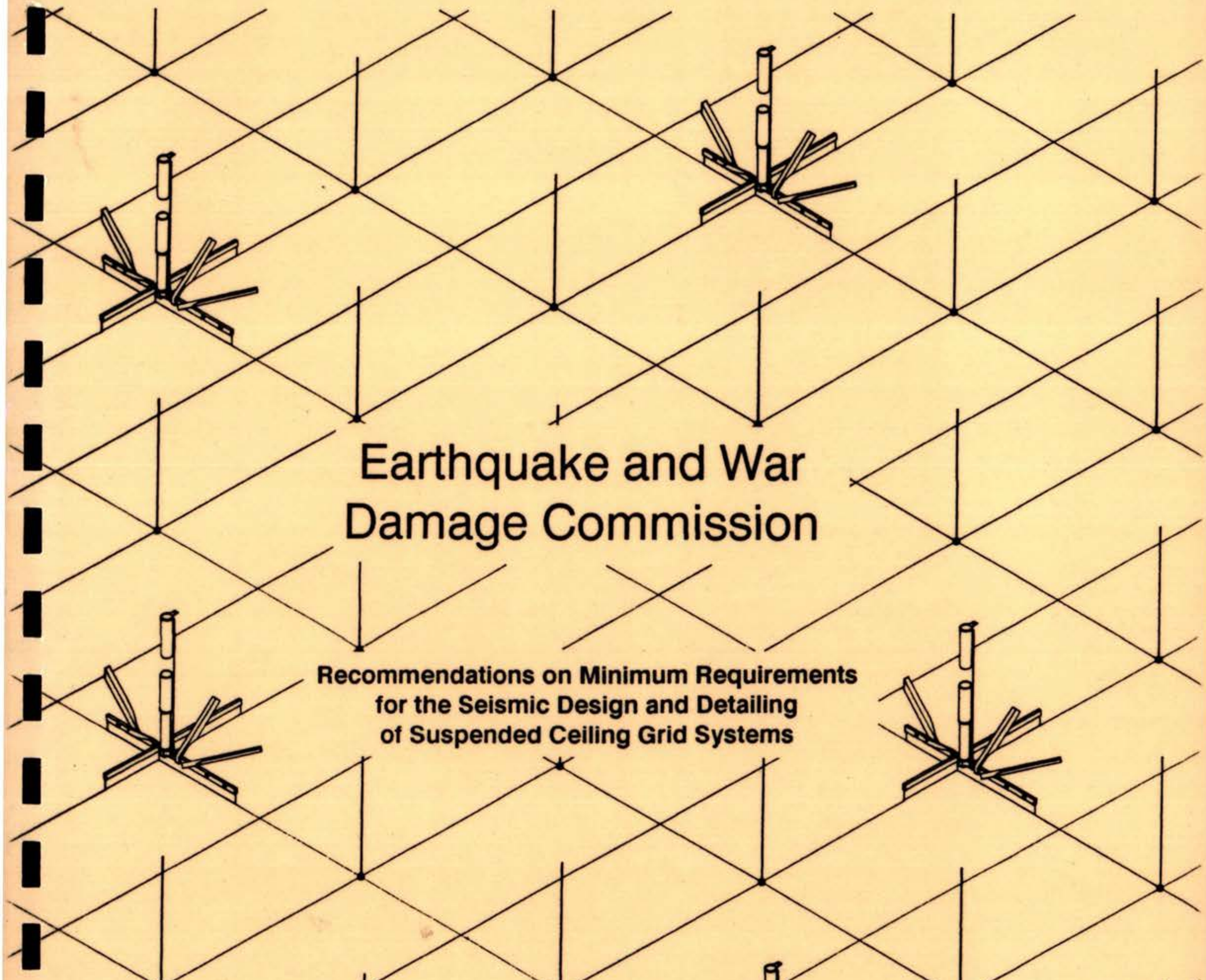
ENG 243-(EQC 1991/46)

Recommendations On Minimum Requirements For The Seismic Design & Detailing Of Suspended Grid Systems

KRTA Ltd



Earthquake and War Damage Commission

Recommendations on Minimum Requirements for the Seismic Design and Detailing of Suspended Ceiling Grid Systems

krta

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USG Interiors Limited
6 Monier Place, Mt. Wellington
PO Box 11-155, Ellerslie Auckland NZ
Telephone (09) 595-601, Fax (09) 596-859, Telex NZ 600166

243

2

Earthquake and War Damage Commission

Recommendations on Minimum Requirements for the Seismic Design and Detailing of Suspended Ceiling Grid Systems

Prepared by

KRTA Limited

Engineers Architects Scientists Planners
Ph. (09) 520 6069 PO Box 9806 Auckland
Ph. (04) 384 7725 PO Box 3582 Wellington NZ

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Also sponsored by

USG Interiors Limited
6 Monier Place, Mt. Wellington
PO Box 11-155, Ellerslie Auckland NZ
Telephone (09) 595-601, Fax (09) 596-859, Telex NZ 600166

Contents

1.0 Introduction

KRTA Limited were commissioned by the Earthquake and War Damage Commission (EQC) to conduct a research project involving a worldwide literature search to gather information on seismic design of suspended ceilings. The project was titled "Recommendations on Minimum Requirements for the Seismic Design and Detailing of Suspended Ceiling Grid Systems". The research was to target four major areas:

(i) To determine the effectiveness, necessity and adequacy of current New Zealand regulations (which appear to be based on dated information);

(ii) To make particular reference to clipping of ceiling tiles, effects of diaphragm action, displacement and its limitations, and the effects of bracing and influence of partitions;

(iii) To present the results of the above research in a manner that would assist designers and specifiers to define the structural aspects of the system where such research is conclusive, and

(iv) To make recommendations to the Earthquake and War Damage Commission on plausible means of implementing suggested modifications to current practice and building controls and/or suggesting what further research will be required.

The international literature search addressed 109 individuals and organisations in 15 different countries. Having received replies from many of these countries it has been possible to extend the scope of the report to include comparisons of Codes and recommendations of both governmental and non-governmental organisations.

The report is primarily written to apply to suspended grid ceiling systems using inverted 'T' rails with lay-in panels. However many of the problems and solutions discussed are equally applicable to other forms of suspended ceilings.

