PROVISIONS FOR SEISMIC DESIGN OF NON-STRUCTURAL BUILDING COMPONENTS AND SYSTEMS

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SYNOPSIS

Requirements for the design of architectural, electrical, and mechanical systems and components in buildings are included in nationally applicable seismic design provisions now being developed for the United States. The design requirements are based on the use or occupancy of the building and the possible life hazard that may result in the event of failure. The requirements for architectural elements involve force resistance and provisions for inter-story drift and out-of-plane deflections. The design of mechanical and electrical systems includes provisions for fixed and resiliently mounted equipment and the utility or service interface with the building. A detailed commentary will be included in the document.

INTRODUCTION

Until recently, little attention, and consequently few regulatory provisions, have been directed toward minimizing the failure of non-structural systems under seismic forces. Recent earthquakes have shown that the life safety of building occupants and the public at large may be jeopardized by such omissions in regulatory requirements. As part of the development of nationally applicable seismic design provisions for the United States, the first comprehensive approach to this area of design has been undertaken, to cover all occupancies and uses of buildings and architectural, electrical and mechanical systems, and subsystems or components therein. Such an overall approach is more appropriate than either the present U.S. model codes provisions for only a limited number of architectural elements and without regard to the building's use or occupancy, or for all non-structural elements and systems found in one occupancy as in the California hospital requirements. The provisions are being developed by the Applied Technology Council under contract with the National Bureau of Standards (NBS) with funding by NBS and the National Science Foundation Research Applied to National Needs Program as part of the Cooperative Federal Program in Building Practices for Disaster Mitigation initiated in 1972 under the leadership of NBS.

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BACKGROUND

For the past 50 to 60 years the major emphasis in seismic design has been to assure that structures would not collapse. As our knowledge of structural behavior improved so did our buildings. Those earthquakes that did occur were followed up by engineering teams to gain knowledge of the performance of various materials and this knowledge led to improvements in design regulations. However only structural failures were studied since the magnitude of these failures overshadowed other considerations.

In recent years, the improved designs of modern buildings have resulted in a lessening of the magnitude of structural failure enabling the study of other failures within and without the structure. The earthquakes in San Fernando and Managua in particular, demonstrated that serious attention must be given to the non-structural systems and components in order to protect the public.

The failure of life support systems in hospitals, the trapping of fire engines and ambulances in their garages due to structural and non-structural collapse, the obstructing of exitways by failure of non-structural walls, are examples of the hazards that need consideration.

OVERALL CONSIDERATIONS

The primary principle in developing criteria for non-structural system performance was to assure life safety in the event of an earthquake. A second principle was to establish three occupancy groupings within which comparable performance of systems is to be achieved. One of the groups covers facilities in which operations must be functional during and after the earthquake such as hospitals, etc. The other two groups are relatively densely populated and lightly populated occupancies respectively (see Table 1).

The third principle was to consider the life hazard relationship of a given architectural, electrical or mechanical system or component to the particular occupancy group. This was done by evaluating the hazard presented based on numbers of persons exposed, ability of occupants to take care of themselves, size of building and need for systems to remain functional. The required relative performance level of a particular system was thus determined.

ARCHITECTURAL PROVISIONS

The architectural systems and sub-systems of a building are the non-load bearing walls, suspended ceilings, stair enclosures and similar interior elements and the exterior non-load bearing walls or wall panels and parapets.

The force the architectural element is to resist is calculated from

$$F = C_p W_p P A \qquad (1)$$

A is the Effective Peak Acceleration and Wp is the weight of the system or component.

The Cp values are based upon "yield" stress levels and thus are generally two to three times the conventional Cp values currently in United States regulatory standards. The value for parapets is a notable exception as they are classed with "exterior walls" with a "yield" level Cp of 0.9 as contrasted to the current 1.0 level.

The performance factor "P" varies from 1.5 for superior (S) performance, 1.0 for good (G), 0.5 for low (L) and 0 for no (N) performance required. A lateral deflection or drift modifying factor and transverse bending criteria are also related to the required level of performance for a particular element or system of the building. For example, from Table 2 a suspended ceiling in Group I would require a "Superior" performance characteristic with a force level modification of 1.5, while the same ceiling in Group III would have a factor of 1.0 or 0.5.

The deflection or drift factor is similarly applied to the calculated drift. Vertical deflection of cantilevered members are required to be considered due to joint rotation. Limits for out of plane or transverse bending are also specified. The design documents are required to include details of all connections as well as consideration of the interaction of the architectural systems and components with the structural system.

ELECTRICAL AND MECHANICAL PROVISIONS

The electrical and mechanical systems needed to provide for life safety, or whose failure would create a life hazard have provisions similar to those for the architectural systems with regard to required system performance. Required force level modifiers are given.

