EXPERIMENTAL EVALUATION OF THE INFLUENCE OF SEISMIC CLIPS ON GRID JOINTS IN A SUSPENDED CEILING SYSTEM

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Abstract

Suspended ceiling failure is frequently reported as a cause of financial loss following earthquakes. In typical suspended ceilings, the seismic inertial force flows from the tiles to the transverse grid members (i.e. cross tees) to the longitudinal grid members (i.e. the main tees) to the buildings through the perimeter supports. Hence, the ceiling system is only as strong as the weakest of the load path components. Experimental tests of different suspended ceiling components have identified the grid connections and rivet fixtures as the weakest components. Following these findings, the study reported herein aims at experimentally investigating the possibility of strengthening the connection between cross tees and main tees in suspended ceilings through the addition of a seismic clip. Different failure mechanisms were identified in the monotonic experiments. The tensile and compressive capacities of the grid joint with and without seismic clips in each failure mode were quantified and comparisons were made between the as-built and strengthened connections. The results showed an improvement in the load bearing capacity of the joints under monotonic tension and compression loading. The seismic clip also increased the deformability of the joint while it still carried reasonable amount of axial load.

Introduction

Perimeter-fixed suspended ceilings commonly used in commercial and educational buildings in New Zealand (NZ) consist of a grid system and lay-in acoustic tiles. The grid/suspension system consists of main tees (MTs) and cross tees (CTs) forming frame modules that support the tiles. The CT and MT ends are either fixed on perimeters via rivets or the suspension system is back braced to the upper floor. Unsatisfactory performance of such ceilings during earthquakes has raised concerns in the past (Dhakal 2010, Dhakal et al. 2011). Failure of ceilings results in costly and time consuming repairs and replacements. Damage to services and engineering systems within the ceiling plenum space can be critical and negatively affect the serviceability and performance of buildings. Identifying the performance issues and damage states in suspended ceilings has been the subject of many recent studies (ANCO 1983, Badillo-Almaraz et al. 2007, Paganotti 2010, Ryu et al. 2013, Soroushian et al. 2014, Pourali et al. 2015 & 2016). Reports are available in literature on shake table tests of full sized suspended ceilings (Badillo-Almaraz et al. 2007, Ryu et al. 2013, Pourali et al. 2015) and investigation of the capacity of individual ceiling components under monotonic and cyclic loads (Paganotti 2010, Soroushian et al. 2014, Pourali et al. 2016). Guidelines and recommendations for seismic design and installation of suspended ceilings have also been produced (AS/NZS 2785:2000, CISCA 2004, NZS 1170.5:2004, ASTM 2011, USG 2012, Armstrong 2013), and fragility curves for ceiling systems and components have also been developed (Badillo-Almaraz et al. 2007, Ryu et al. 2013). These provide valuable information for the industry in terms of the capacity and shortcomings of suspended ceiling systems. However, gaps still remain in the areas of retrofitting existing ceilings or developing more resilient ceiling systems.

According to capacity design principles, a ceiling system’s strength is defined by its weakest load-bearing component. Researchers (Badillo-Almaraz et al. 2007, Paganotti 2010, Ryu et al. 2013, Pourali et al. 2016) have identified that the weakest components of suspended ceiling system are the CT-MT connections and rivet fixtures around the perimeters of the ceiling grid. The rivets can be strengthened by increasing their size. However, the CT-MT connection still remains the weakest element contributing to ceiling system failure.

The primary goal of the experiments reported in this paper is to investigate the effectiveness of a proposed suspended ceiling CT-MT joint strengthening solution. Monotonic tension and compression tests are conducted on two configurations of CT-MT joints; the connection as built in practice and the connection strengthened with a cross-shaped seismic clip. The experiments aim to quantify the load bearing capacity of each connection configuration and provide qualitative endorsement of the proposed strengthening solution.