Sections 3 to 6 of this report are a summary of the information gleaned from this literature search. Dynamic, full scale testing reports are discussed in Section 4. This work backs up many code requirements and exposes others as either inadequate or inappropriate. Sections 7 and 8 make comparisons between the provisions of various publications and their relevance to New Zealand regulations. Most details and requirements are drawn from American experience and regulations, and New Zealand guidelines. Section 9 deals specifically with the controversial topic of clipping of tiles.

Section 10 of the report outlines the text for a possible code or for inclusion in a revision of a code such as NZS 4219:1983. This section could also be used as an outline specification for suspended ceiling designers.

2.0 Extent of Research

The initial phase of this research project was to collect, both nationally and internationally, whatever literature was available concerning seismic requirements for suspended ceilings. In order to achieve this, letters requesting information were sent to 45 New Zealand and 64 overseas organisations in 15 countries that were involved in the suspended ceiling industry or may have been aware of pertinent information.

A copy of the letter sent to suspended ceiling manufacturers and installers, and the standard letter sent to other organisations are contained in Appendix C. A summary of the letters sent out and the responses received is given in Table 2.1. Table 2.2 indicates the countries from which replies were received.

Table 2.1: Summary of Contacts and Responses

Categories		New Zealand	Overseas	Replies
A	Ceiling Installers	32	-	11
B	Ceiling Manufacturers/ Distributors	5	1	5
C	Universities	-	38	13
D	Research Organisations	4	11	8
E	Government Agencies (other than C and D)	-	9	6
F	Companies (other than A and B)	3	1	3
G	Others	1	5	5
	TOTALS:	45	64	
		109		50

Table 2.2: Countries Contacted

Countries of Contact	No.
New Zealand	45
USA	31
Japan	11
Canada	4
Greece	3
Mexico	3
Switzerland	2
China	2
Chile, Israel, France, Turkey Spain, India, Italy, Philippines	1 each

As more specific information was obtained or other contacts suggested, more specific requests for information and publications were made. The replies received varied from no information through to complete dynamic test reports. Briefly, the responses received yielded:

1. Code requirements for the country addressed.

2. Recommendations of seismic requirements.

3. Methods for reducing the seismic hazard of suspended ceilings.

4. Earthquake Reports.

5. Reports of dynamic, full scale testing.

A full list of all the contacts made and the information obtained is given in Appendix A. Section 12 of this report lists all the reference material received in the literature search.

3.0 Suspended Ceiling Damage

3.1 Description of Suspended Ceiling Components

The typical suspended ceiling grid consists of interlocked main and cross tees. The tee rails have a wide bottom flange and a web with a thickened bulb at the top. The main tees are hung by wires (1.2m centres typically) from the structure above. Sections of the main tee clip together to become continuous. Cross tees run between the main tees and clip together through slots in the main tee web. (Fig 3.1) The ceiling tiles are then laid in this grid system.

The perimeter of the ceiling is typically either terminated short of any walls, columns or bulkheads, or it may be pop rivetted to a wall angle which is in turn fixed to the wall, or other supporting structure.

3.2 Description of Ceiling Bracing Components

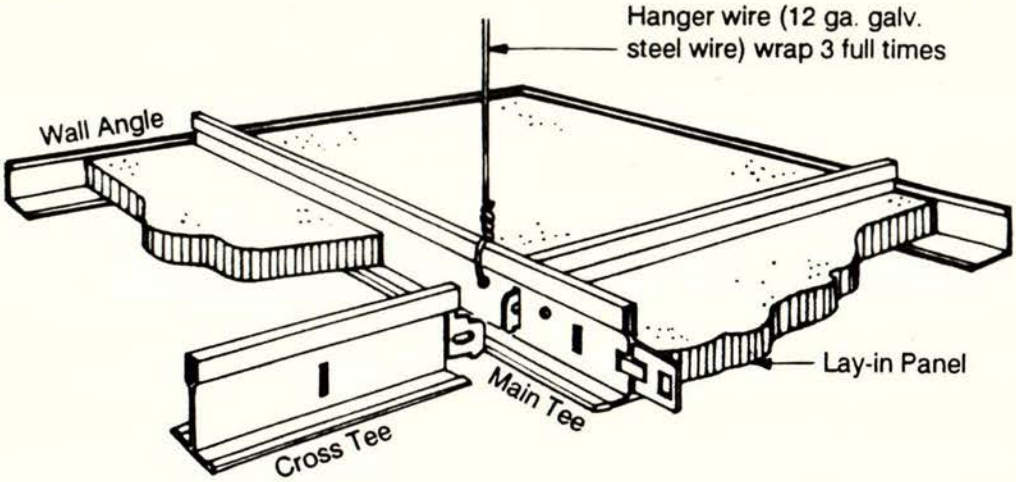
The typical bracing system described in American codes consists of four wires splayed at 90 degrees in plan usually connected to the main tee near the junction with the cross tee. The wires are placed at no more than 45 degrees to the ceiling plane, and connect to the structure above. In conjunction with the wire braces a vertical compression strut extends from the main tee to the structure above (Fig. 3.2a). The vertical strut may be a standard steel section or more recently an extending purpose - made strut. Other forms of bracing such as K-bracing (Fig. 3.2b) are also used in New Zealand to provide lateral restraint.

