Briefing Paper 5

Seismic Response of Nonstructural Components

Part A: Overview of Component Types and Behavior

Introduction

This Briefing Paper 5, *Seismic Response of Nonstructural Components*, consists of three parts that discuss how earthquakes affect a variety of nonstructural building components, and how they should be anchored or braced to resist seismic forces. This Part A provides background on the damage earthquakes can cause to nonstructural components, defines the types of systems and equipment that can be affected, and describes the way they respond to earthquake motions. Part A also discusses various methods of anchorage systems and their limitations. Parts B and C describe the vulnerability and proper anchorage methods for seven specific types of nonstructural components.

Typical Nonstructural Components

The term nonstructural components refers to the systems, parts, and equipment that do not carry vertical and horizontal loads. These include architectural elements such as suspended ceilings and partitions; mechanical elements such as HVAC ducts and plumbing pipes; electrical elements such as lights and switch gear, as well as other parts of the building envelope like window walls, cladding, veneers, and parapets. Nonstructural components are permanent built-in items rather than building contents and furniture, which are typically movable. Seismic performance of building contents is also an important topic, but it is not covered in this Briefing Paper.

Nonstructural component damage is a frequent cause of earthquake-related fires.

How Earthquakes Affect Nonstructural Building Components

The seismic response of nonstructural building components is an important concept to be understood by those responsible for writing specifications or detailing the installation of these components. It must also be understood by those responsible for installing and inspecting components. Many injuries, and often more than one-half of the total economic loss in an earthquake, stem from or are related to damage to nonstructural components. The economic losses are not limited to the cost of repairing the damaged components; they often include damage to other equipment and building contents plus the extensive loss-of-use costs associated with repairs and restoration. In fact, these collateral losses can be greater than the cost of repairing structural damage. Nonstructural component damage is a frequent cause of earthquake-related fires, which can result in the total loss of a building and its contents. Leaks and spills of hazardous materials from inadequately braced piping or fluid tanks can threaten the health of those located in a wide area around a damaged building.

The different physical characteristics of nonstructural components affect their response to earthquake motions. Therefore, appropriate means of preventing damage will also vary. Specific component response depends on several parameters.

The mass of the object is important because the earthquake forces acting on every nonstructural component depend on their mass. As described in Briefing Paper 1, Part B, these are known as inertial forces. Inertia results in heavier components requiring anchorage that can resist larger forces.

The location of the component with respect to the base of the building is important because the roof and upper stories are subject to larger motions and accelerations. All buildings are to some extent structurally flexible, and the size of the lateral drift is cumulatively larger with each increasing story. This effect has only recently been addressed in the 1997 *Uniform Building Code* (UBC) requirements for designing the anchorage of nonstructural components.

The flexibility of a nonstructural component affects its response to earthquake motion. Examples of flexible components include cantilevered parapets, chimneys and storage racks anchored only at their base (Figure 1). With the top edge or end free to move, these are much more flexible than components braced at both the top and bottom. These flexible components experience a whiplash effect and are subject to greater earthquake forces than are rigid components.

The method of anchorage also affects response. A flexible connection may be necessary for proper functioning of the component under normal conditions. For example, an HVAC unit mounted on vibration isolators is a relatively rigid piece of equipment that is flexibly mounted. The flexible mounting allows earthquake motions to be amplified if resonance occurs, and consequently the equipment's anchorage must be designed for higher forces. In other cases, the anchorage or bracing may be rigid to provide maximum restraint. In such cases, the anchorage can be designed for lower forces.

Connections using ductile materials (e.g., bolts, nails, and light-gauge steel connectors) are well-suited to resist the dynamic cyclic motions produced by earthquakes. Certain types of connections (e.g., adhesives) are deemed nonductile because they are susceptible to sudden failure. Although they are permitted to be used, the 1997 UBC requires the use of higher force levels when designing these nonductile connections.

Failure Modes Resulting in Damage and Potential Injuries

Damage and serious injuries can result from several failure modes observed in nonstructural components. Unrestrained objects can fall, slide, overturn or swing when acted upon by earthquake forces, depending on their location, size, shape, and orientation of attachment to the building. Falling hazards are the largest cause of serious injuries. Consequently, parapets, exterior cladding or veneer (Figure 2), suspended equipment, and heavy ceilings (Figure 3) are of great concern and should be the top candidates in any retrofit project. Components with a high center of gravity and a relatively small base such as electrical switch gear panels, storage racks, and interior partitions are likely to overturn, posing a significant safety hazard. Items that are mounted on floors, roofs, or platforms are primarily susceptible to sliding. However, that sliding movement can sever electrical and piping connections, causing fire hazards or water damage. Sliding can also cause physical damage to the component itself and to adjacent components. A suspended component with only vertical support, or less-than-sufficient bracing, can swing like a pendulum, breaking piping or electrical connections and colliding with other nearby components. If the swinging motion damages the vertical support connections these items can fall on occupants below.

Figure 1. Earthquake-damaged book shelves (EERI photo).

Figure 2. Cladding damage resulting from 1995 Kobe earthquake (C. Rojahn photo).