Description of Experimental Program

Test Specimen. Commonly available standard CT and MT sections in NZ were selected for testing (USG 2012 and USG 2011) that were also consistent with previous experiments conducted at the University of Canterbury (Paganotti 2010, Pourali et al. 2016). The seismic clips for strengthening the connection point is a proprietary product provided as a 4-way seismic separation joint (Figure 1a). Details of the sections and components used are provided in Table 1.

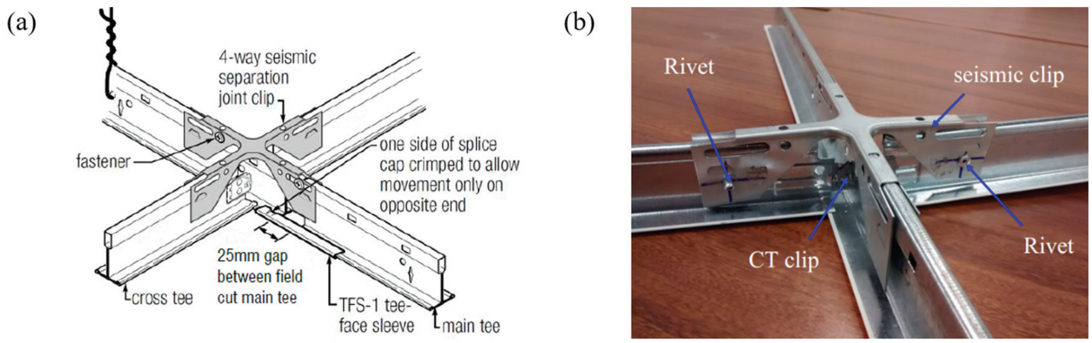
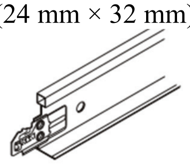
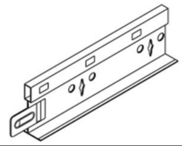
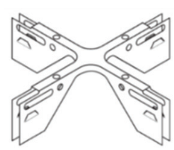


Figure 1. (a) DH4 seismic clip as seismic joint; (b) CT-MT connection specimen with seismic clip and 2 rivets on CTs.

Table 1. Details of Components used in Tests

CT Section	*MT Section*	*Seismic Clip*	*Rivet*
DX30M-1200 (24 mm × 32 mm) 	DX38D-3600 (24 mm × 38 mm) 	DH4 	1/8” or 3.2 mm AA 4-4 

The cross-shaped specimens consisted of one horizontal MT and two vertical CTs that passed and connected through a MT slot. The MT length was such that specimens could fit in the test machine. Each CT was 300 mm long, making the CT part altogether 600 mm long. The cut ends of the CTs were flattened by pressure and screwed to the loading arms of the test machine. Two configurations of specimens were tested experimentally. The first consisted of MT and CTs, while the second used a seismic clip pushed in place on top of the CT-MT joints, fastened to CTs via two 3.2 mm Aluminium rivets (Figure 1b). The rivet on each wing was placed 10 mm from the clip edges.

Test Setup. An Instron Universal Testing machine was used for tension and compression loading with strain control. The tension or compression forces and displacements applied were measured through a load cell and a potentiometer installed on the upper arm of the machine (Figure 2a).

The test setup in the tensile tests consisted of the cross-shaped specimens and measurement instruments. The seismic clip maintained orthogonality between CTs and MT. In specimens without seismic clips, elastic strings were used to straighten up the MT without interfering with the load path. In compression tests, boundary conditions were introduced via additional components in the test setup in order to simulate the effect of ceiling tiles (Figure 2b). The rig consisted of a timber panel and eight 50 mm × 50 mm × 5 mm angles. The angles were screwed to the timber panel 4 mm from the edge of the grids to allow for limited in-plane buckling. The MT piece was held horizontal to represent the effect of tiles, however small lateral displacements were allowed, as for real installations tiles are about 5 mm smaller than the module formed by the grids (this difference in size facilitates the installation of tiles in practice).