3.3 Observed Suspended Ceiling Damage

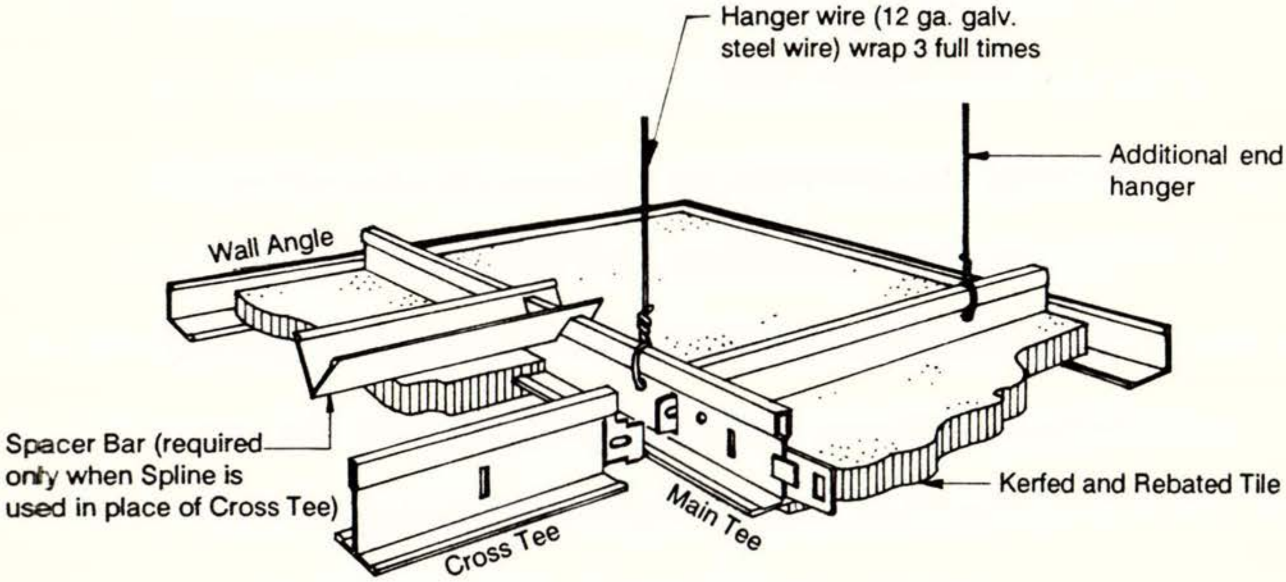
The types and degrees of damage sustained by suspended ceilings in earthquakes varies. Some particular types of damage occur frequently and these are discussed in detail below.

Unfortunately, the observations of suspended ceiling damage in actual earthquakes are rather sparse. This has been due in the past to the rapid cleanup, especially of this sort of nonstructural damage, following earthquakes. The October 17, 1989 Loma Prieta earthquake highlighted this effect once again.

The observations detailed below have been extracted from earthquake reports both directly, and indirectly from introductions to suspended ceiling recommendations. Where appropriate, further details are included on similar damage types observed in full scale dynamic testing. A more complete summary of the dynamic testing is given in Section 4.

