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THE LATEST DEVELOPMENTS IN SEISMIC MITIGATION OF SUSPENDED CEILING SYSTEMS

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SUMMARY

The primary objective of seismic mitigation of suspended ceiling systems is to protect the general public from death and injury. The secondary objective is to reduce economic loss and increase building occupancy recovery time. One of the most widely reported types of nonstructural damage in earthquakes is the failure of suspended ceiling systems. Even under moderate shaking, the lightweight acoustical tile panels, which rest on the main and cross runners of suspended ceilings, can be easily dislodged. Building codes and guidelines have been progressively developing for the last fifty years. This is a sector of the industry where an effective building code prescription is largely dependent on the availability of products. In the past decade, new testing criteria have emerged providing minimum performance requirements that enable manufacturers to develop products that will meet the intent of the building code. In some cases the test criteria must address the required seismic response behavior of a combination of products working together in a system. The new concept of nonstructural components reacting to seismic loading as modules instead of reacting as individual single components provides a better understanding of the overall behavior of a system. The impact that individual components can have on other components can only be realized when tests are conducted on the system. The data collected from those tests can be incorporated into new criteria that helps clarify code intents and allow improved industry practice to code adherence.

INTRODUCTION

The latest development in seismic mitigation of suspended ceiling systems is the development of "Acceptance Criteria for Attachment Devices for Lighting Fixtures (Luminaries) in Suspended Ceiling Systems (AC) 184". The purpose of this criteria is to establish requirements for attachment devices, recognized in International Conference of Building Officials Evaluation Service, Inc. (ICBO ES) 5360 Workman Mill Road Whittier, California, evaluation reports, that are used to attach recessed lighting fixtures (luminaries) to suspended ceiling systems under Part III of UBC Standard 25-2, in the 1997 Uniform Building Code (UBC), and under Ceilings &

Interior Systems Construction Association 3-4-91 (CISCA) as referenced in Section 1621.2.5.2.2 of the 2000 International Building Code (IBC).

AC 184 is a criteria that defines the load requirements and testing procedure for devices that are used to attach lighting fixtures to suspended ceiling systems. Static tests were conducted to determine the failure mode of the suspended ceiling system, the light fixtures and the connection of the light fixture to the suspended ceiling system. Dynamic testing was conducted at the University of British Columbia in Canada to verify the behavior of the components subjected to a peak acceleration of 1.4 g. These test results lead to a new concept where the light fixture and the suspended ceiling system work together as a single module, rather than individual components. A single module can respond to seismic loading in unison with no damage, where individual components can cause damage to each other, leading to possible failure.

Building codes such as the International Building Code 2000 Section 1621.2.5, the Uniform Building Code 1997 Standard 25-2, the New Zealand Building Code, the Japanese Building Code, the European Building Code and the National Building Code of Canada all have provision for the Seismic Design Requirements for suspended ceiling systems. Comparisons of these codes reveal similarities in that nonstructural components are required to be restrained to prevent them from damage as well as preventing one nonstructural component from impacting and damaging a second nonstructural component. However, there are variations in the safety factors with each model code. Variation in load factors can extend to individual types of components in the same environment in the same code.

HISTORIC EARTHQUAKE DAMAGE

An analysis of commercial buildings following the 1971 San Fernando, California, earthquake revealed direct damage to buildings and other structures exceeded $0.5 billion (1971 dollars). Structural damage was 3% of the total losses. Losses, due to failure of electrical, mechanical, plumbing and sprinkler systems, together with damage to architectural systems such as exterior cladding and interior finishes was 97% of the cost.

The 1989 Loma Prieta, Santa Cruz County, California, earthquake was the largest earthquake to occur in the San Francisco Bay area since 1906, and the largest anywhere in California since 1952. The earthquake was responsible for 67 deaths and about 7 billion dollars worth of damage, making it the biggest dollar loss natural disaster in United States history at the time. Approximately 500 homes and 100 businesses suffered severe damage, with an additional 18,000 homes and 2,500 businesses suffering minimum to moderate damage. Damage to nonstructural components contributed largely to the overall cost from water damage, electrical systems damage, ceiling system failure and operational and functional components damage.

