The Design of the Suspended T-bar Ceilings in accordance with AS 1170.4 for the New Royal Adelaide Hospital

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ABSTRACT

In the past, although earthquake design has been required for non-structural elements includes suspended T-bar ceilings in Australia, it has been poorly considered, generally not understood and usually disregarded even though being required of the BCA. Section 8 of AS 1170.4, the Australian Earthquake Standard covers the design of parts and components but no Australian ceiling suppliers have been able to provide a ceiling system that complies, until now, with the Australian Earthquake Standard, although some overseas systems are available. However these overseas systems have not tested for Australian or New Zealand design conditions. In addition, the current ceiling standard AS/NZS 2785: 2000 is badly out of date and structural engineers do not know how to design such ceilings for seismic loads in Australia.

With the design of the new Royal Adelaide Hospital (NRAH), seismic design is required not only the structure but for parts and components and it has dominated the design of the hospital. This paper describes the review of design of T-bar ceilings in the USA, consideration of how such ceilings should be designed in Australia in accordance with AS 1170.4 and dynamic testing carried out at Buffalo University in the United States of America to confirm the viability of a particular manufacturer's T-bar ceiling system for the NRAH.

Keywords: AS 1170.4 section 8, T-bar Ceilings, Dynamic Testing, New Royal Adelaide Hospital

Introduction

There have been a number of major earthquakes around the world in recent years including the 1989 Loma Prieta Earthquake, the 1994 Northridge Earthquake both in the USA, the 1995 Kobe Earthquake in Japan and the 2011 earthquake in Christchurch in NZ. All these earthquakes have shown that suspended T-bar ceilings systems are extremely vulnerable in significant earthquakes interacting with the sprinkler systems, light fittings and the like and collapsing and falling to the floor and severely hindering egress.

Failures have occurred in T-bar ceilings under earthquakes actions because they are of lightweight construction with many individual components, often with poor connections and they are not robust systems.

Dynamic testing of ceilings systems using shake table tests has been carried out for about the past 10 years in the USA. In high seismic risk areas such as California, only dynamic testing together with static testing and provision of fixings and connection details, is acceptable for the design of suspended T-bar ceilings.[1]

This paper describes the process adopted for the seismic design of the suspended T-bar ceilings for the new Royal Adelaide Hospital. It also presents recommendations for the complete rewriting of the Australian and New Zealand Standard AS/NZS 2785 [2] for the design of ceilings, to provide designers and the construction industry with the necessary information to design ceilings for seismic loads.

In order to understand what was required to design the suspended T-bar ceilings for seismic loads for the new Royal Adelaide Hospital, the following activities were undertaken.

- A review of design of suspended ceilings overseas, particularly in the USA
- Static testing at the University of Adelaide of various T-bar ceiling components
- Dynamic testing of the proposed ceiling systems (three different ceiling systems were tested) at Buffalo University in the USA
- Further structural design with limited periodic inspections on site

Background to design of buildings for seismic loads

For commercial buildings in Australia, the Building Code of Australia (BCA) sets out the regulatory requirements for the design of commercial buildings in Australia. There are two approaches allowable for design being either the deemed-to-satisfy solutions (DTS) or alternative solutions which need to be justified by experts or other approved means.

The DTS method is commonly used, and it involves design in accordance with the relevant Australian Standards, e.g. for actions (loads) to AS/NZS 1170. That approach has been adopted on the new Royal Adelaide Hospital for the earthquake design of the T-bar ceilings. However, it could be argued the ceiling supplier has complied with the alternative solution with the dynamic testing of the proposed T-bar ceiling system in the USA.

It is a mandatory requirement of AS 1170.4 [3] through the BCA, that all suspended ceilings be designed for earthquake actions. However based on current practices in

Australia, the design of T-bar ceilings for seismic loads are largely ignored, because it is all too difficult and there is insufficient information available on how to carry out such design and detailing for seismic actions.

Post disaster buildings in Australia require the application of design requirements that are more stringent or with additional considerations and design criteria, such as was adopted for the new Royal Adelaide Hospital.