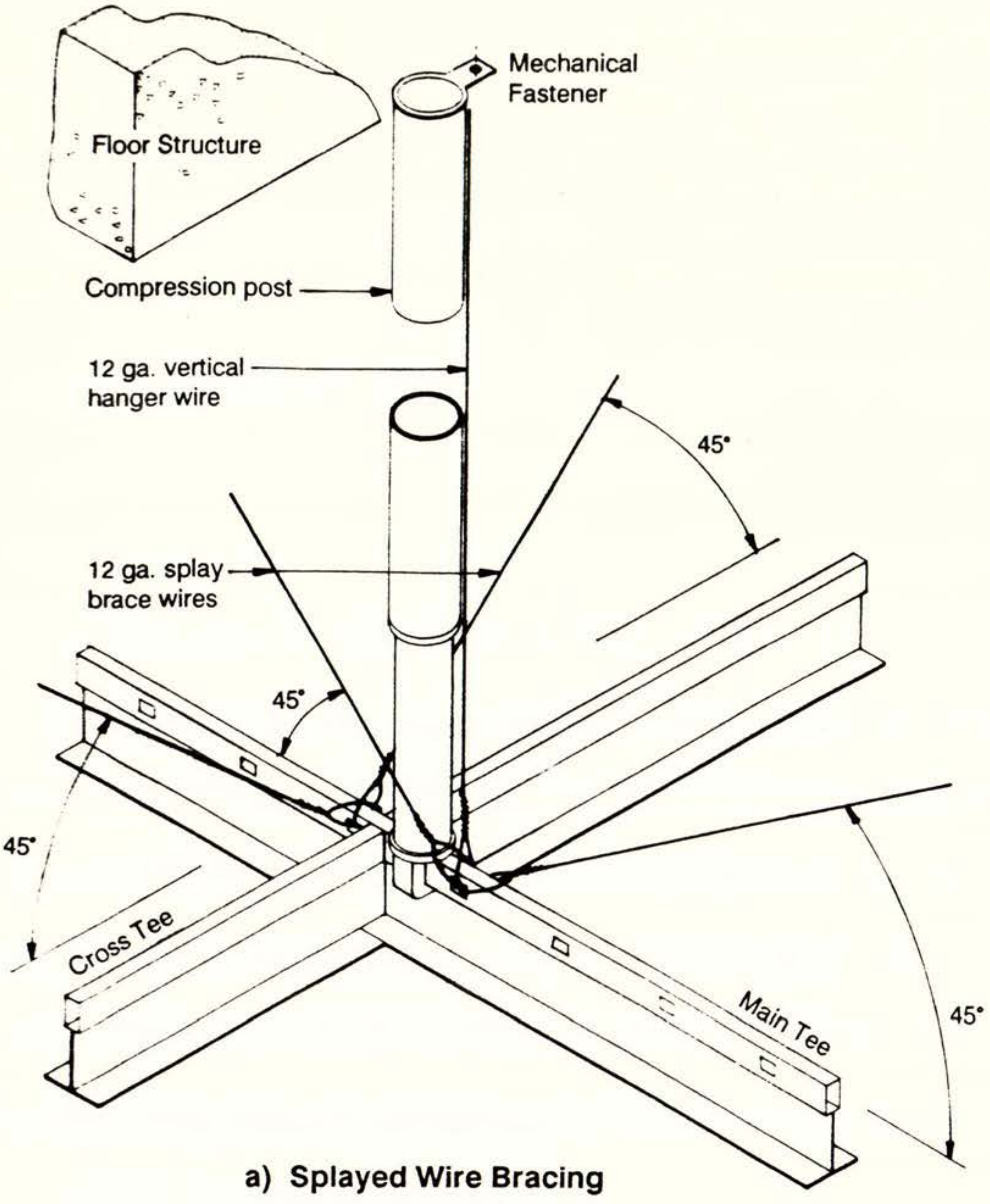


a) Exposed Grid

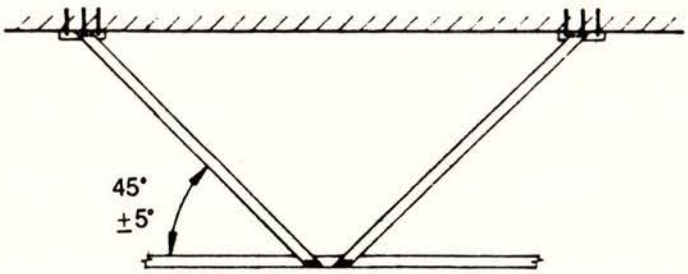


b) Concealed Grid

Suspended Ceiling Components Fig. 3.1



a) Splayed Wire Bracing



b) Typical K-Brace

Typical Bracing Arrangement Fig. 3.2

Apart from the brief report on Loma Prieta contained in the NZNSEE journal (Ref. 1), information was also obtained from: the NZNSEE journal reconnaissance report on the September 1985 Mexico earthquake (Ref. 2); the San Fernando February 1971 earthquake report (Ref. 3); the great Alaska quake of March 1964 report (Ref. 4); AIJ reports (in Japanese, but with a good number of photos) on the 1978 Miyagikeu Oki (Ref. 5) and the 1982 and 1983 earthquakes (Ref. 6), which have whole sections on ceiling damage; and a paper by EQE Engineering Inc. on the performance of suspended ceilings in earthquakes (Ref. 7). Some information also comes from a range of recommendation papers which have summaries of earthquake damage observed.

Much of the suspended ceiling damage observed has occurred in earthquakes which are smaller than the design load levels. The observed damage described in Sections 3.3.2, 4 and 6 and the probable causes outlined in Sections 3.3.3, 5 and 7 are used as the basis for the discussion on relevant code provisions (*refer* Section 7).

3.3.1 Mechanisms to Resist Lateral Load

There are two basic methods of lateral restraint of suspended ceilings. The first is by the use of braces at isolated points throughout the grid. This is referred to as a "braced" ceiling and is covered in more detail in Sections 3.2 and 7.6. A braced ceiling is connected to the floor or roof structure immediately above the ceiling.

The second method of restraint is to allow the tee rails to transfer the seismic loads in compression and/or tension to the perimeter walls, or other structural members which transfer the load to the main building structure. For the purposes of this report this system is referred to as an "unbraced" ceiling.

Some large area ceilings incorporate both forms of resistance.

3.3.2 Braced Ceiling Damage Observed

As the majority of earthquake reports received concern the United States, the braced ceilings were all of the splayed wire type. Some installations had the vertical strut as required by the current (1988) UBC (Refs. 8 and 9) while others did not. The relevant testing performed (Refs. 10-12) is also for this bracing configuration.

The most commonly occurring type of damage throughout all the reports is that of edge damage. There are a number of effects seen at edges. These include pulling away of wall angles attached to tee rails; rupture of the wall angle/tee rail junction; pounding of the ceiling against the perimeter; buckling of tee rails; drooping of ends of tee rails and drop out of tiles.

Penetrations of columns and walls through a braced ceiling that have minimal or no separations, exhibit similar pounding effects as observed at the perimeters as described above.

Other aspects of damage observed occur at the bracing points. These include slackening of bracing wires; tearing by wires of connection holes in tee rails;

buckling of the tee rail at bracing points and damage to the compression strut connection.

3.3.3 Braced Ceiling Damage Causes

Edge damage observed falls into two categories. The first is that which occurs at tee rails separated from the perimeter, and the second category is where tee rails are fixed to the wall angle, as is allowed by the American codes.

In the case of ceilings which have a separation gap at the perimeter the initial damage is pounding of the ceiling against the wall, or other structure. The separation required by codes is typically 6mm to 15mm for this type of installation (*refer* Section 6.1). When pounding occurs in a braced ceiling it is due to an inadequate clearance, which may be accentuated by insufficiently rigid bracing. Pounding results in damage to the tiles and buckling of the tee rails, or compression failure of the tee rail joints.

Sagging of tee rails and dropout of tiles occurs at the free edge detail when the seismic lateral movements exceed the supporting ledge dimension. Tests where additional hangers are added at the terminal ends of tee rails show no evidence of this mode of failure. The falling of other tiles within the body of the ceiling is discussed in Section 3.3.6.

A second, but less common cause of edge tile falling is spreading of the tee rails. If ceiling rails are able to spread laterally then the tiles can drop from between the rails. Evidence of this has been observed, and noted only in full scale testing. The provision of a connection between the terminal ends of both main and cross tee rails is recommended in much of American and Japanese literature of more recent times.

The second category of damage occurs to braced ceilings when the ceiling is attached to the wall at the edges, as is allowed by the American codes. The intention of this is to assist installation and it is limited to two adjacent edges. However connections initially act as the seismic load resisting system by default due to the greater stiffness of this mechanism. Once the strength of the wall angle and/or the perimeter fixings (normally rivets) is exceeded these will bend, or pull out, respectively. Once the perimeter fixing has failed the ceiling is free to move away from the wall but will cause pounding damage due to motion in the other direction, with results similar to that for the unconnected perimeter described above.

The falling of edge tiles is primarily due to the inadequate provision of end support for the tee rails. Thus, tee rails fixed to the perimeter as outlined above will only allow edge tiles to fall after failure of the perimeter detail.

Perimeter details providing what would be considered to be adequate separation for a braced system, have still exhibited pounding. This has been caused by splayed wires which are installed slack, or become slack under load. The slackening of wires comes from tightening of tying loops and connection twists, and at higher loads from tearing of the hole through the tee rail.

The slackness of bracing wires tends to increase the flexibility of the ceiling system, resulting in some cases of damage that is normally only associated with inadequately separated ceilings.

In testing, occurrences of buckling of the main tee at the bracing point and damage to the vertical strut connection did not result in any falling hazards. Although damage occurred, the point of rupture was not reached. The buckling of the main tee at the bracing point is most likely due to the out of plane action of bracing wires placed in the direction of the cross tees. As these wires act upon the top of the main tee, in its weak direction, and slightly away from the cross tee junction, the induced torsional load causes the main tee to buckle. This same effect is probably also responsible for the compression strut connection damage.

"Seismic bouncing" is a term used to describe a phenomenon observed in large ceiling areas. It describes the wave-like motion of the ceiling system under seismic excitation. It is mooted that the use of seismic struts as required by the UBC would eliminate this effect (Ref.34).

3.3.4 Unbraced Ceiling Damage Observed

An unbraced ceiling is restrained by connection to two or more adjacent perimeter walls without internal braces. This was a common installation method, and still is in some countries. It is only allowed for very small ($13.4m^2$) ceilings in the USA (Ref. 9). Within New Zealand, unbraced ceiling are used for larger areas where tee lengths are based upon the strengths of the main and cross tees.