Of the 66,546 buildings inspected after the 1994 Northridge, California, earthquake, 6% were severally damaged and17% were moderately damage. The remaining 77% of the damage to the buildings was attributed largely to nonstructural components damage. The total cost of the damage from the earthquake was about 20 billion dollars.

The 1995 Kobe, Japan earthquake suffered 5500 deaths and an additional 35,000 injured. The total economic loss was approximately 140 billion with 180,000 structures destroyed or damaged beyond repair. Many buildings suffered structural collapse due to soft soil conditions, fires also contributed greatly to the total damage. The newer buildings preformed well in comparison to the older buildings. Houses suffered collapse from the heavy loads of the clay roofs causing a large number of deaths and injuries. The impact of the damages to nonstructural components in the Kobe earthquake is not proportional to the impact of damage to nonstructural components in the Northridge, Loma Prieta and San Fernando earthquakes because of the number of buildings that were totally destroyed.

In the NE Olympia Washington earthquake in February, 2001 the city of Seattle also received considerable damage to nonstructural components. The head office of Starbucks in Seattle had major damage due to a sprinkler pipe that was broken by the impact of an unrestrained light fixture.

BACKROUND OF CURRENT CODE REQUIREMENTS

Due to the suspended ceiling damage noted after the 1969 Santa Rosa, California, and the 1971 San Fernando, California earthquakes, the Structural Safety Section of the Office of the State Architect (OSA) of California prepared a set of staff notes that suggested certain improvements in ceiling design and installation practice. As a direct result of the extensive hospital damage caused by the 1971 San Fernando Earthquake, the state of California assumed responsibility for the design review of hospital construction.

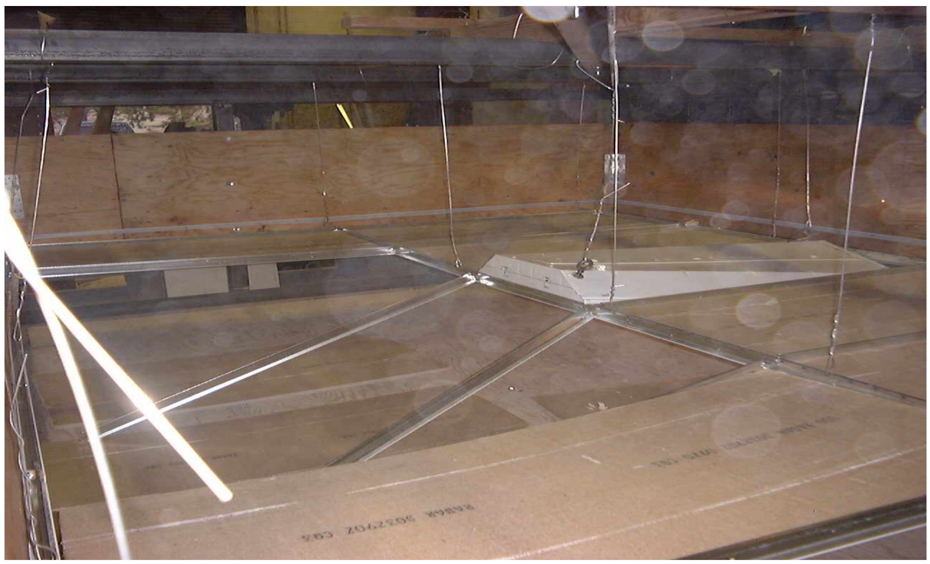
The OSA staff notes were used as the basis for certain sections of the state building code, a modified Uniform Building Code. Additionally, the staff notes were used as bases of the 1972

CISCA Recommended Standards for Seismic Restraint of Direct-Hung Ceiling Assemblies. The general damage modes to suspended ceilings noted by OSA (circa 1970) were as follows:

Frequent cross runner/main runner intersection pullout, which allowed the cross runners, panels and supported light fixtures to fall to the floor

Buckling and loss of wall angle support of main runners and cross runners around the perimeter of rooms as well as near the intersection of columns or other ceiling penetrations.

The supports did not fall down. The ceiling fell apart, allowing the ceiling loads to release.



