STRUCTURAL BEHAVIOUR OF SUSPENDED CEILING

Ajay Chourasia
Chief Scientist and Head of Structural Engg. & 3D Concrete Printing Group
CSIR-CBRI, Roorkee

Shubham Singhal
Assistant Professor
Amity School of Engineering and Technology
Amity University, Noida

INTRODUCTION

Recent events have demonstrated that ceiling damage can result in the loss of property and functionality, as well as injury or even death. This can occur at shaking levels that are less than necessary to cause evident structural damage. Although it is widespread in India, there is not sufficient seismic design or efficient installation of many suspended ceilings damaged by earlier earthquakes. The irregularity of the limit status employed in the ceiling design is also a growing concern.

The suspended ceilings are both acceleration and displacement sensitive architectural components. They are classified as perimeter fixed or floating systems depending on the structure and load-bearing system. As shown in Fig. 1, the perimeter-fixed suspended ceiling is attached on every side of the structure around. This setup was later adjusted to be fastened on two sideways while the two other ends on the outer support are free. (Fig. 1) This layout transfers the inertial force created by the ceiling system to perimeter attachments, which make them the most vulnerable components of the system. The floating suspended ceiling as illustrated in Fig. 1(c) is supported by braces to the structure above and is therefore separated from the surrounding construction. The bracing system carries the forces and accelerations from the upper floor.

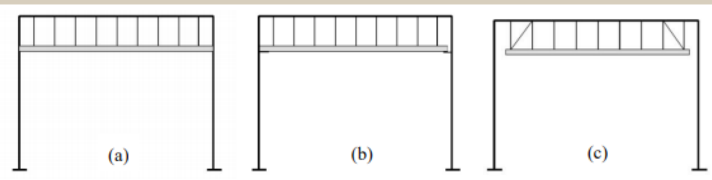

Fig.1: Schematic of a & b) Perimeter fixed and c) Floating suspended ceiling (Pourali, 2014)

The applicability and details of both systems depend on the construction and size of the ceiling as a result of the seismic request. For example, for all suspended ceilings in seismic category D-F, ASTM E580 requires the use of lateral restrictions if the ceiling size exceeds 1000 ft^2 (93 m^2).

"The suspended ceilings are both acceleration and displacement sensitive architectural components."

A common suspended ceiling is a grid system of inverted T-shaped beams that are perpendicular to each other and are made up of square or rectangular grids on which the lay-in panels can be installed. Cross slots are already established in the main tee's webs and are connected via the click-fit connectors to the next cross tee. In the grid system assembly itself, no additional mechanical fasteners are used. At fixed ends, the grid system is joined employing mechanical attachments such as rivets, screws or specific clips to the perimeter angle attachable to the surrounding walls. The tiles are not attached to the grids but are freely placed on the inverted tee flanges.

The company supports society and environment equally to actively pursue a better future both within and outside of the core business area. In addition to the charitable Hilti Foundation, the company's values of integrity, courage, teamwork and commitment are demonstrated every day in its interactions with team members, partners and customers in addition to the charitable Hilti Foundation.

The retainer clips for control upward movement of fittings are recommended by IS 2441: 1984. [9] However, because of installation challenges, these clips are not often used. The grid system is also connected at regular intervals to the upper structure through hanger wires. These vertical wires have no side resistance but their use has helped control the movement of the ceiling system and the damages that arise in the event of earthquakes, especially on perimeters. Four diagonal cables and a vertical strut can be used as a compression station. Instead of wires the diagonal channel or the strut can alternatively be utilized.

According to accounts of damage following earthquakes and especially recent in India, even if the building remains nearly undefeated hanging ceilings are significantly affected by earthquakes. In virtually all cases, the damage is comparable, which might be a good indication for identifying key components. Elements demonstrating significant susceptibility to soil movement excitement include rivet connections at perimeter fixtures, cross-tee connections and main-tees splitting.