As unbraced ceilings of larger sizes are no longer allowed by American codes, the experience of damage to this type of ceiling is limited to installations pre-dating the splayed wire bracing requirements; ceilings installed without bracing (non-complying) and dynamic testing done for comparisons. Hazard mitigation recommendations also make references to the type of damage observed or expected.

The most common damage of unbraced ceilings observed is joint ruptures, perimeter fixing failures, tile falling and damage at penetrations.

Joint ruptures usually occur in the cross tee at the splice through the main tee. Perimeter fixing failures observed are tearing of pop rivet connections of the tee to the wall angle, or pull out of the wall angle fixings to the wall. Tile falling is usually associated with other types of damage but has also occurred to some ceilings without significant grid member damage (refer section 3.3.6).

Penetrations through the ceiling which have not been detailed for flexibility will either fail themselves or cause local failure of the suspended ceiling. Common cases of this are columns, walls, sprinkler heads and HVAC distribution terminals. The situation with sprinkler heads is of particular importance as cases are cited where the value of water damage caused by broken sprinkler heads is far in excess of all other structural and nonstructural damage to the building (*refer* Section 3.3.6).

3.3.5 Unbraced Ceiling Damage Causes

Joint ruptures most commonly occur at the cross tee splice. For most ceiling grid systems the splice of the cross tee through the main tee is the weakest point.

The tee rail to wall angle connection is another source of joint rupture. This is caused by shear of the rivets, or tearing of the rivet through the tee rail or wall angle material. In some earlier installations the tees were not fixed to the wall angles.

The failure of the connection of the wall angle to the perimeter walls or other structure occurs when the tee/wall angle connection or the wall angle fixings are inadequate for the applied load. In these cases the ceiling pulls away from the wall and pounding with associated damage results. Damage to full height partitions restraining the ceiling, or other supporting structure may occur where these are inadequate for the load. However cases of this have not been reported in the research literature obtained.

Damage at penetrations is caused in the case of HVAC terminals by inflexible connections, by lack of separation, or other similar situations. Column and sprinkler penetrations are damaged or cause damage when inadequate clearances are provided. Walls which pass through to the structure above, and are not detailed as a part of the seismic load resisting system, may cause ceiling damage at the ceiling/wall junction due to deflections which are incompatible with the load resisting system.

3.3.6 General Ceiling Damage Observed

In addition to the damage detailed above which is specific to either braced or unbraced ceilings there are a number of other failure modes which occur. Observations indicate that the form of lateral restraint does not affect the occurrence of the damage patterns detailed below.

The most significant form of damage is that of tile falling within the body of the ceiling. This has not only been observed to occur in ceilings which are older, but also in buildings with ceilings complying to the UBC requirements. This tile falling is distinct from edge tile falling and often the ceiling grid system is largely undamaged.

Another falling hazard is that of lights and/or HVAC duct terminals. This problem is addressed in both American and New Zealand codes where requirements are given for the fixing of such fittings (Sections 6.3 and 6.4). However, earthquake damage reports suggest that there are a lot of buildings which do not have fixtures which comply with the codes.

Pendant lights which are suspended from the ceiling grid have caused buckling of the tees due to rotation of the support bracket. Where attached to cross tees this rotation has caused joint failure and the light, tee rail and associated ceiling tiles to fall.

3.3.7 General Ceiling Damage Causes

The dislodging of tiles can be attribnuted to a number of factors. The first of these is vertical earthquake forces. Vertical forces large enough to lift tiles have not been measured in many earthquakes yet tiles have been dislodged (Refs. 10 and 11).

A second factor is the jolting effect that the seismsic restraining system, especially bracing, can have on the ceiling. As the ceiling moves back and forth relative to the building, the take up of load in braces, as the wires become tight, can cause large upward forces on the ceiling at brace locations.

A third factor is the wave-like motion of the ceiling as shown in Fig. 3.3. This is caused by both of the previous effects as well as being a natural vibration shape for the ceiling grid. The curve of the tee allows the tile to be lifted from its seating, at which time it is free to slide from its position and may fall from the grid.