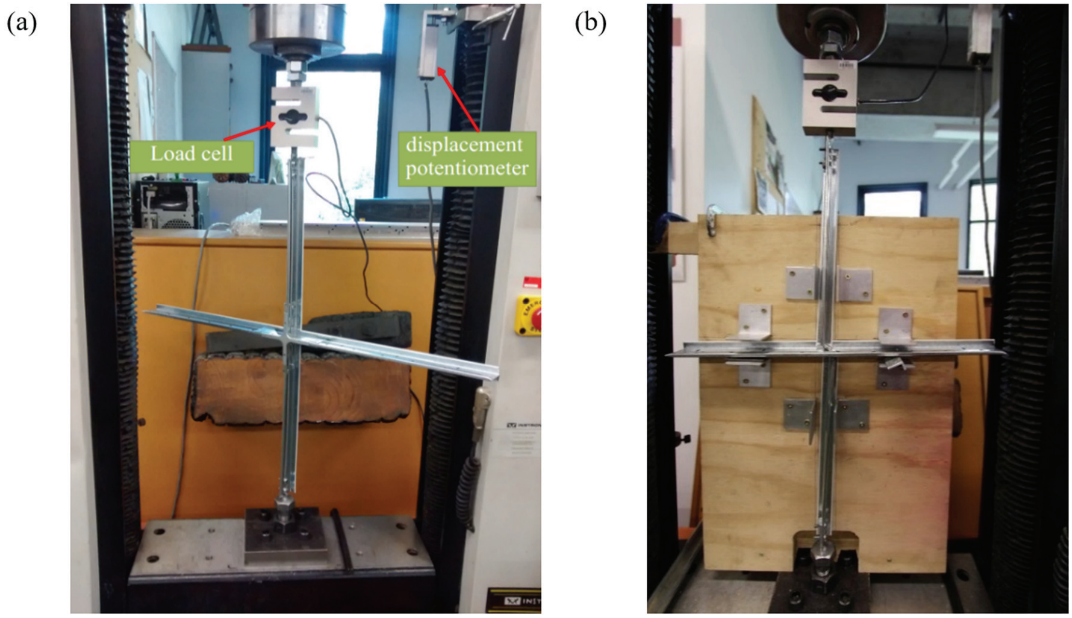


Figure 2. Test setup in (a) tension, and (b) compression tests

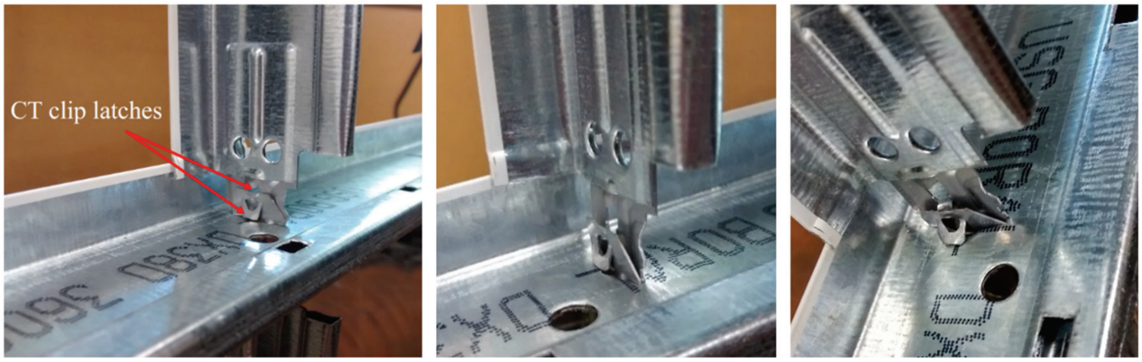
Experimental Program. Four series of ten tests were carried out, with 40 monotonic tests recorded in total, refer Table 2 for details. The loading rate in both tensile and compressive tests was 0.5 mm/min and the tests were continued until either brittle failure or very large deformations occurred at the CT-MT joint.