Under compression, tees may buckle but mainly when the connections fail or when a perimeter contour is not sufficient, the system loses its integrity. In some cases, the lack of enough perimeter hanger wires and spacer bars causes tees to spread and tiles to fall. The damage also included damage due to different motions of the ceiling compared with the perimeter structure, the interaction with the services of the roofing and mechanical systems, the failure of independent support or heavy fixtures, fire-relief post-earthquake damage, hazardous material leak, etc. Other common forms of damage observe included damage. The combination of smaller ceilings and lighter tiles leads to lower demands for grid connections and connections leading to safer ceilings. [2,3,4]

PREVIOUS STUDIES

In recent decades, seismic research has gained popularity, especially on the performance of non-structural elements and suspended ceilings, following the extensive non-structural damage reported by recent seizures. Some of these studies have been briefly reviewed.

“Under compression, tees may buckle but mainly when the connections fail or when a perimeter contour is not sufficient, the system loses its integrity.”

ANCO Engineers Inc.'s (ANCO 1983) industry tested a prototypical suspended ceiling. It was found that the couplers buckled and detach from the wall angle at wall-deck intersection. The most common damage points in suspended ceiling systems were located at the perimeter of a room. Furthermore, the investigations have shown that installation of the Pop Rivet is more important than sweeping wires and that swaying wires will not be active in lateral retention if installed with a perimeter fixing.

Satwant et al. (1984) studied the effectiveness of the current provisions on building code and installation practices in a series of dynamic tests for suspended braced and unbraced ceilings with and without partitions. The results showed less uplift of specimens with vertical struts. Deep damage has been observed to the ceiling on an unconnected perimeter. The addition of vertical cross-tees suspension wires of 8 inches maximum from an unattached perimeter prevented tiles from collapsing, but the cross-tee pounding caused damage to perimeter angles. The authors evaluated the effect of tile size and weight, the use of retainer clips, the installation of compression posts and the physical status of grid components on the performance of the ceilings during their full-scale earthquake and simulator tests. The damages observed in the systems were assessed in four limit states and accelerations of the threshold peak floor associated with each boundary state were identified.

The experimental process and the performance matrix, based on limited state evaluation and qualifying innovations, were developed for the evaluation and quantitative evaluation of the effectiveness of various code design and installation requirements in a series of studies by Gilani et al. (2012, 2017). [7,8] A study case showing that the intermediate substitution of heavy-duty main-racers does not adversely affect the system's seismic response was also tested for intermediate duty main runners in high seismic regions.

Grid members and their connections were tested in compression and tension in a study done by Paganotti (2011) [11] at the University of Canterbury.

CURRENT DESIGN AND INSTALLATION METHODOLOGY

Structure demand versus ceiling demand

In India, the suspended ceilings are mainly designed for a serviceability-limited State based on current standards in India (IS 2441: 1984) unless they are in buildings of high post-disaster importance such as hospitals and police stations. Recent seismic experiences have shown, however, that suspended ceiling damage can pose a life-threatening and cause significant financial loss. In many cases, suspended ceilings suffered considerable damage when the structure performed satisfactorily. The inevitable substitution then imposes large financial costs on the building owners and disrupts the building's operability, resulting in downtime and cumbersome. The roof has been reported to have been designed without proper accounting for seismic demand, or not properly installed in many buildings that have been evaluated following

> **In India, the suspended ceilings are mainly designed for a serviceability-limited State based on current standards.**

> **Recent seismic experiences have shown, however, that suspended ceiling damage can pose a life-threatening and cause significant financial loss.**

the Canterbury earthquake [2,3] due to a lack of consistent, clear design and installation guidelines for suspended roof systems. Even when the requirements were fully met, the ceilings were damaged because they were not intended to remain intact at this level of shaking.

The hanging ceilings have no high ductility. Hence the loss of SLS - and the loss of integrity and the failure of its originally intended operation, thus threatening occupants - ULS - are rather close. The review and thorough assessment of design and installations in New Zealand, therefore, appears to be inevitable and highly useful in the prevention of future losses.