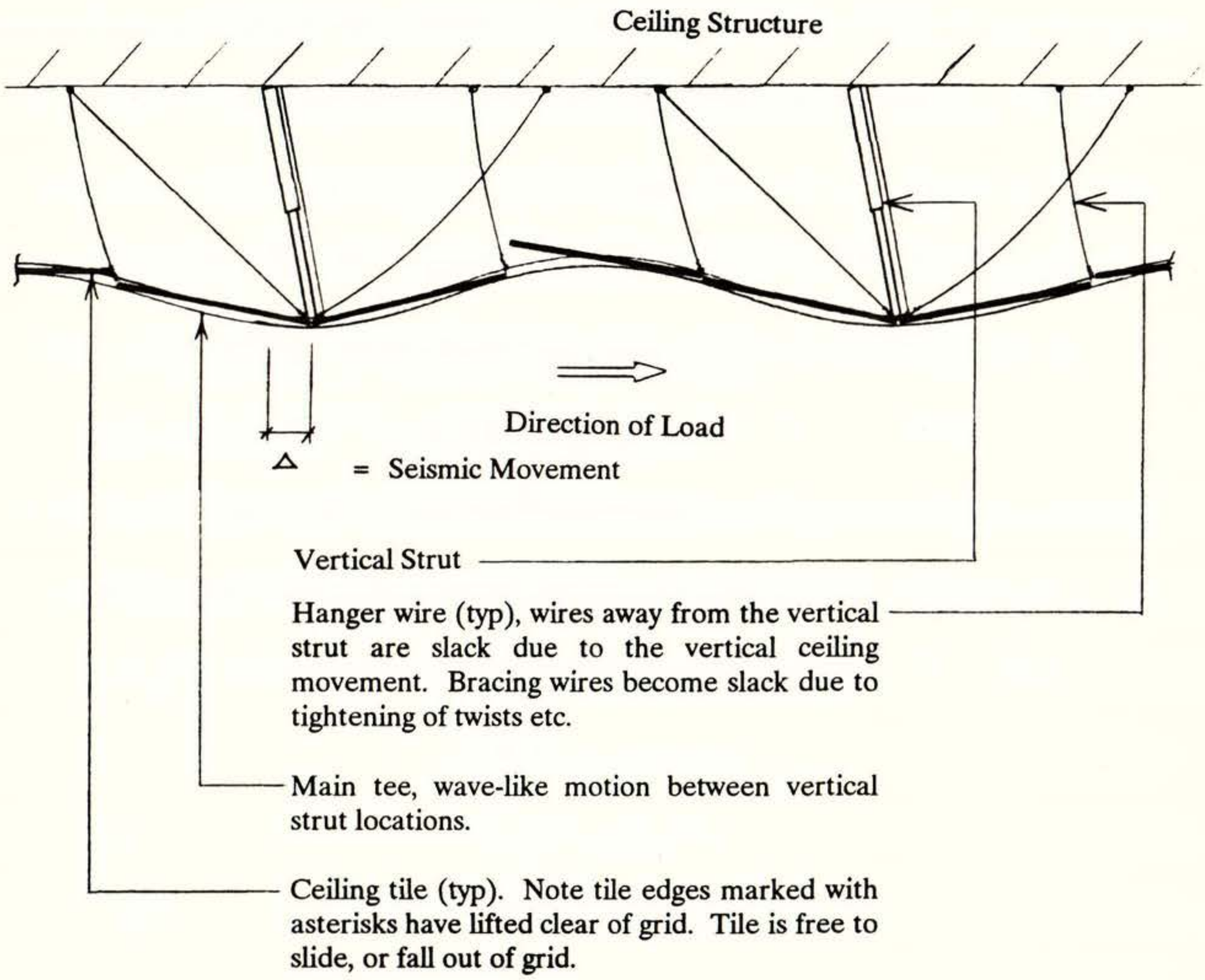


Fig. 3.3 Ceiling wave motion

The actual cause of the tile drop out is most likely a combination of the above three factors. All three of these factors tend to lift the ceiling tile from its seating.

Falling of lights and HVAC duct terminals seems to occur only in installations where fixings to the grid and/or hangers are not used. The dynamic testing programs have indicated that the use of hangers adequately addresses this problem (*refer* Section 4).

The damage caused by pendant lights is due to the pendulum motion of the fixtures. The connections to tee rails are sufficiently rigid, in some cases, to apply torsion to the rails causing buckling of the rail or rupture of joints.

3.4 Damage Costs

The actual cost of suspended ceiling damage is difficult to determine. Little work has been done in the area of nonstructural damage costs. Some detail is contained in "Seismic Design of Architectural Elements" (Ref. 13) and is summarised below.

The relative values of damage to structural and nonstructural components of four typical buildings is shown in Table 3.1. Damage statistics for high-rise buildings following the 1971 San Fernando earthquake are summarised in Table 3.2.

No information is available on the costs of suspended ceilings in particular, and any comments are restricted to this limited information. Also the cost of the failure of lighting and HVAC fixtures are buried in the electrical and mechanical components for Buildings, yet the seismic restraint of these items is a part of the suspended ceiling installation. The contribution of the suspended ceiling to the damage of partitions is also not quantified.

Overall the ceiling and lighting damage accounts for between 2% and 4% of earthquake damage in building with ceilings.

However the cost of down time in buildings where clean up of collapsed ceilings and lights has occurred may be many times greater than these values. For example, the AT&T offices in Oakland, California, USA were closed for more than 5 weeks following the Loma Prieta earthquake of 17 October 1989, even though it suffered only nonstructural damage. This included areas of fallen tiles and ruptured sprinkler pipes. The cost of relocating staff alone could amount to many thousands of dollars.

Much of the damage to suspended ceilings and lights could be eliminated by adequate bracing and detailing of these components. It is apparent that the extra work required to properly brace and detail ceilings is more than justified by earthquake experiences.

Table 3.1: Relative Value of Structural and Nonstructural Components for Four Sample Buildings

Component % Of Cost				
Components	Building 1	Building 2	Building 3	Building 4
Structure	19.6	10.28	13.8	23.0
Exterior Cladding	10.39	15.9	14.9	10.45
Partitions	9.17	13.31	4.8	1.0
Ceiling/Lighting	3.77	3.70		
Arch. Nonstructural	22.3	33.01	19.7	11.45
HVAC	9.73	17.08	18.30	25.5
Plumbing	9.33	8.70	5.20	10.20
Electrical	5.66	5.86	9.20 (1)	16.25
Services Nonstructural	24.72	31.64	32.70	52.0
Other (finishes, roofing, elevators, fixed equipment, general contractor items)	33.38 (2)	35.07 (3)	33.80	13.55
TOTALS:	100.0	100.0	100.0	100.0

Building:
1 5 storey, University Biosciences building, poured concrete waffle slab structure
2 5 storey, University Science and Engineering building, poured concrete frame structure
3 19 storey, private office building
4 1 storey, steel frame industrial building

Notes:
1 Includes lighting
2 Includes 11.17% lab casework
3 Includes 7.97% lab casework

Source: Building Systems Development, Inc.

Table 3.2: Damage to High-Rise Buildings, San Fernando Earthquake 1971

Components	Damage Cost ($)	% of Damage Cost
Structural	2,330,909	21%
Mechanical	597,978	5%
Electrical	397,621	3%
Elevators	409,056	4%
Ornamentation	1,029,441	9%
Partitions	2,596,531	23%
Ceilings	250,144	2%
Exterior	1,088,474	10%
Glass	147,825	1%
Paint	1,130,502	10%
Other	1,386,721	12%
TOTAL	11,365,202	100%

Whitman, R.V., Shen-Tien Hong, John Reed.

<u>Source</u>: Damage Statistics for High-Rise Buildings in the Vicinity of the San Fernando Earthquake:
Department of Civil Engineering, M.I.T. (1973)

4.0 Dynamic Testing

4.1 ANCO Engineers Inc. Testing (Ref. 10)

The report is titled:

Final Report
SEISMIC HAZARD ASSESSMENT OF NONSTRUCTURAL CEILING COMPONENTS - PHASE I

It was prepared for:

National Science Foundation
NSF Grant CEE-8114155
Washington, DC
USA

It was prepared by:

The Technical Staff
ANCO Engineers, Inc.
9937 Jefferson Boulevard
Culver City
CA 90230-3591
USA

The reported is dated September 1983.