THE INTENT OF SEISMIC CODE PROVISION

The intent of the seismic code provisions is not to prevent damage, but to protect the life safety of the occupants and the general public.

In a minor or moderate earthquake, the objective is no structural damage and some to no, nonstructural damage. The suspended ceiling system provisions relate to permitting the system to float and have the dead load absorb the seismic energy, but not permitting the movement of the system components to impact each other and damage themselves or other system components.

In major earthquakes, the objective is no collapse of buildings, some structural damage and some nonstructural damage. The suspended ceiling provisions for major earthquakes require perimeter attachment and bracing to restrict movement, hence the seismic energy is absorbed by yielding.

STANDARDARDIZED DAMAGE STATES

To provide an understanding of the expected performance of buildings in a seismic event the Earthquake Engineering Research Institute (EERI) produced the document Expected Seismic Performance of Buildings. There are five ranges of damage given in the document, which prescribes the level of damage expected and the risk of injury to occupants for each range. The understanding that a building in a specific area will perform to a specific Damage State lends to seismic mitigation considerations that can be expected to increase the seismic performance of that same building in a seismic event. The five ranges of Damage State are:

1. A - No damage
2. B - Minor damage
3. C - Moderate damage
4. D - Extensive damage
5. E - Complete damage

The objective of Engineers and Designers is to maintain damage state C or less.

DAMAGE STATE C

Primarily Nonstructural Damage. There could also be minor but non-threatening structural damage. Building will probably be closed for 2 to 12 weeks.

Remote chance of life-threatening situation, from falling nonstructural elements and debris that may block hallways and exits.

Interior damage may be extreme, and there may be cracks in structural elements. This level of damage often requires engineering analysis to determine its severity.

IMPACTS OF DAMAGE TO NON-STRUCTURAL COMPONENTS

Economic Loss- direct cost repairing the damage

Experience in recent EQs indicates that aggregate loss is high.
Mainly the result of small amount of damage to a large number of buildings.

The value of the NSC in a building may be as high as:

80-90% of the total cost in a complex facility (i.e., hospitals).
20-30% of a facility with low system costs and minimal architectural features.

Combined effects of damage to NSC generally exceed those of direct structural damage in an earthquake.

Loss of Building Function- damage to components or systems necessary for useful function such as power and plumbing systems, or it may be due to disruption created by the repair of architectural or other NSC components.

Prolonged loss of function may severely impact small businesses

HOW EARTHQUAKES AFFECT NON-STRUCTURAL BUILDING COMPONENTS

1. The mass of the object is important because the earthquake forces acting on every NSC depend on their mass.
2. 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.
3. The flexibility of a nonstructural component affects its response to earthquake motion.
4. The method of anchorage also affects response. A flexible connection may be necessary for proper functioning of the component under normal conditions.
5. 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.

ACCEPTANCE CRITERIA 184

Acceptance Criteria (AC) 184 was developed by the International Conference of Building Officials Engineering Staff and adopted in 2002. A number of issues were examined when developing AC 184.

1. The attachment of the light fixture to the suspended ceiling system. The first failure mode noted was main runner/cross runner failure that allowed the light fixture to fall to the floor. The second failure mode observed was when the end plate of the light fixture was screwed to the suspended ceiling system. When load was applied the end plate/fixture housing connection failed.

The attachment of the light fixture to the suspended ceiling system is the only means of maintaining the light fixture, preventing it from swinging and damaging other nonstructural components such as a sprinkler pipes or sprinkler heads. The impact of light fixtures will activate a head, or in some cases break the pipe off.

AC 184 4.1.4.1 is as follows: Attachment Devices Used for Positive Attachment of Lighting Fixtures to Suspended Ceiling Framing: The average ultimate test result of each test series shall be divided by an adjustment factor of 6. The resulting adjusted values for each test series shall be compared, and the lowest value is the maximum weight of the light fixture that can be recognized. The maximum fixture weight that can be recognized is 56 pounds (25.4 kg). The adjustment factor of 6 is based on the UBC and IBC requiring a minimum of two devices, where each device shall have an allowable load equal to 100 percent of the weight of the lighting fixture, and a safety factor of 3.