Review of standards

Indian suspended ceiling standard [9] lays down the minimum requirements for internal and outside suspended ceilings for use in commercial, industrial and domestic buildings for design, construction, installation, maintenance and testing. The standard includes design loads, limits and installation guidelines. The recommendations, however, are primarily qualitative rather than quantitative. The users are often referred to the specifications of the private manufacturer. More quantitative guidelines for seismical design and installation of suspended ceilings are also provided by other standards such as ASTM C635, C636, and E580, ASCE 7-05, FEMA, and CISCA. [1,5,6] For example, CISCA offers 45-degree socket bracing wires to be mounted in each direction at 4 m from center to center in seismic areas 3 and 4.

These wires are designed to provide the horizontal part of the earthquake force with resistance. Additionally, hanging wires are necessary for all runners on the walls to decrease ceiling perimeter damage within 20 cm of a wall. The ASTM E580 [1] stipulates the installation of suspended ceilings in the seismic category C areas as well as the D-F categories that include tee capacity, correct hanger wires spacing, clearing of wall grid components, sized and type of perimeter support contour-specified or free-etc.

SEISMIC BEHAVIOUR OF CEILING

The damage to the ceilings during the Northridge earthquake of 1994 was one of the most predominant damage. It was observed that the ceiling damage was more extensive near the top of building than at lower stories with failure of lighting, diffusers and suspended ceiling system. In 2010, Chile earthquake, the airport in Santiago was shut down for several weeks as most of the ceiling tiles collapsed and many of the supporting elements also collapsed.

Even in 2010, Haiti earthquake schools were closed because of damaged ceilings and collapse of air conditioning equipment. During 2011 Japan earthquake, very wide scale damage to suspended ceilings in large rooms like swimming pools, auditoriums, etc. were observed. (Fig. 2)

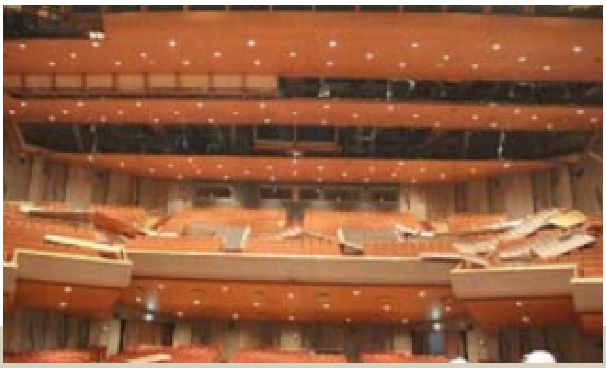

Fig. 2: Damaged ceiling at auditorium [10]

The ceiling boards at the gymnasium of a junior high school and swimming pool in Tochigi prefecture collapsed mainly because of the failure at the joints. It was observed that very long suspension length of ceiling usually used in auditoriums, make the ceiling system rather unstable and often cause failure of the ceiling.

Very heavy panels for the acoustics of ceiling may also cause early collapse of the system due to increased forces as shown in Fig. 3.

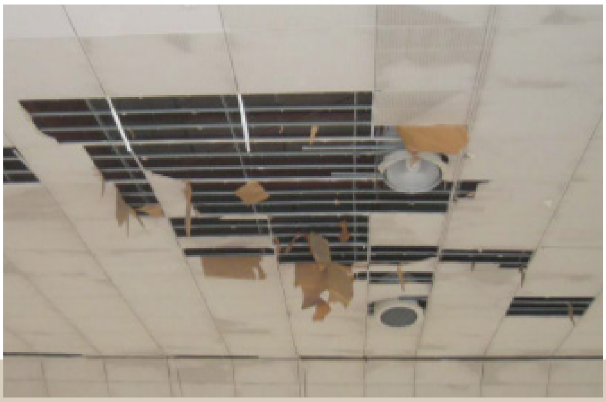

Fig. 3: Damaged ceiling in school gymnasium [10]

GAPS AND ISSUES

If completely complied with, the current design rules can adequately fulfil the demands for serviceability. However, the suspended ceilings cannot work adequately even when the structure suffers from little damage if the proposed system is subjected to a more severe earthquake. With substantial advances to date in the design and satisfactory seismic performance of structural components, the design of non-structural components has recently acquired increased importance. This sort of non-structural damage could put the lives of the inhabitants at risk, harm crucial and vital contents and installations or just temporarily render areas unusable. Big facilities, such as gyms and auditoriums, are important for the provision of shelter and refuge services in significant earthquakes where damages are extensive. Consequently, it is very important to operate immediately and continuously in these spaces. On the other hand, it is very difficult to ensure the safety and evaluate the quality of the systems sold on the market until there is a uniform conformity standard to identify the boundaries and the borders explicitly. Less well-known producers who may not necessarily and fully comply with the international codes could deliver suspended ceilings. Furthermore, the availability of a standard rule ensures that all companies compete on fair terms. The design and installation procedures must be coordinated to achieve a consistent level of quality and safety.