4.1.1 Report Objectives

The following is a copy of Section 1.1 of the report headed "Scope and Objectives".

> "The major objective of this Phase I study was to demonstrate the feasibility of using shake table testing procedures to evaluate seismic restraint of building nonstructural components. As originally conceived, the focus of the study was upon lighting fixtures and their interaction with various ceiling components. However, based upon review of current code requirements and discussion with construction industry representatives, the focus of the study was expanded to evaluate the seismic restraint of an entire ceiling finish system with adjunct light fixtures. Current code provisions require positive attachment of lay-in light fixtures to the ceiling grid and additional safety wires to prevent the drop-out of light fixtures. Code provisions now require that wire splays be installed to restrict ceiling motion during an earthquake and that additional hanger wires be installed within 8 in. of a perimeter to prevent drop-out of the ceiling grid at the periphery. These code provisions have been developed based upon

engineering judgement in an attempt to prevent the damage modes noted in past earthquakes. However, the dynamic behaviour of ceilings that incorporate these provisions has not been established. Thus, while the primary objective of the study was to demonstrate the feasibility of using shake table testing procedures to evaluate seismic restraint of nonstructural ceiling components, secondary objectives were established to demonstrate that shake table testing (1) may be used to assess the effectiveness of building code requirements, (2) may be used to assess component dynamic behaviour, and (3) has the potential for qualification of components which cannot be supported by rational engineering calculations. In particular, fragility testing can be utilised to establish both expected damage patterns and reserve margins of various restraint designs obtained by application of criteria static force levels."

4.1.2 Test Procedures

A typical 8.53m x 3.66mm area of tee rail suspended grid with lay-in tiles was used for testing. The grid consisted of intermediate duty (ASTM C635, Ref. 14) main and cross tees at 1220mm and 610mm centres respectively. The average ceiling weight, including 14kg (32lb) light fixtures was 0.082 kPa (1.71 psf).

The ceiling was tested by mean of a shake table. The input motion selected was the Taft strong ground motion recorded during the 1952 Kern County earthquake. Three sets of input table motions were generated using the 1952 Taft record as follows:

1. Taft Ground Motion (GM)

   a. 0.2g horizontal S69E component
   b. 0.1g vertical component.

2. Building Motion, Type A (A)

   a. 0.3g filtered horizontal S69E component (3 Hz, 10% damping SDOF filter)
   b. 0.1g vertical component.

3. Building Motion, Type B (B)

   a. 0.5g filtered horizontal S69E component (3 Hz, 5% damping SDOF filter)
   b. 0.1g vertical component.

The terms in brackets: GM, A and B refer to the types used in Table 4.1. Motion set 1 represents ceiling motion which is not amplified by the building structure (*i.e.* a stiff structure). Motion set 2 corresponds to motion in a three to four storey building (3 Hz fundamental period) with moderate partition damage (*i.e.* a ductile frame). Motion set 3 is for a three to four storey building (3 Hz fundamental period) which has essentially an elastic response.

"The test programme considered the following ceiling restraint configurations:

1. Without wall perimeter:

   a. Free-free pendulum without restraints
   b. 45° splay wire seismic restraints (current UBC code)
   c. 45° splay wire with centre post or strut
   (SF code, UBC proposed) (spring or rigid).

2. With simulated wall perimeter (pop rivet attachment along one wall):

   a. 45° splay wire with centre post or strut
   b. 45° splay wire restraint
   c. Pop rivet attachment only (two methods of attachment)".

Item 2c comprises two test series. A summary of the test configurations is given in Table 4.1. A number of runs for each test set up were conducted using different input motions and input factors. The input factor of 0.8 was selected as the reference level for all tests. Only tests 6 and 7 were taken to failure.

Table 4.1: **Test Matrix** (from Ref. 10)

<table>
<tr><th colspan="2">Suspended Ceiling System</th><th colspan="3">Restraint Condition</th><th colspan="5">Building Characteristics</th></tr>
<tr><th>Test No.</th><th></th><th>Wall Perimeter Attached</th><th>45° Wire Splays</th><th>Centre Struts</th><th>Run No.</th><th>Type</th><th>Freq. (Hz)</th><th>Damping (%)</th><th>Test Input Data</th></tr>
<tr><td>1</td><td>Intermediate duty T-bar grid; 4-ft x 4-ft standard module; Lighting @ 1.4 W/ft^2.</td><td>No</td><td>No</td><td>No</td><td>1
2
3
4</td><td>GM
A
A
A</td><td>*
3
3
3</td><td>-
10
10
10</td><td>0.8
0.8
0.8
0.8</td></tr>
<tr><td>2</td><td>Intermediate duty T-bar grid; 4-ft x 4-ft standard module; Lighting @ 1.4 W/ft^2.</td><td>No</td><td>Yes</td><td>No</td><td>1
2
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5</td><td>GM
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5</td><td>0.8
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<tr><td>3</td><td>Intermediate duty T-bar grid; 4-ft x 4-ft standard module; Lighting @ 1.4 W/ft^2.</td><td>No</td><td>Yes</td><td>Yes</td><td>1(s)
2(s)
3(s)
4(r)</td><td>A
GM
B
A</td><td>3
*
3
3</td><td>10
-
5
10</td><td>0.8
0.8
0.8
0.8</td></tr>
<tr><td>4</td><td>1-in. wall angle @ X-perimeters; Pop rivets @ 2 ft</td><td>Yes</td><td>Yes</td><td>Yes</td><td>1(r)</td><td></td><td>3</td><td>5</td><td>0.8</td></tr>
<tr><td>5</td><td>1-in. wall angle @ X-perimeters; Pop rivets @ 2 ft</td><td>Yes</td><td>Yes</td><td>No</td><td>1
2
3
4
5</td><td>B
A
GM
B
B</td><td>3
3
*
3
3</td><td>5
10
-
5
5</td><td>0.8
0.8
0.8
1.5
1.0</td></tr>
<tr><td>6</td><td>1-in. wall angle @ X-perimeters; Pop rivets @ 2 ft</td><td>Yes</td><td>No</td><td>No</td><td>1
2
3
4
5</td><td>B
A
B
B
B</td><td>3
3
3
3
3</td><td>5
10
5
5
5</td><td>0.8
0.8
1.0
1.5
2.0</td></tr>
<tr><td>7</td><td>1-½ in. wall angle @ X-perimeters; Pop rivets @ 4 ft</td><td>Yes</td><td>No</td><td>No</td><td>1
2
3
4</td><td>B
B
B
B</td><td>3
3
3
3</td><td>5
5
5
5</td><td>0.8
0.8
1.0
1.5</td></tr>
<tr><td colspan="10">* Ground Motion (an infinite frequency building with no amplification)
(s) Spring Strut
(r) Rigid Strut</td></tr>
</table>

4.1.3 Test Results and Discussion

Comparisons are made in the report between different configurations. These are made on the basis of accelerations, deflections and time history plots.

