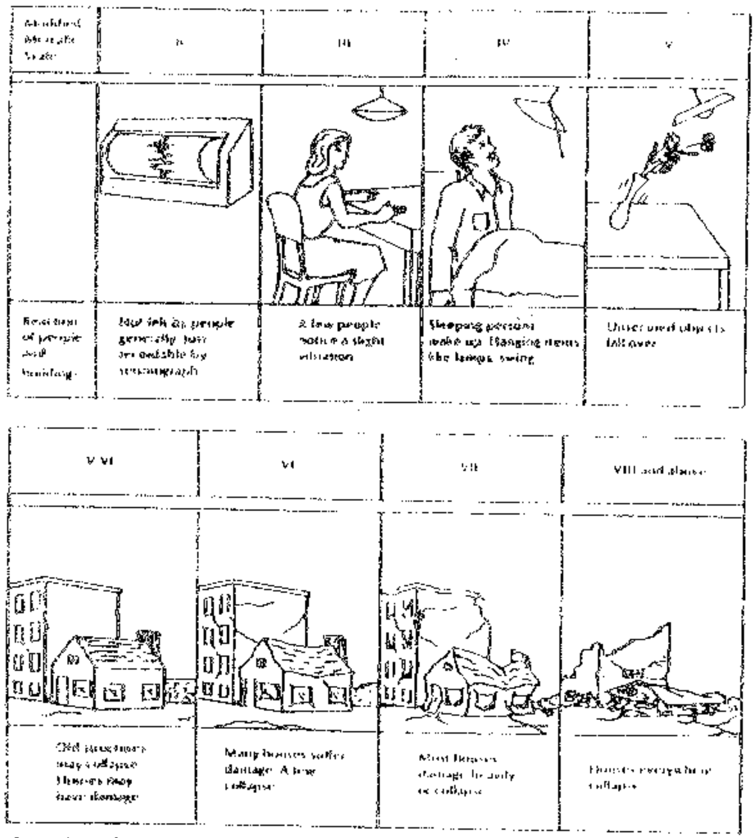

Figure 5.16 Approximate relation between earthquake intensity and observed effects. (*Courtesy of Engineering Planning and Management, Inc.*)

size, duration, etc.) have been established as design criteria, analytical loads to which the structure must be designed can be determined.

Prior to the beginning of the twentieth century, few formal design criteria were used for earthquake design. Buildings in areas of seismic activity were constructed with sufficient space or of such lightweight material that failure of any structure would cause minimal damage to adjacent structures and minimal injury to the inhabitants. Japanese design of housing against earthquakes resulted in lightweight single-story structures.

The Japanese building code was published just prior to the U.S. building code, with both produced because of damage from a severe earthquake. The 1923 earthquake in Tokyo and Yokohama prompted the Japanese to issue their first building code, while the Santa Barbara, California, earthquake of 1927 prompted the United States to do likewise. Since both building codes were developed at about the same time, they have many similarities.

5.3.3.1 Uniform building code. The Uniform Building Code (UBC) is published by an organization that provides data on a national basis. This code provides a means of determining the design loads for earthquakes based on an estimate of the damage potential in a particular region. The damage potential is related to seismic intensity ascribed to four zones labeled 0, 1, 2, and 3, with zone 0 predicting minimal damage and zone 3 predicting major earthquake damage potential. The map showing the various earthquake zones of the United States is shown in Fig. 5.17.

A structure's response to an earthquake varies throughout the event and depends on the frequency and magnitude of acceleration of the ground motion, the natural frequency and damping characteristics of the structure, and the nature of the foundation anchoring the structure to the ground. The building codes have devised methods of converting these dynamic loadings to equivalent static loads. For example, the UBC recommends that a lateral seismic force, assumed to act nonconcurrently along the major axes of the structure, be calculated as

$$V = ZKCW \tag{5.14}$$

where V = lateral seismic force, lb (N)

Z = seismic zone factor: 0.1 for zone 0, 0.25 for zone 1, 0.50 for zone 2, and 1.00 for zone 3

K = building type factor, usually between 0.67 and 3.0

C = $0.05/T^{1/3}$ but not greater than 0.1

T = fundamental period of structure, s

W = total weight of building, lb (N)

This method may be used to determine seismic loading on commercial piping in those regions covered by the UBC after it is verified that the limiting conditions imposed on the use of this formula have been adhered to.

5.3.3.2 Nuclear seismic design. Prior to 1961 in regions of low seismic activity, such as in the north, south, and midwest of the United States, there was little seismic damage postulated in building designs. The development of the U.S. nuclear power industry and its regulatory bodies, along with the availability of computers, has rapidly expanded earthquake analysis knowledge. The publication of 10CFR100 Appendix A mandated the design of nuclear safety-related structures and systems to withstand earthquake loads.