Anchorage of Nonstructural Components

The anchorage or bracing methods used to resist earthquake forces must be carefully considered if they are to be truly effective. Not only must the correct seismic loads be calculated to determine the size and amount of bracing or anchorage, but the compatibility of the anchorage with the functional characteristics of the component being braced or anchored must also be considered. The layout and location of bracing or anchorage must be carefully chosen to provide adequate clearance, particularly in above-ceiling spaces or other areas where the ability to maintain or service equipment or systems is necessary. It may also be necessary to reserve enough access space for the servicing of other components. Lastly, the specific type of anchorage fasteners to be used must be compatible with the structural member or substrate into which the anchorage will be placed. Please also refer to the companion Briefing Paper 6 titled, "Seismic Code Requirements for Anchorage of Nonstructural Components," for a more detailed explanation of the 1997 *Uniform Building Code* (UBC) anchorage requirements.

The 1997 UBC requires that anchors with embedment depths less than eight times the anchor diameter must be designed to resist twice the normally computed seismic forces.

Anchorage Methods and Limitations

Flexible anchorage is needed whenever the component requires some freedom of motion to perform its intended function. Examples include those components subjected to large thermal expansion and contraction cycles and those requiring vibration isolation. Flexible connections are also needed when piping, conduits, or ducts cross a seismic separation gap in a structure or pass between two adjacent separate structures.

The capacity of anchorage into concrete and masonry is always sensitive to the depth and spacing of the embedded anchors and to their location relative to the nearest edge of the concrete or masonry. If the available depth is shallow, the minimum design force that the anchor must resist has to be increased. In fact, the 1997 UBC requires that anchors with embedment depths less than eight times the anchor diameter must be designed to resist twice the normally computed seismic forces. This applies to expansion anchors, chemical anchors, and cast-in-place bolts. This is in addition to the capacity reductions that may apply due to a reduced distance between the anchor and an edge or end of the concrete or masonry. The allowable pull-out or tension capacity of certain anchors may depend on whether or not special inspection and testing of the anchors is to be provided during their installation. Multiple anchors must be spaced apart a minimum distance that is based on the diameter of the anchor used, with expansion anchors typically requiring larger minimum distances than

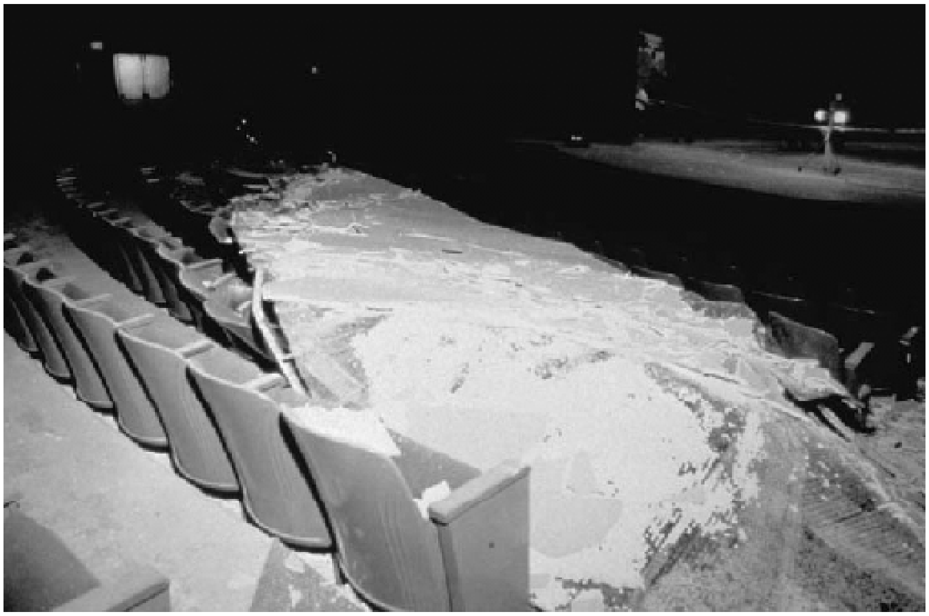

Figure 3. Collapse of heavy plaster ceiling during 1994 Northridge earthquake (EERI photo).

withdrawal values in the standard were not based on cyclic loading.

If anchorage is accomplished using nonductile materials or adhesives, the 1997 UBC requires minimum design forces that are three times larger than those used with ductile anchorage materials. This requirement compensates for the fact that nonductile materials can fail suddenly and completely, resulting in potentially dangerous falling hazards.

chemical anchors. The anchor manufacturer's product evaluation report should always be consulted to obtain the correct allowable capacity as a function of spacing. The minimum spacing permitted generally provides lower capacity than the standard spacing. The reports also specify if the product is not suitable for earthquake loading or for anchoring equipment subject to vibration. The reports on chemical anchors should also note whether they are sensitive to high temperatures.

Anchors connecting to wood must be properly designed to account for the angle at which the forces act compared to the grain direction of the wood member into which the nail, bolt or screw is connected. When the load is applied in a direction other than parallel to the grain, the anchor capacity must be reduced based on the angle between the load direction and the parallel-to-grain direction of the member. Wood member end and edge distances must also be maintained. If nails are placed so that they are resisting forces along their length (subjected to withdrawal), they should not be considered reliable for resisting earthquake forces, even though they may have a withdrawal capacity published in the National Design Standard. This is because the

References

ICBO, 1997, *Uniform Building Code*, International Conf. of Building Officials, Whittier, Calif.

Resources for Additional Reading

ATC, 1998, *Proc. of Seminar on Seismic Design, Retrofit, and Performance of Nonstructural Components*, Applied Technology Council, Report ATC 29-1, Redwood City, CA.

About this Briefing Paper Series

Briefing papers in this series are concise, easy-to-read summary overviews of important issues and topics that facilitate the improvement of earthquake-resistant building design and construction quality.

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