There is another design dilemma as the architect or the building designer is responsible for designing and specifying the suspended ceilings in a building and the structural engineer for the building will not be involved in the ceilings, even though they are the ones with the design knowledge. Generally, this design responsibility is either the builder/contractor, the ceiling supplier or the ceiling subcontractor/installer for the project. Experience is that the ceiling subcontractors/installer practically cannot provide this advice and nor do they have the experience or design skills, so the ceiling supplier will have to provide this information. Most ceiling suppliers will struggle with the design requirements for seismic actions as they are not structural engineers. As a result, this statutory requirement is generally ignored except on larger projects including importance level 4 buildings where sufficient pressure can be brought to bear on the supplier of the ceiling systems to rectify this requirement.

A most unsatisfactory situation all round.

While Australia is not as great a seismic risk as countries such as New Zealand or parts of the USA, there have had significant earthquakes in Australia such as Meckering in 1968 and Newcastle in 1989 and failures of suspended ceilings occurred in the latter earthquake, based on observations by the writer.

The general aim of the earthquake standard AS 1170.4 is to prevent collapse, but not to prevent damage. For suspended ceilings, this is assumed to prevent them from falling on the occupants causing injury and hindering egress from the building. There have been too many examples of ceiling failures in earthquakes both overseas and in Australia, to ignore the need for the design of ceilings for earthquake actions and it is time we got this right. In the case of the new Royal Adelaide Hospital, it was a requirement that the T-bar ceilings withstand a typical 1:500 year event without any failure and a major 1:1000 year event without collapse but some damage acceptable.

In addition, it is vital to ensure that the failure of a vertical hanger for a suspended ceiling does not lead to a progressive collapse. T-bar ceilings are typically supported at a 1.2 m grid. Testing of hangers and their fixings into the structure above should be carried out prior to use to provide design values for the chosen hanger and fixing. In many cases shot fired fixings are not allowed for safety reasons and are not adequate into cracked concrete and therefore only pre-drilled fixings approved for cracked concrete are recommended.

For importance level 4 buildings, such as the New Royal Adelaide Hospital, parts and component including T-bar ceilings were required to be designed in accordance with the general method given in Clause 8.2 of AS 1170.4 involving floor accelerations. This approach gives reduced value for earthquake loads compared to the simplified method, as it is a more refined design approach.

Review of earthquake design of T-bar ceilings in the USA

To provide background on how suspended T-bar ceilings were designed in the USA, J Woodside Consulting (JWC) carried out a desktop survey to establish what criteria has been adopted in the United States in recent years for suspended T-bar ceiling design. We also discussed the design of suspended T-bar ceilings with Professor Andrew Whittaker, who was subsequently engaged to provide us with further advice for the NRAH project.

The general consensus is that the following matters must be considered in the design of any T-bar ceilings in medium to high seismic risk areas.

- The ceiling must be braced to the structural floor ceiling above so to synchronise the ceiling movements with the movements of the building.
- Heavy light fittings supported by the ceiling should be supported to the structure above to prevent falling into occupied spaces. Even with lighter weight, light fittings some slack wires should be used to connect to the structure above in the event of any local failure of the ceiling
- Only intermediate or heavy duty T-bar systems should be used in ceilings in areas of high seismic design
- Perimeter support wires are required to prevent the grid ends of the T-bar from falling from the perimeter closures and causing damage to ceiling framing
- A minimum strength is required for both main T-bars and cross T-bar connections
- The grid ends at the perimeters of the ceiling need to be tied together to prevent loss of ceiling tiles

From 2012 in the USA, there has been a significant change in the process for the seismic design for suspended ceilings. [4]

The design of suspended ceilings for the USA are set out in the International Building Code (IBC) [5], which in turn reference the loading standard ASCE 7-10 [6]. Further additional guidelines are then set out in ASTM E580 [7], which are referenced in ASCE 7-10 and these set out the design and detailing requirements for ceilings under seismic actions.

The USA has adopted the following design approach for the design of ceilings.

