Section 3
Commentaries

The commentaries in the following subsections were provided by committee members with expertise in particular technical disciplines. The titles and authors of each subsection are as follows:

- 3.1 **Geotechnical and Seismological Aspects** by Klaus Jacob
- 3.2 **Loads and Load Procedures** by Joseph Kelly
- 3.3 **Seismic Design of Nonstructural Components, Elements of Structures and Non-Building Structures** by Leo E. Argiris
- 3.4 **Application to Building Additions and Alterations** by Ramon Gilsanz
- 3.5 **Economic Impact Study** by Irwin Cantor

3.2 Loads and Load Procedures

The New York City Building Code prescribes minimum seismic design loading provisions that include both dynamic and static lateral load procedures. The static load procedure is applicable to regular buildings and the dynamic load procedure applicable generally; where both can easily be combined with the gravity loads to be used to design the structural framing. The static lateral load procedure has been developed based on actual building seismic response experience of many years to approximate the dynamic response which a building frame undergoes during an earthquake. The lateral load coefficients represent the base acceleration, site soil dynamic displacement effects, as well as to approximate the nonlinear response characteristics of the structure. The “R_w” factor used in the building code has been developed to adjust the allowable stress design for the nonlinear inelastic response. The resulting total foundation seismic forces on the building are distributed at each floor to approximate the effects of the various modes of structural vibration. Special detailing of structural components is used to assure that ductility is provided for the expected inelastic strains that take place with the range of lateral seismic displacements.

3.2.1 Ground Motion

An earthquake causes the ground to shake. The amount of ground shaking at a particular building site will depend upon the energy release or magnitude of the earthquake at the source, distance to the location of the epicenter (point on the ground surface below which rupture begins) of the earthquake, and the characteristics of the soil at the site. The earth shaking decreases with distance to the building site. This decrease in earth vibrations is empirically established by attenuation relationships, which are a function of magnitude and distance. Several such attenuation equations have been used in establishing seismic loading in the northeastern United States.

For a building design in New York City which may be considered within 13.7 miles of a possible earthquake site with a maximum earthquake magnitude of 5 and also within 33.6 miles of another possible earthquake site with a maximum magnitude 6, a number of earthquakes can be expected during the lifetime of the building from each of the sites. Design loads are based on a return period of 475 years which has a 10% probability of being exceeded in 50 years. This criteria has been traditionally used in structural engineering practice for seismic design. It is of interest to note that the magnitude 6 earthquake centered 33.6 miles away will likely be less severe than a magnitude 5 earthquake 13.7 miles away. Combinations of both the magnitude and distance of the various design earthquakes possible have been considered to determine the basic seismic ground motion prescribed within the building code.

3.2.2 Response of a Structure

As the ground shakes, mass (weight/gravity) of all of the building components of a structure will be excited through their inertia characteristics, and the structure and components will vibrate, resulting in dynamic forces, stresses and displacements. A simple, single-degree-of-freedom, pendulum structure with a single mass, M, supported by a column with a lateral stiffness, k, will respond to a ground acceleration time history in its natural period, T. The period will be $2\pi\sqrt{M/k}$. The amplitude, velocity and acceleration of its response will be dependent on the amplitude and period characteristics of the ground motion and on the structural damping, β, of the structure. The response of the mass of the structure can be described either in terms of displacement, acceleration or velocity time histories. The single mass structure represents a very simple structure, however, it can be used to represent each mode of vibration of a multi-mass system such as a multi-story building.

A series of structures with varying periods will each respond differently to an earthquake ground motion. The maximum response acceleration of each structure is determined to form a plot called a response spectrum. This curve can then be used to calculate the maximum acceleration of any multi-degree-of-freedom system responding to the expected site ground motion. A multi-story building can be analyzed elastically to determine the various modes of vibration. Through the use of an elastic modal analysis and the participation factors, the maximum response for each component of the structural framing can be calculated and the design forces can be determined by adding the effects of each mode of the structure. Maximum story displacements, accelerations, forces, shears, and overturning moments can be approximated for each mode. The modal values can be combined by various random variable techniques such as, the Square Root of the Sum of the Squares (SRSS) and the Complete Quadratic Combination (CQC), to establish design forces and displacements.

The effects of various soil conditions at the site change the shape of the response spectrum at the site of the building. The S-factor in the code is used to adjust for these conditions. At a soft site (e.g., loose soil profile) the response will be greater for the building design, certainly with the longer periods. On a harder site (e.g. a dense granular soil or a soft rock site) the response will be lower for building design.

The seismic forces used in the design of buildings by the New York City Building Code are substantially less than the forces associated with maximum possible earthquake capable of happening in this area. If a structure were designed to remain totally elastic during such a maximum earthquake, the forces could be greater than the code prescribed lateral forces. However, because of the objective of preventing building collapse and accepting some building damage, building structures are not expected nor are they designed to remain elastic for the largest such earthquake at the building site. The excessive demands of such earthquakes on average can be resisted by framing ductility, redundancy and other nonlinear effects of the structural response.

3.2.3 Capacities of Structures to Resist Major Earthquakes

The explanation of the differences between the large demands of a major earthquake and the relatively lower design loads in the code is of further interest. Some of the differences may be explained by means of load factors and reduction factors (ϕ), or differences between average strengths of framing being greater than specified minimum strengths. Further differences can be accounted for by oversized members and reserves from unused gravity load capacities. After these adjustments, the ratio of the major earthquake demands and the design yield capacities can still be a substantially high factor. Redundancy and ductility are required. If the structure can respond in an inelastic ductile manner without collapsing, the effective demands of the earthquake will be reduced. The effective period lengthens, damping increases, and the amplification due to resonance decreases.