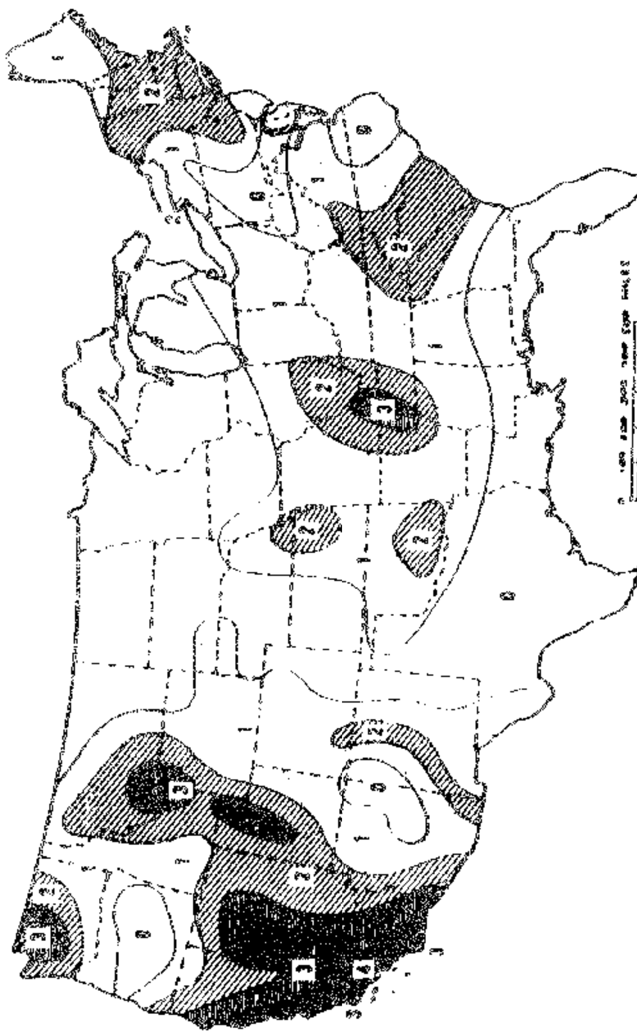

Figure 5.17 Map for seismic probability—contiguous 48 states. *(Note: This material reproduced with permission from American National Standard A.58 1-1982, copyright 1982, copies of which can be purchased from the American National Standards Institute, 1430 Broadway, New York, N.Y. 10018.)*

A commitment by a nuclear plant licensee to comply with adequate earthquake design criteria is made in the safety analysis report (SAR), which is submitted for approval at both the construction permit and operating license stages of regulatory review. According to design criteria established in 10CFR100, plant documentation must substantiate the ability of all seismic category I piping systems and components to withstand two levels of site-dependent postulated earthquakes. These are called the *safe shutdown earthquake* (SSE) and the *operating-basis earthquake* (OBE).

The SSE is an earthquake which is postulated based on an evaluation of the maximum earthquake potential given the regional and local geology, seismology, and specific characteristics of local subsurface material. It is that earthquake which produces the maximum vibratory ground motion for which certain structures, systems, and components are designed to remain functional. These structures, systems, and components are those defined in 10CFR100 as necessary to assure (1) the integrity of the reactor coolant pressure boundary, (2) the capability to shut down the reactor and maintain it in a safe shutdown condition, or (3) the capability to prevent or mitigate potential off-site radiation exposure.

The OBE is an earthquake which could reasonably be postulated to affect the plant site during the operating life of the plant. For conservatism, the OBE must usually be equal to at least one-half of the SSE.

Piping may be analyzed for seismic loadings through one of three methods: time history analysis, modal-response spectra analysis, or static analysis.

5.3.3.3 Time history analysis. Time history analysis is based on a record of the postulated earthquake versus time. Data in the form of ground displacement, velocity, or acceleration (as shown in Fig. 5.18) is plotted for the duration of the estimated earthquake record, which may last up to 40 s. This information is plotted for three directions (north-south, east-west, and vertical, or along the major axes of the structure). This data is then used to simulate the seismic excitation of the piping system in a computerized dynamic model, which monitors the stresses, displacements, and restraint loads for the system at regular intervals throughout the seismic event. The computer analysis is usually performed in the elastic region by numerical integration of a lumped-mass mathematical model. The time history computer analysis, although quite accurate, is generally very expensive, since each time interval requires a new calculation.

5.3.3.4 Modal analysis, damping factors, and load combinations. For most applications, the time history method of analysis is too expensive and time-consuming. Therefore, piping systems are frequently analyzed by