- The design of the building is in accordance with the International Building Code IBC and the design loads are in accordance with ASCE 7-10

- The design loads for earthquake are determined in accordance with the loading code ASCE 7 – 10 [3] which in turn refers to detailing in ASTM E 580

- The detailing of ceilings shall comply with ASTM E580

A similar approach is required in Australia and the first two parts of the design approach are already in place and it is a matter of getting AS/NZS 2785 upgraded similar to the requirements of ASTM E580, suitable for Australian and New Zealand conditions.

In our discussions with Prof Andrew Whittaker, Professor and Chair in the Department of Civil, Structural and Environmental Engineering at the University at Buffalo and a licensed Structural Engineer in the State of California, he advised, “*The University at Buffalo has done a lot of work on the seismic response of ceiling systems. Nowadays, all ceiling systems used in California must be seismically qualified to stringent standards. Earthquake simulators are used for this purpose. Qualification by analysis is not accepted to my knowledge because the seismic response of ceiling systems is highly nonlinear.* ”

Installation Requirements for Suspended Ceilings

While some minor damage to the ceiling can be expected under seismic actions, the following are the main requirements for designing suspended T-bar ceilings for earthquake actions without collapse. We suggest minor damage as some local buckling or bending of the T-bar system or local damage to the tiles particularly at the edges or the falling of debris which accumulates in ceilings over the years. Significant damage would be the collapse of ceiling system, the dropping of a large number tiles to the floor below or the falling of services such as light fittings supported by the ceilings to the floor below.

Therefore, the design of the suspended T-bar ceilings must meet the following general principles.

- To provide a suspension system strong enough to resist lateral forces imposed upon it without failing
- to prevent border panels in a T-bar system from falling from the ceiling
- To prevent light fittings and the like supported by the ceiling from falling to the floor below

The Design of Suspended Ceilings in Australia to AS/NZS 2785

The design of suspended ceilings in Australia and New Zealand is currently covered by AS/NZS 2785:2000 which is 14 years old, badly out of date, has incorrect load factors and is totally inadequate for both Australia and New Zealand in its present form. For some reason, Standards Australia does not seem to want to rewrite the standard, which is a really major design issue both in Australia and New Zealand and despite the author’s attempts to try and get them to rewrite the document.

The Standard states, *"The standard sets out the minimum requirements for the design, construction, installation, maintenance and testing of internal and external non-trafficable suspended ceiling systems of dry construction with a suspension system attached to a supporting structure. It is intended to be used for commercial, industrial and residential applications."*

AS/NZS 2785 requires the horizontal and vertical actions shall be considered in the earthquake design of ceilings in accordance with the Standard as specified in Clause 3.2.1 using the earthquake mass of the ceiling as assessed. Unfortunately, the Standard does not provide any detailed advice on how these earthquake actions are to be resisted or any specific detailing requirements.

ASTM E580/M

Because the Australian Standard for ceilings was entirely inadequate for the design for the NRAH, we then referred to the American Standard ASTM E580/M as this represents current practice in the USA. This document covers the installation of suspended systems for acoustical tile and lay-in panels and their additional requirements for two groups of buildings that are constructed to resist the effects of earthquake motions as defined by ASCE 7-10 and the International Building Code. These groupings are for Seismic Design Category C (light to moderate risk) and Seismic Design Categories D, E and F (high risk areas).

The Proposed Method for the Design of Suspended Ceilings for Earthquake Actions in Australia

As there is insufficient information for the design of ceilings for earthquake loads in Australia, other than the general requirements as set out in section 8 of AS 1170.4 and the vague requirements AS/NZS 2785, we adopted the following principles as set out in ASTM 580 for the NRAH for the design and detailing of the ceilings.

With the low to moderate seismicity in Australia, most ceilings requiring seismic design would be similar to design category B or C as used in USA where the ceiling is not braced, and the ceiling is allowed to move laterally under seismic loads but has to meet minimum standards. However, where the earthquake design requires the ceiling to be braced, or the building has a post-disaster function such as the new Royal Adelaide Hospital, then it would be similar to category D as used in the USA. In the case of New Zealand it is likely to be categories D, E and F.