Static load tests verify the capacity of the connection devices and are required to be conducted to failure in a series of three single tests for each direction. First, is gravity load, second, is vertical uplift load, third, is load parallel to the main runner and fourth, is load parallel to the cross runner, with none of the test results varying by more then 15 percent from average the of the three tests. The load rating of the devices is then based on the average result in the test series, with the minimum load capability. The minimum load rating of the devices cannot be less then 336 pounds (1494.5 N).

2. The improper attachment of the two slack wires from the structure above to diagonal corners of the light fixtures where the attachment typically was to the end plates of the fixture. This observation concluded that the structural capability of the end plate attachment on the light fixture was inadequate to withstand the seismic load that would be applied to the light fixture in an event and the end plate would tear off. This reinforced that the attachment of the two wires must be attached directly to the light fixture housing, with a connector capable of withstanding a load of 300 pounds (1334.4 N) at each corner.

The same static load tests as above will apply to determine the load capacity of the devices for attachment without additional hanger wires.

AC 184 4.1.4.2 is as follows: Attachment Devices Used in Lieu of Code Requirements for Two Slack No.12 Gage Wires Attaching Light Fixtures to the Structure Above the Suspended Ceilings: The average ultimate test result, as determined in AC 184 Section 4.1.1.2, of each test series shall be equal to or greater than 600 pounds (2669 N). The 600-pound (2669 N) value is based on applying a safety factor of 3 to an assumed ultimate load capacity of 100 pounds (444.8 N) for each of the two No.12 gage slack wires required by the code.

Devices that qualify in the static tests are then subjected to a series of dynamic tests to verify the performance of the components in a seismic event. Each series of dynamic tests shall consist of two assemblies and be conducted on a combination of eight different assemblies to represent all field applications