Since many of the systems contain rotating or reciprocating parts and involve heavy concentrated loads, the method of attachment or anchorage is specified for fixed conditions or to allow for motion amplification when resilient mounts are used. All equipment that is regulated is required to be attached to the building; friction is not allowed.

The force equation for electrical and mechanical systems is:

$$F = CpWpPAMf_h \qquad (2)$$

where Cp, Wp, P and A have the same definitions as in equation (1). M is a dimensionless multiplication factor which equals 1 for fixed or seismic-activated restraining device attachment to building. Where an elastic restraining device is used and the ratio of the vibrational period of the mechanical or electrical component (including anchorage system) is greater than 0.6, or equal to or less than 1.4, M = 2. For all other cases M = 1.

The coefficient f_h is a factor to allow for amplification within the building. The factors M and f_h provide for the amplifications due to type of mounting and location in building. Their calculation is considerably simplified in the provisions.

To insure compliance of the equipment with the design requirements, methods of testing and certification will be needed, especially where high performance of equipment is required or fixed equipment is to be used in Seismic Zones 3 and 4. Similarly, equipment on resilient mounts would require such certification in any Seismic Zone. This may require testing on shaking tables or comparable means of demonstrating the capability of the component to withstand the specified seismic motion.

CONCLUSION

The proposed provisions for seismic design of architectural, electrical and mechanical systems and components is the direct result of the severe damage and life hazards from failures in recent earthquakes. These provisions will present new challenges to engineers throughout the United States and will require new relationships be developed and dialogue established between the several design professions so that the final design fully carries out the intent of the provisions and to ensure public safety consistent with the public's needs and available technology. New standards of performance, testing, and certification will be required for electrical and mechanical equipment so that the design professional can proceed with confidence.

TABLE 1

SEISMIC HAZARD EXPOSURE GROUPS

GROUP I

Buildings housing critical facilities which are necessary to post-disaster recovery and require continuous operation during and after an earthquake. These include facilities for fire departments, police, hospitals, emergency preparedness, emergency communications, power generation and distribution, and others required in an emergency.

GROUP II

Buildings housing high population density, occupancies having a highly transient population and/or sleeping facilities. Critical facilities requiring operation in the immediate post-disaster period, restricted movement facilities, and large hazardous occupancies. These include facilities for public assembly of 100 or more persons; open air stands for 2,000 or more persons; day care centers; schools; colleges; retail stores with 5,000 sq. ft. floor area per floor or more than 35 ft. in height; shopping centers with covered malls, over 30,000 sq. ft. gross area excluding parking; offices over 4 stories in height or more than 10,000 sq. ft. per floor; hotels, apartment houses, wholesale stores, factories, and printing plants over 4 stories in height; hazardous occupancies utilizing flammable or toxic gases, and flammable or toxic liquids including storage facilities for same.

GROUP III

Buildings housing low population density occupancies and generally a less transient population. These include facilities for aircraft hangars factories, wholesale stores, printing plants, hotels, and apartment houses 4 stories or less in height; woodworking facilities; repair garages; service stations; storage garages; ice plants; one- and two-family dwellings; townhouses; retail stores less than 5,000 sq. ft. per floor and 35 ft. or less in height; public assembly for less than 100 persons; and offices 4 stories or less in height or less than 10,000 sq. ft. per floor.

TABLE 2

ARCHITECTURAL FORCE AND DRIFT PERFORMANCE FACTORS

Architectural Systems or Components	C_p* Factor	Hazard Exposure Group I	II	III
Exterior non-structural walls	0.9	S	G	L
Veneers	3.0	G	G	L
Roofing units	0.6	G	G	N
Containerized and miscellaneous elements (free standing)	1.5	G	G	N
Stairs and shafts	1.5	S	G	G
Elevators and shafts	1.5	S	L	L
Vertical shafts	0.9	S	L	L
Horizontal exits	1.5	S	S	G
Public corridors - includes ceilings	0.9	S	G	L
Private corridors	0.6	S	L	N
Full height separation partitions	0.9	S	G	G
Full height structural fireproofing	0.9	S	G	L
Full height other partitions	0.6	G	L	L
Partial height partitions	0.6	G	L	N
Ceilings - fire-rated membrane	0.9	S	G	G
Ceilings - non fire-rated membrane	0.6	G	G	L
Equipment - ceiling mounted	0.9	S	G	L
Equipment - wall mounted	0.9	S	G	L
Equipment - floor supported	0.9	S	G	L

Legend:

S = Superior performance
G = Good performance
L = Low performance
N = No performance

*Based on compatibility for material stresses approaching the yield level.