Category D installation requirements include the following requirements:

- The ceiling is generally braced and the T-bar sections should have an ultimate capacity of at least 80 kilograms or twice the calculated ultimate load, whichever is the greater
- A minimum of 50 mm wide wall moulding should be provided at walls where the ceiling abuts the wall. (a 35mm wide wall moulding was adopted for the new Royal Adelaide hospital)
- The grid must be attached to 2 adjacent walls, and the opposite walls must have a 20 mm clearance
- Ends of main T beams and cross T beams must be tied together to stop them from spreading apart
- Heavy duty grid system should be used
- Ceiling areas over 95 m² in area should have horizontal restraint wires or rigid bracing
- Ceiling areas over 230 m² should have seismic separation joints or full height partitions to break up the ceiling
- Ceilings without rigid bracing must have 50 mm oversized trim rings around sprinklers and other penetrations which are not fixed to the ceiling grid
- Changes in the ceiling plane must have positive bracing
- Ductwork, cable trays, pipework and electrical conduits and the like must be independently supported and braced from the ceiling system
- Suspended ceiling should be subject to a special inspection by the builder and the certifying engineer
- Perimeter support wires provided to the T-bar

- Individual items such as light fittings, air-conditioning ducts etc should have not less than two 2 mm hanger wires at diagonal corners of the fixture and where such fixtures exceed 30 kg in weight, then they should be independently supported above the ceiling
- The ceiling system must not provide lateral support to walls and partitions. Walls and partitions may be attached to the ceiling provided they allow the ceiling to move laterally and the wall or partition is braced to the structure over and this bracing should be independent of any ceiling bracing
- At the perimeter of the ceiling, grid members should rest on the edge moulding and provide at least 6 mm clearance and the perimeter ends of cross runners and main runners should be independently supported within 200 mm of wall
- Provision of bracing points at a maximum of 3.6 m centres in both directions to the main T-bar runners with the first bracing point being 1.8 m from any edge. (Bracing at 9 m grid was adopted for the NRAH, based on the dynamic testing)
- Bracing should consist of wire bracing clusters of four wires with at least 2 mm diameter wires attached to the main T beams within 50 mm of the intersection with cross Tees. Wires should be spread at 90° from each other at an angle not exceeding 45° in the plane of the ceiling and attach adequately to the structure over. Alternatively tension / compression members in two planes at right angles could be used
- A vertical strut of adequate stiffness to resist the vertical loads should be attached at the suspension system to the structure above each bracing point, where required
- Bracing members should be spaced at a minimum of 150 mm from all horizontal piping or ductwork
- All light fittings should be positively fixed to the suspension system

The general principles noted above are shown in Figure 1 below.

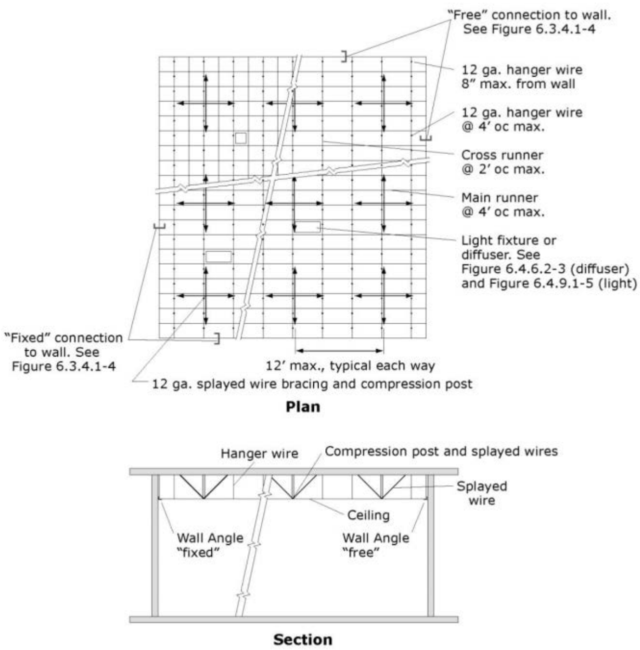

Figure 1 Plan and section of a typical T-bar ceiling system

Static testing Adelaide

In order to provide initial design information, limited static testing of the connections of the T-bar ceiling system was carried out at Adelaide University under the guidance of Professor Mike Griffith. This was a valuable exercise as certain fixings were considered not to be adequate and were strengthened as a result of this testing.