Dynamic Testing Configurations

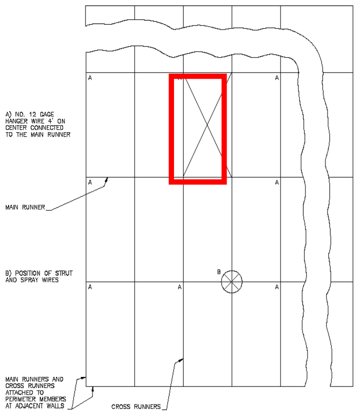


FIGURE 2
SINGLE LIGHT FIXTURES (LUMINAIRES)
PERPENDICULAR TO MAIN RUNNERS

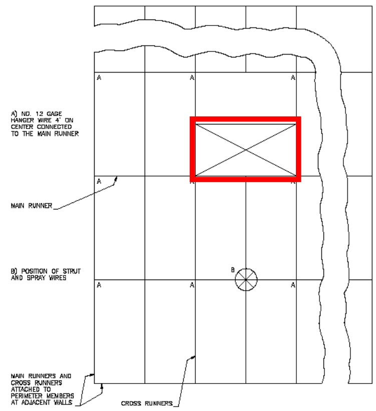


FIGURE 3
SINGLE LIGHT FIXTURES (LUMINAIRES)
PARALLEL TO MAIN RUNNERS

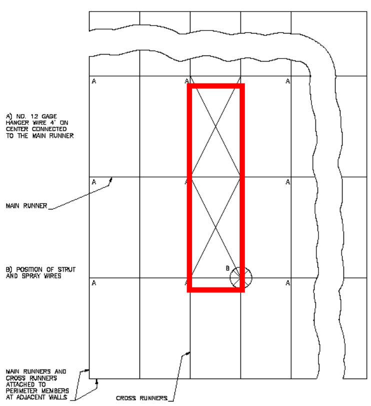


FIGURE 4
TWO LIGHT FIXTURES (LUMINAIRES)
PERPENDICULAR TO MAIN RUNNERS
END TO END

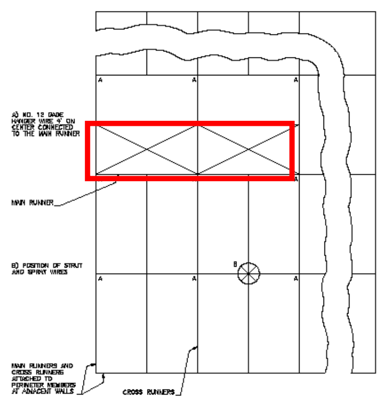


FIGURE 5
TWO LIGHT FIXTURES (LUMINAIRES)
PARALLEL TO MAIN RUNNERS
END TO END

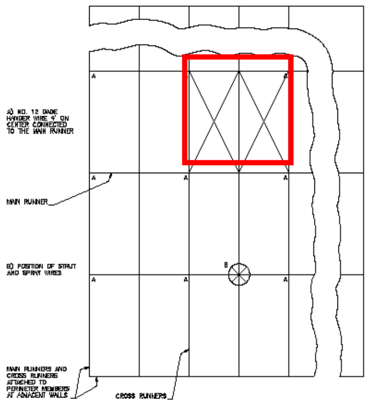


FIGURE 6
TWO LIGHT FIXTURES (LUMINAIRES)
PERPENDICULAR TO MAIN RUNNERS
SIDE TO SIDE

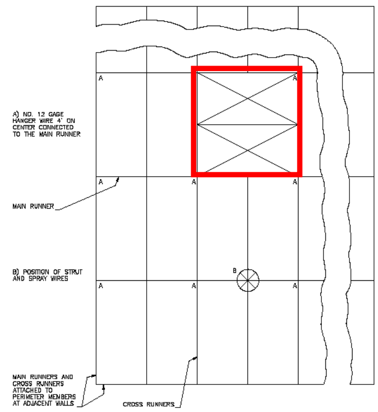


FIGURE 7
TWO LIGHT FIXTURES (LUMINAIRES)
PARALLEL TO MAIN RUNNERS
SIDE TO SIDE

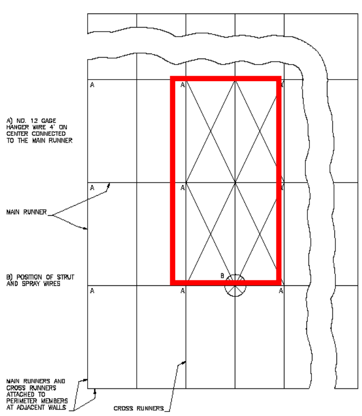


FIGURE 8
FOUR LIGHT FIXTURES (LUMINAIRES)
PERPENDICULAR TO MAIN RUNNERS
SIDE TO SIDE & END TO END

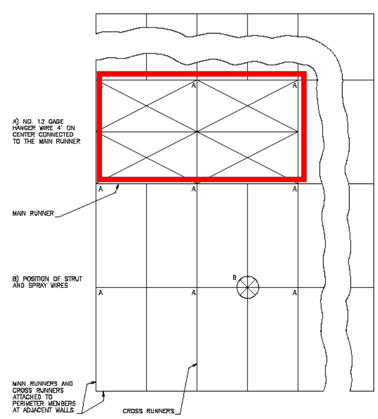


FIGURE 9
FOUR LIGHT FIXTURES (LUMINAIRES)
PARALLEL TO MAIN RUNNERS
SIDE TO SIDE & END TO END

Direction of Shaking:

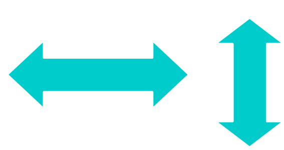


Figure 1 above, top left, is a single light fixture, perpendicular to the main runner.

Figure 2 above, is a single light fixture, parallel to the main runner where the cross runners must transfer the load to the second main runner.

Figure 3 above, second row left, are two light fixtures, end-to-end perpendicular to the main runner.

Figure 4 above, are two light fixtures, end-to-end parallel to the main runner.

Figure 5 above, third row left, are two light fixtures, side-by-side perpendicular to the main runner.

Figure 6 above, are two light fixtures, side-by-side parallel to the main runner.

Figure 7 above, bottom row left, are four light fixtures, side-by-side perpendicular to the main runner.

Figure 8 above, are four light fixtures, parallel to the main runner.