Table 2. List and Number of Specimens

Test Series Name	***Test Description***	***No.***
CT-MT-T	CT-MT connection in tension	10
CT-MT-C	CT-MT connection in compression	10
CT-MT-CL-T	CT-MT connection with seismic clips in tension	10
CT-MT-CL-C	CT-MT connection with seismic clips in compression.	10

Experimental Results & Observations

Tests under Tension. The CT-MT joint was observed to carry the axial load through an interlocking mechanism as shown in Figure 3. For this mechanism to work to its desired capacity, the CT latches (Figure 3-a) must be fully engaged and the load path needs to be aligned with the joint. Any rotations or small deformations may lead to latches disengaging and with no other mechanical fastening in the joint, they may carry a lower force than expected and easily disconnect under tension.



(a) (b) (c)

Figure 3. Mechanism of failure due to yielding in CT clip with the clip well engaged.

In tension tests without clips two failure mechanisms were observed: i) failure with complete engagement of CT clips (Figure 3-b) (referred to as “TF1”), and ii) failure with premature disengagement of CT clips (referred to as “TF2”). Figure 3b-c show gradual yielding of a CT clip when latches on two connected CTs were engaged. In a less desirable condition, the latches prematurely released allowing the clips to slide past each other. When this occurred only the top and bottom dents in CT latches were observed to pull against the MT slot briefly before the joint disconnected, exposing the ceiling to local failure of grids and panel dislodgement. The premature failure in the CT clip resulted in failure of the joint at almost 30% of its intended capacity (Figure 5).

With seismic clips added during tensile tests the CT-MT joint remained capable of transferring forces and withstanding deformations, despite the disengagement of the CT clip latches. The difference between specimens with good or premature engagement was mainly in the rate of deformation and development of buckling in the joint (Figure 4). Even after premature failure, unlike connections without seismic clip, the joint continued carrying forces (Figure 6). Complete joint failure involved total loss of load bearing capacity, which occurred after relatively large displacements between the disconnected CT clips. The use of seismic clips in this example increased the deformability of the CT-MT joint significantly. The final tensile failure modes with seismic clip were recorded as failure of the lower rivet connecting seismic clips to CT (Figure 4c) or tearing of the CT web at the location of rivet hole (Figure 4b).

(a) (b) (c)

Figure 4. Failure of CT-MT joint with seismic clip in tension.

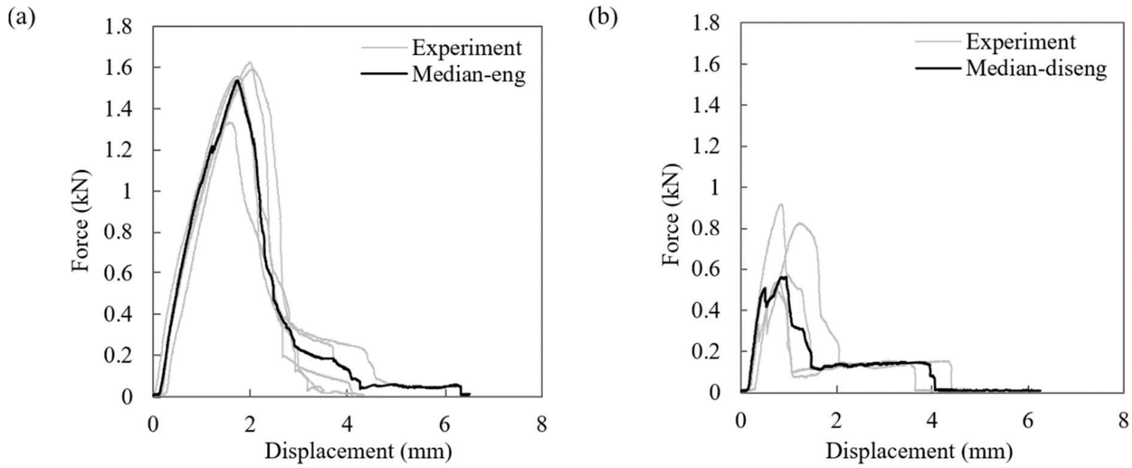


Figure 5. Results of tensile tests on CT-MT joints without seismic clips with (a) complete CT clip engagement and (b) CT clip disengaged.

