Massachusetts Earthquake Design Codes

Geologic conditions at a site allow for alternatives in meeting seismic design regulations.

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Design requirements for new or altered structures are included in Chapter 780 of the Commonwealth of Massachusetts Regulations under Article 7, Sections 716.0 and 720.0.[1] The design considerations for earthquake resistant construction, with reference to those sections, are included in Sections 725.0 and 2204.0 of Article 22. The codes were adopted as of September 1, 1980 and no formal changes to them have been made since then. A lengthy and very thorough preparation of the seismic design requirements preceded adoption of the codes. The critical elements were considered by design panels consisting of academicians, seismologists, structural design engineers, architects, soils engineers, geologists and government representatives who were familiar with the procedures and requirements for formalizing technical design criteria.

The objective of the provisions in the codes is to protect the lives and safety of the population of Massachusetts. The provisions apply to all structural designs except one- and two-story structures and minor accessory buildings. The rehabilitation or modification of existing structures falls under the codes — *i.e.*, when a building is undergoing renovations and/or additions the new seismic design rules apply. Technical requirements in the codes are often somewhat complicated and cannot be readily applied by the non-technical person. In fact, the satisfaction of the requirements necessitates the services of registered professional engineers in a number of instances. The codes also require careful consideration of the specific geological conditions that may be encountered in the Massachusetts terrain.

The primary factor considered in the codes for ground motion from earthquakes is the horizontal force that might be introduced into a structure. This force is determined in terms of a horizontal force factor (related to the structural bracing and framework), base shear (related to the fundamental period of oscillation of the structure or structural elements), a foundation material factor (material class and thickness beneath the structure) and the weight of the structure (dead load with consideration for non-permanent loadings).

TABLE 1
Assumed Bearing Values of Foundation Materials

Class of Material	Tons/sq. ft.
Massive crystalline bedrock including granite diorite, gneiss, trap rock and dolomite (hard limestone)	60
Foliated rock including limestone, schist and slate in sound condition	40
Sedimentary rock including hard shales, sandstones and thoroughly cemented conglomerates	20
Soft or broken bedrock (excluding shale) and soft limestone	20
Compacted, partially cemented gravels, and sand and hardpan overlying rock	10
Gravel, well-graded sand and gravel mixtures	6
Loose gravel, compact coarse sand, loose sand	4
Loose coarse sand, loose sand-gravel mixtures and compact fine sand (confined)	2
Loose medium sand (confined)	1
Loose fine sand	(+)
Hard clay	4
Medium stiff clay, stiff varved silt	2
Soft clay, soft broken shale	1
Soft inorganic silt, pre-loaded material, shattered shale or any natural deposit of unusual character not provided for herein	(+)
Disturbed varved silt	0
Compacted granular fill	(2-5+)

From Ref. 1

Each of these factors may be derived through the application of formulas and numerical factors for general classes of conditions, or alternate factors may be developed based on the measured or modelled dynamic reactions of the structure assuming a given level of dynamic input. It is interesting to note that if an essentially "pre-fabricated" design were being considered (one that would include the horizontal force factor, base shear and weight), the critical element that would make the design acceptable or not acceptable under the codes would be the geological conditions present (soil factor).

The codes also identify design provisions for various types of construction materials (concrete, steel, masonry, timber, pre-fabricated, *etc.*) and for the different design elements that may be employed (beams, columns, walls, foundations and interconnections). All such design considerations are based on the potential lateral accelerations that could be applied to a structure under the occurrence of a "design earthquake" that includes a basic 0.12 g lateral acceleration modified by a height-related fundamental period spectrum. Different methods may be used to demonstrate a satisfactory design that would not cause risk to life and public safety in the opinion of a qualified registered engineer. Sophisticated dynamic methods may be employed, or the analysis may be as simple as demonstrating that similar structures on a similar geologic foundation have been able to withstand the basic level of disturbance without damage.

For earthquake design purposes in the Commonwealth of Massachusetts, foundation materials (or "soil" in engineering parlance) are considered to be either Class A or Class B materials.