CONCLUSION

Damage to suspended ceilings has resulted in significant economic loss in the recent earthquakes, one of the most widely employed non-structural elements. In recent years, this observation has focused a lot on seismic performance and design research programs. This study examines briefly the relevant studies, recommendations, and standards concerning the design and installation of suspended ceilings. It can be concluded that the current systems should function satisfactorily under the seismic level of serviceability, if correctly implemented and installed. However, key components may achieve capacity that leads to system failure in case of greater excitations. Given the relevance of ceilings for continuous operation and structural safety, reconsiderations of specified limit statements in the code seem unavoidable for the design of suspended ceilings. The first results and the assessment of the existing codes illustrate the criticality of the problem and the need for further comprehensive, focused research in this field.

> **"However, key components may achieve capacity that leads to system failure in case of greater excitations."**

REFERENCES

1. ASTM–E580/E580M. "Standard Practice for Installation of Ceiling Suspension Systems for Acoustical Tile and Lay-In Panels in Areas Subject to Earthquake Ground Motions." (2014)
2. Dhakal, R., MacRae, G.A. and Hogg, K., 2011. Performance of ceilings in the February 2011 Christchurch earthquake.
3. Dhakal, R.P., 2010. Damage to non-structural components and contents in 2010 Darfield earthquake. Bulletin of the New Zealand Society for Earthquake Engineering, 43 (4), pp. 404-411.
4. Dhakal, R.P., MacRae, G.A., Pourali, A. and Paganotti, G., 2016. Seismic fragility of suspended ceiling systems used in NZ based on component tests. Bulletin of the New Zealand Society for Earthquake Engineering, 49 (1), pp. 45-63.
5. General, A., Comply with ASTM C635, as applicable to the type of suspension system required for the type of ceiling units indicated. Coordinate with other work supported by or penetrating through the ceilings, including but not limited to light fixtures, HVAC equipment and partition systems.
6. General, A., Complying with ASTM C635. ASTM C636, ASTM C, 645, pp. 09260-2.
7. Gilani, A.S., Takhirov, S.M. and Tedesco, L., 2012, September. Seismic evaluation procedure for suspended ceilings and components, new experimental approach. In Proceedings of the 15th World Conference on Earthquake Engineering. Lisbon, Portugal: WCEE (Vol. 326).
8. Gilani, Sara, and William O'Brien. "Review of current methods, opportunities, and challenges for in-situ monitoring to support occupant modelling in office spaces." Journal of building performance simulation 10, no. 5-6 (2017): 444-470.
9. IS 2441:1984. "Code of practice for fixing ceiling covering." (2014).
10. Kawaguchi, K.I., Damage to non-structural components in large rooms by the Japan earthquake, March 11th, 2011.
11. Paganotti, G., MacRae, G.A. and Dhakal, R.P., 2011, April. Development of typical NZ ceiling system seismic fragilities. In Ninth Pacific Conference on Earthquake Engineering (PCEE) (pp. 14-16).
12. Pourali, Atefeh, Rajesh P. Dhakal, Gregory MacRae, and Ali Sahin Tasligedik. "Fully floating suspended ceiling system: experimental evaluation of structural feasibility and challenges." Earthquake Spectra 33, no. 4 (2017): 1627-1654.
13. Satwant, S.R. and Granneman, G., 1984. Experimental Investigation of the Dynamic Behavior of Building Partitions and Spended Ceilings during Earthquakes. In 8th World Conference on Earthquake Engineering (Vol. 5, pp. 1135-1142).