The variation of test configurations makes allowance for devices to be acceptable for all of the different configurations or the devices can be restricted to only one application. In order for any devices to be acceptable they must comply with the qualification criteria of AC 184.

AC 184 4.2.3 Qualification Criteria

4.2.4.1 The results of the dynamic load tests shall demonstrate that the tested assemblies satisfy the following criteria:

4.2.41.1 The light fixture(s) remain in place, attached to the main runners and cross runners and supported by the hanger wires.

4.2.4.1.2 The main runner and cross runners remain attached by the device at each main-runner-to-cross-runner intersection.

4.2.4.1.3 The plastic light diffuser and fluorescent tubes of the light fixtures remain in place and intact.

PROVISIONS FOR CEILING SYSTEMS

The provisions for seismic mitigation of nonstructural components referred to in the International Building Code and the Ceiling & Interior Systems Construction Association are determined from the category requirements. Each category is representative of a combination of factors, statistical analysis of earthquakes that have been experienced, soil condition, ground acceleration and ground velocity probability. Category A, being the lowest seismic risk, areas with no earthquake history and hard rock, where as category F being the highest seismic risk, areas with earthquake history and a quick and highly sensitive clays or the like soil condition. The general requirements for suspended ceilings in Seismic Design Category D, E or F, are:

a. A heavy-duty T-bar grid system. The structural classification of a T-bar system is determined by the load-carrying capacity of the main runners for the structural network although the dimensions, high, width and length often are the same for each classification. The minimum pound per linear foot (kg/m) for intermediate-duty is 12 pounds (17.9 kg) and for heavy-duty systems is 16 pounds (23.8 kg).

b. The width of the perimeter supporting closure angle shall be not less than 2 inches (51 mm). In each orthogonal horizontal direction, one end of the ceiling grid shall be attached to the closure angle. The other end in each horizontal direction shall have a 0.75-inch (19.1 mm) clearance from the wall and shall rest upon and be free to slide on a closure angle.

c. For ceiling areas exceeding 1,000 square feet (93 m2), horizontal restraint of the ceiling to the structure shall be provided. The horizontal restraints shall be designed to minimize diaphragm loads.

d. Exception: Rigid braces may be used instead of diagonal splay wires. Braces and attachments to the structure above shall be adequate to limit relative lateral deflections at point of attachment of ceiling grid to less than 0.25 inch (6.4 mm) for the loads prescribed in section 1621.1.4.

e. For ceiling areas exceeding 2,500 square feet (232 m2), a seismic separation joint or full height partition shall be provided unless analyses are performed that demonstrate ceiling system penetrations and closure angles provide sufficient clearance to accommodate the additional movement.

f. Except where rigid braces are used to limit lateral deflections, sprinkler heads and other penetrations shall have a 2-inch (51 mm) oversize ring, sleeve or adapter through the ceiling tile to allow for free movement of at least 1 inch (25 mm) in all horizontal directions. Alternatively, a swing joint that can accommodate 1 inch (25 mm) of ceiling movement in all horizontal directions shall be provided at the top of the sprinkler head extension.

g. Changes in ceiling plane elevation shall be provided with positive bracing.

h. Cable trays and electrical conduits shall be independently supported and braced independently of the ceiling.

SUMMARY AND CONCLUSIONS

Much advancement in seismic mitigation of nonstructural components has been made over the past ten years. These advancements are attributed to the ongoing study of the behavior of buildings during earthquakes and continual development of concepts that are tested in earthquake labs. The result is better-defined code requirements, new products and methods and procedures of testing these products.

A suspended ceiling system is a complex array of many different components assembled to work together to serve the occupancy. An important consideration in seismic mitigation of suspended ceiling components is to allow individual components to work together as a module or system. The term module takes a concept to the level of understanding that all the related components in a system are examined both individually and as a group providing the most effective seismic mitigation assembly. An example of this is Acceptance Criteria AC184.

Subsequent to this new development, the challenge is implementation by industry. Implementation will take time in education, providing proper interpretation of the procedures and methods to Engineers, Architects, Building Officials, Contractors, and Building Owners.

ACKNOWLEDGMENTS

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