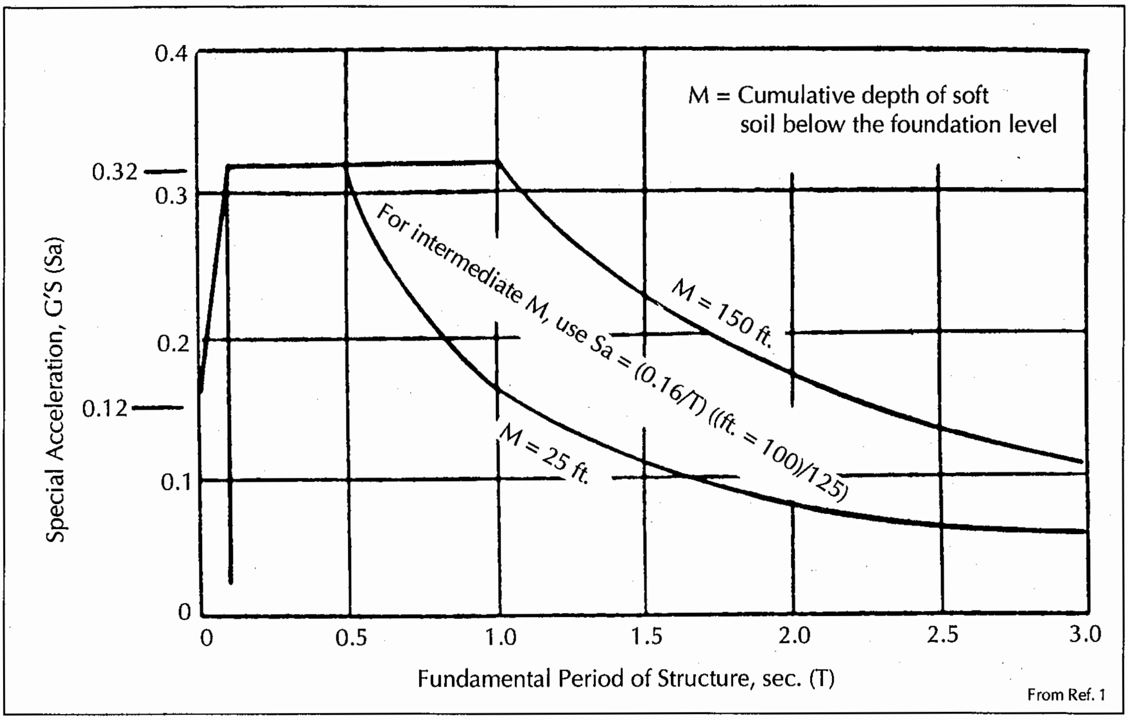

FIGURE 1. Diagram showing the acceleration-period relation of a structure for different depths of soft soil below the foundation level.

Class A materials include massive igneous rocks and conglomerate, slate and argillite, glacial till, gravel or well-graded sand and gravel, coarse sand, medium sand, clay and compacted granular fills. Granular materials must be dense to very dense; clay must have an undrained shear strength of at least 488 g/cm^2 (1,000 lbs/ft^2); and, compacted granular fills must have proper placement and demonstrate a bearing strength. Typical bearing strengths for these materials are shown in Table 1.[1]

All other materials are considered to fall within Class B. This classification requires an increase in the lateral load factor by 50 percent for the evaluation of the design. The thickness of soft foundation material affects the acceleration-frequency relations as well as other ground motion factors at any site from an earthquake (see Figure 1). Modifications to this requirement may be made if satisfactory investigations and evaluations of the actual material conditions are performed that demonstrate that a lesser increase is proper.

Liquefaction is given special consideration in the codes. The presence of clean saturated fine to medium sands in the subsurface may indicate the need for considering liquefaction in earthquake-resistant designs. The Standard Penetration Test (blows/30 cm) in such material, with an adjustment for the depth of such material below the ground surface, is considered the primary guideline for determining liquefaction potential. Material of this type is excluded from consideration if it is present beneath level ground at depths in excess of 18 meters (60 feet). Compacted granular fills may also be excluded, provided that tests or other procedures demonstrate that the risk of liquefaction is not present. Sites where such materials are present, and a clear exclusion of the liquefaction risk cannot be established, must be investigated in some detail. Alternate solutions are given in the codes if liquefaction poses a risk. These alternatives include using foundation designs that can accommodate liquefaction, densification of the deposit to reduce the risk or even total removal of the materials to make the site safe. Sites that are underlain by saturated sands and subject to potential slope instabilities, such as sloping terrain and man-made excavations, must be evaluated by a registered professional engineer for liquefaction and slope instability risks.

Building codes are well known to be excessively rigid, sometimes not very applicable to the average situation, and even counterproductive when enforced by well-intentioned but poorly-informed inspectors. The seismic design codes for earthquake load in Massachusetts, however, have been prepared to furnish a basic guideline that will provide a minimum standard for the evaluation of designs in terms of resistance to damage in the event an earthquake occurs. Additional beneficial features, not always common to the building codes, include flexibilities that permit, and encourage, participation by qualified professionals to propose variations to the basic guidelines. This mandate permits the use of information from well-documented site investigations to modify design requirements, as well as the application of more sophisticated analytical methods in weighting the suitability of a design in terms of the planned structure and the geological conditions present.

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REFERENCES

1. Commonwealth of Massachusetts, *Massachusetts State Building Code*, 3rd ed., Massachusetts State Building Commission, Boston, April 1979.