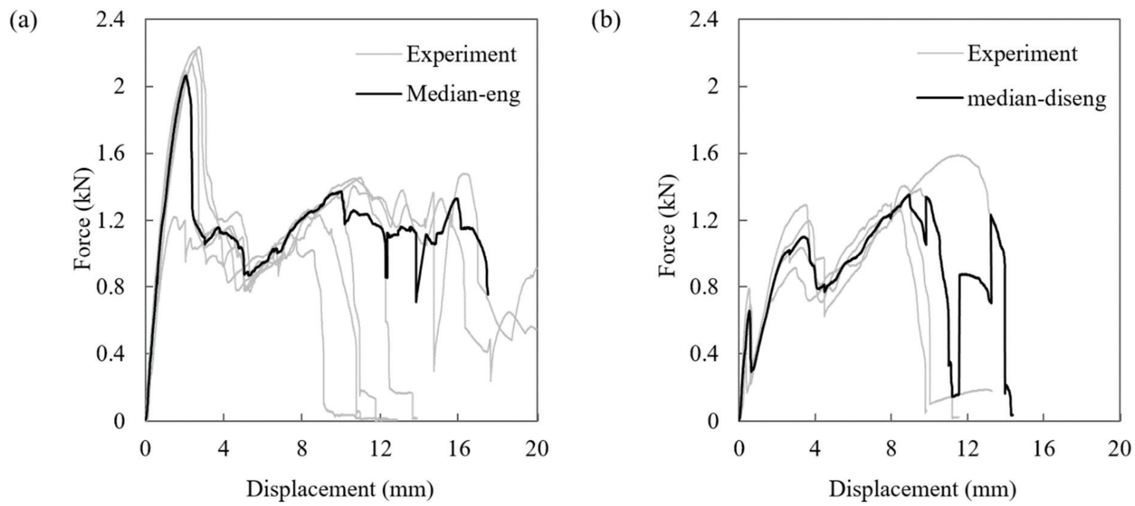


Figure 6. Results of tensile tests on CT-MT joints with seismic clips with (a) complete CT clip engagement and (b) CT clip disengaged.

Comparing the median response curves for the two aforementioned conditions (CT clip engaged and disengaged) from Figure 5 and Figure 6 shows that adding seismic clips increased the load bearing capacity and deformability of the joint in both cases. Nevertheless, the stiffness of the joint was not significantly affected by this change.

Tests under Compression. Compression failure mechanisms of CT-MT joints included in-plane and out-of-plane yielding of CT clips and penetration of CT section into MT web. The majority of specimens without seismic clips first underwent yielding in the CT clip latches. This was quickly followed by lateral buckling of the CT clip (Figure 7a). However, in some cases, CT clips were not engaged in the load path and slid parallel to each other and into the MT slot (Figure 7b), eventually tearing into the MT web (Figure 7c). Unlike tensile tests, the ultimate forces in compression tests were not significantly affected by the engagement of CT latches. This is due to the similarity of load bearing mechanism after the disengagement of the latches.