Earthquake Simulator USA

Because of the difficulty in designing ceilings for seismic loads, it was decided that the proposed Studform ceiling system for the new Royal Adelaide hospital be dynamically tested.

The qualification procedure adopted was the ICC-ES-AC156, "*Acceptance Criteria for Seismic Qualification by Shake-Table Testing of Nonstructural Components and Systems*" (ICC, 2010) as used in the USA.

The Kwikloc ceiling systems were provided and installed by Studform and were subjected to different levels of earthquake shaking for the purpose of seismic qualification. The experimental studies were performed in the Structural Engineering and Earthquake Simulation Laboratory (SEESL) of the University at Buffalo (State University of New York) using a six degree-of-freedom earthquake simulator and a test frame with dynamic properties that simulate a floor bay and a story of a laterally stiff building. The ceiling systems tested in this program was constructed with lay-in tiles and a suspension system, and was subjected to a set of combined horizontal and vertical earthquake excitations, in February 2013. Testing covered both Australian, New Zealand and USA requirements.

In addition and based on the requirements of the New Zealand Standard on earthquake loads (NZS 1170.5, 2004 [8]), the ceiling system was subjected to a series of tests with higher vertical shaking than that required by ICC-ES-AC156. The intensity of the earthquake shaking was characterized by the maximum earthquake short period spectral acceleration, as defined in the International Building Code (IBC, 2012) (USA). The target values ranged between 0.25 g and 3.00 g.

While we were unable to be present at the testing, we have seen videos of various tests and have also reviewed the reports prepared by the University of Buffalo on the testing.

The dynamic testing has clearly shown the Studform ceiling systems did not only comply with the requirements for the specification for the new Royal Adelaide hospital but exceeded those requirements in providing an exceptionally robust and appropriate ceiling system for use in the hospital and meeting best practice.

Conclusions

This paper shows a suggested approach that can be adopted for the design of ceilings in Australia and New Zealand for seismic loads. It is imperative that AS/NZS 2785:2000 is updated to provide designers with the required information for the design and detailing of suspended ceilings for both Australia and New Zealand and to overcome the problem of ceilings in Australia not been correctly designed in accordance with the BCA.

References

[1] *California require component tests to establish capacities of T-bar grid, splice & connectors (to perimeter, etc.) to satisfy ASTM C635 (/E580/ICC-ES AC 368) , assembly test using ICC-ES AC 156 with a minimum of two (2) tests with at least 4-psf loads and an OSHPD Preapproval of Manufacturer's Certification (OPM), which covers everything from T-bar grids (supports) to attachments to structure*
[2] *AS/NZS 2785:2000, Standard Australia, Suspended ceilings— Design and installation*
[3] *AS 1170.4—2007, Standards Australia, Structural design actions Part 4: Earthquake actions in Australia*
4 New Seismic Requirements for Suspended Ceilings, Dennis Alvarez, Structures Congress 2010, ASCE
[5] *The International Building Code (IBC) is a model building code developed by the International Code Council (ICC) for the USA.*
[6] *ASCE 7-10, American Society of Civil Engineers, Minimum Design Loads for Buildings and Other Structures*
[7] *ASTM E580/M, American Society for Testing and Materials, Standard Practice for Installation of Ceiling Suspension Systems for Acoustical Tile and Lay-in Panels in Areas Subject to Earthquake Ground Motions*
[8]*AS 1170.5—2004, Standards Australia, Structural design actions Part 5: Earthquake actions - New Zealand.*