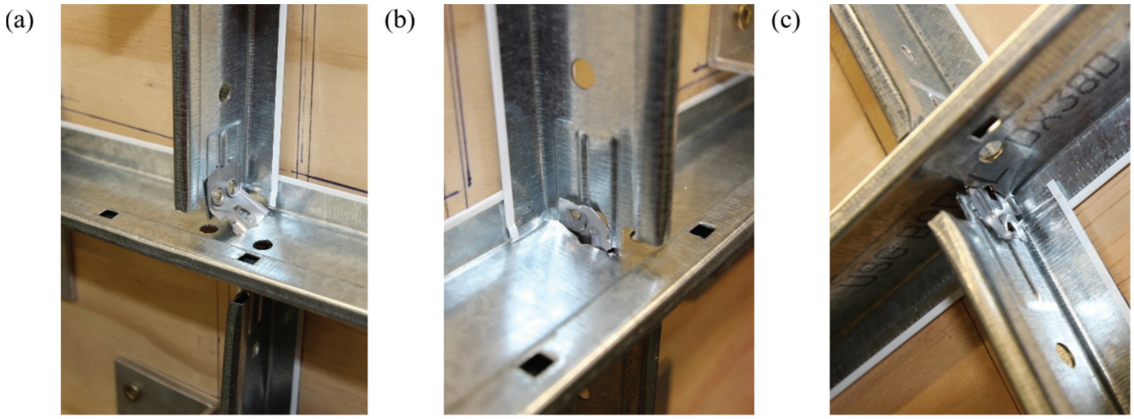


Figure 7. Failure of CT-MT joint in compression.

With the addition of seismic clips, the deformation in the joint area changed to out-of-plane buckling as the seismic clip reduced the sideway deformation of the CT clip (Figure 8b). Here the CT clips bent about their major axis (Figure 8a), and afterwards the CT section pressed to the MT web, and consequently the force-displacement curves did not show a brittle failure as they did under tension (Figure 9). The addition of seismic clips increased the maximum force carried by the joint (Figure 9). This addition had no effect on the stiffness of the CT-MT joint.

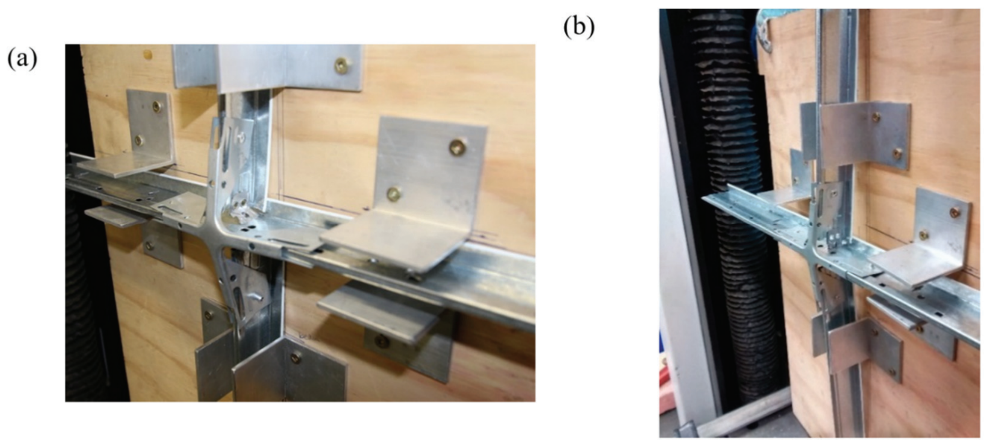


Figure 8. Failure in CT-MT joints with seismic clip: (a) bending in CT clip, and (b) out of plane buckling

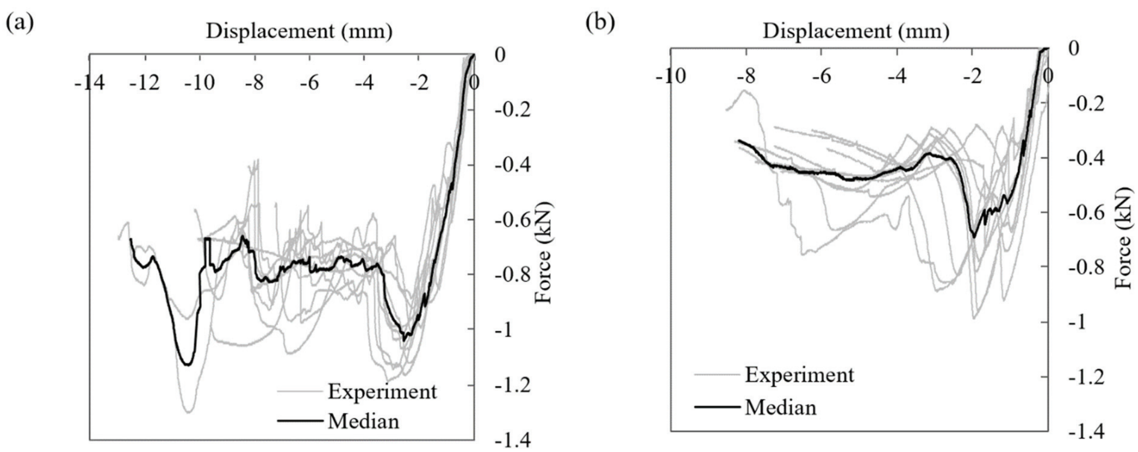


Figure 9. Results of compression tests on CT-MT joints (a) with, and (b) without seismic clips.

Development of Fragility Curves

The fragility curves presented here are based on one damage limit state; The failure force is the maximum joint force carried before brittle failure, with a rapid drop in force or large deformations. Fragility curves for the tested specimens are created using lognormal distributions. Under tension the results showed a larger dispersion than in compression tests (Figure 10) due to the different performance of the joint with regard to the engagement of CT clip in carrying load. Separating the fragility curves in two categories based on the addition of seismic clips (Figure 10) quantified the improvement resulting from the strengthening solution. This improvement was more noticeable in tension tests due to the failure mode and the level of involvement of the seismic clip in load bearing.

To determine the capacity of the entire ceiling system, fragility curves from Figure 10 need to be compared with the fragility curves previously derived for other components of a suspended ceiling e.g. end fixing rivets or MT splices (Figure 11) (Pourali et al. 2016, Paganotti 2010). When making such comparisons, it is important to consider that these results were obtained for standard grids which have a lower capacity than heavy-duty grids (Refer Section 2.1). Based on the comparisons in Figure 11, it is clear that the addition of seismic clips significantly improves the performance in tension, and some improvement can be observed in compression, too. However, Figure 11b emphasises that the strengthening solution needs to be accompanied with improvements in other components such as end fixing rivets.

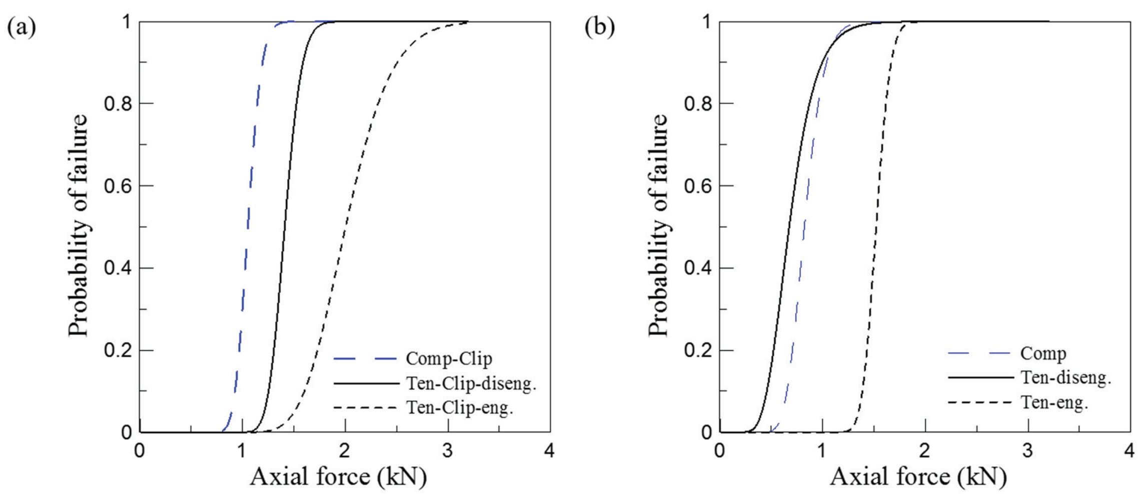


Figure 10. Fragility curves for all CT-MT joint tests (a) with, and (b) without seismic clip.

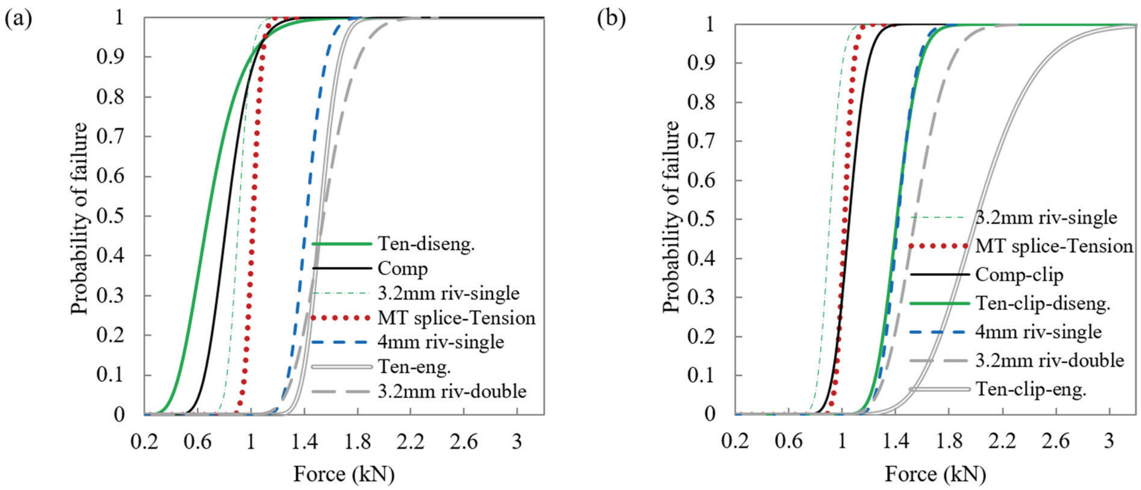


Figure 11. Fragility curves comparing other ceiling components (Paganotti 2010, Pourali et al. 2016) with CT-MT connections (a) without, and (b) with seismic clips.

Conclusions

Monotonic tension and compression tests were carried out on suspended ceiling cross tee-main tee (CT-MT) connection specimens with and without seismic clips. Results showed that using seismic clips improved CT-MT connection performance in two ways: i) increasing the capacity, and ii) adding deformability. During these tests different failure modes were observed in the connection point including disengagement of the CT clip, engagement and yielding of the CT clip, deformation and buckling of the CT clip, and penetration of CT clip into the MT web. When seismic clips were added, initial failure always occurred in the CT clip, followed by larger deformations and bending in the seismic clips. Comparison showed that using seismic clips in all cases increased the failure force in the connection. This improvement however, must be accompanied by strengthening the splices on MTs (e.g. by using a 2-way seismic separation joint clip) and increasing the size or number of end fixing rivets. With these improvements, if seismic clips are added, the system capacity will increase and the failure mode will no longer be brittle. The connection with clip underwent a number of failure and yielding phases while still carrying forces as large as that of the CT-MT connection alone. This ductility in the grid of suspended ceilings can delay the spread of damage and allow for the safe evacuation of occupants while still showing signs of damage.

Acknowledgements

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