1. Effect of Splay Bracing

   The splayed bracing causes an increase in measured accelerations (1.6 to 2.6 times) and a decrease in ceiling deflections (to 20-45%). The free ceiling had displacements of up to 62mm. The high accelerations of the splay braced ceiling are due to the slack wires suddenly becoming taut.

2. Effect of Strut on Splay Braced Ceiling

   The introduction of the strut had no noticeable effect on either the ceiling accelerations or displacements.

3. Effect of Rigid Strut In Lieu of the Spring Strut

   There is little difference between the ceiling accelerations of the rigid and proprietary spring strut cases, although a small (approximately 15%) reduction in displacements is observed in the rigid strut case. ANCO Engineers concluded that the struts are not effective in reducing ceiling displacement.

4. Effect of Strut when Perimeter is also Fixed

   The comments made under Item 3 apply equally here. However the report goes on to add that test data, as well as observations during testing indicate that the bracing is ineffective and that the perimeter attachment is the effective seismic restraint.

5. Effect of Splay Bracing on Perimeter Fixed Ceiling

   The conclusion drawn is that the perimeter fixing, although intended for installation alignment, becomes a defacto seismic restraint.

6. Tests to Failure

   The two tests (6 and 7) which were taken to failure were tests with perimeter attachment only.

   Failure of the ceilings occurred at 3.57g and 1.7g for tests 6 and 7 respectively. Calculation of the loads in the cross tees at the points of failure (1.30 kN and 1.44 kN respectively) indicated that they exceeded the static cross tee capacity value of 1.24 kN (280 lb). Figs. 4.1 and 4.2 show the ceiling damage that occurred during testing. Fig. 4.2 also shows the effectiveness of the slack safety wires to the lights in preventing drop-out.

In Test 6 failure was first observed to occur at the attached perimeter. Compression crippling of the cross tees then occurred at the unattached perimeter followed by drop-out of tiles.

The damage pattern of Test 7 was substantially different. Test 7 had a larger clearance (19mm in lieu of 13mm) at the unattached perimeter and less frequent restraint points (double fixings at 1.22m in lieu of single fixings at 0.61m centres). Failure of the cross tee junction occurred at a lower value of acceleration and no impact was observed at the unattached perimeter. By this method the perimeter failure, as in Test 6, which leads to chain reaction type failure is replaced by a local component failure.

4.1.4 Report Conclusions

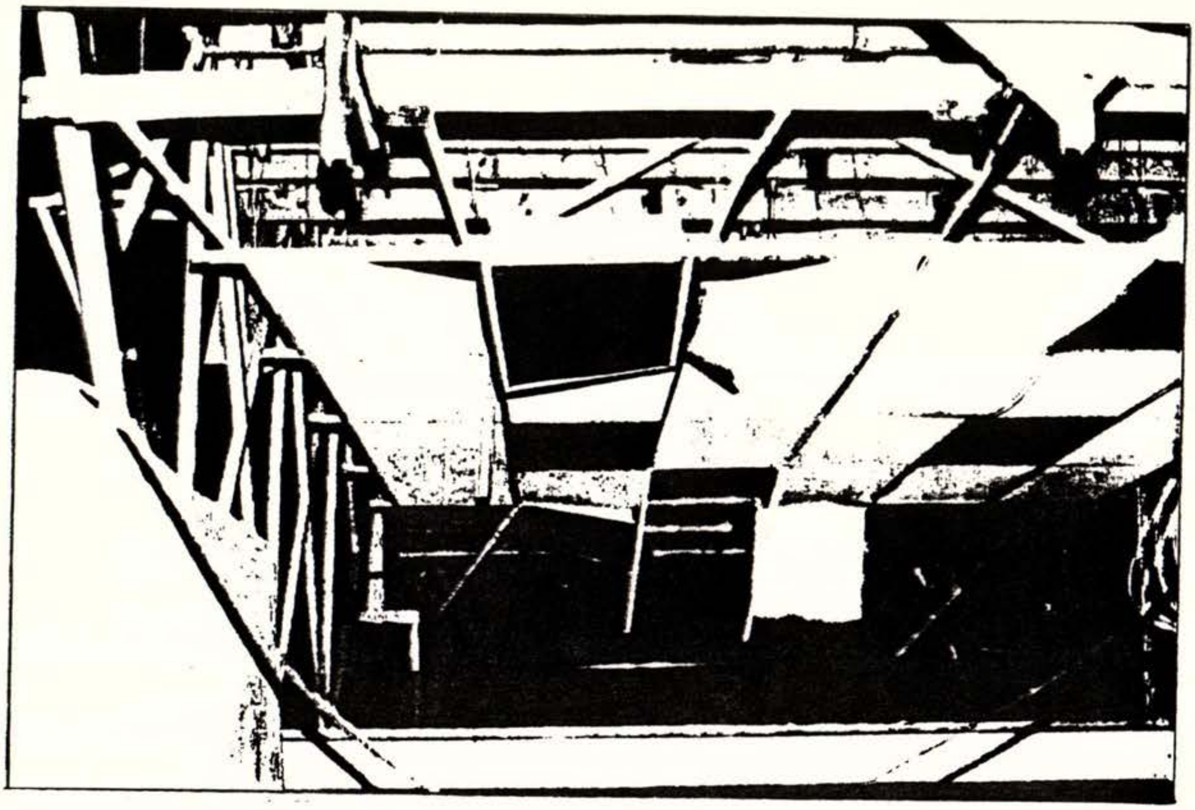
The report concludes that the use of a shake table to provide qualifying tests for ceiling components, restraint configurations and identification of failure modes with realistic building motions has significant potential.

Further specific conclusions drawn include:

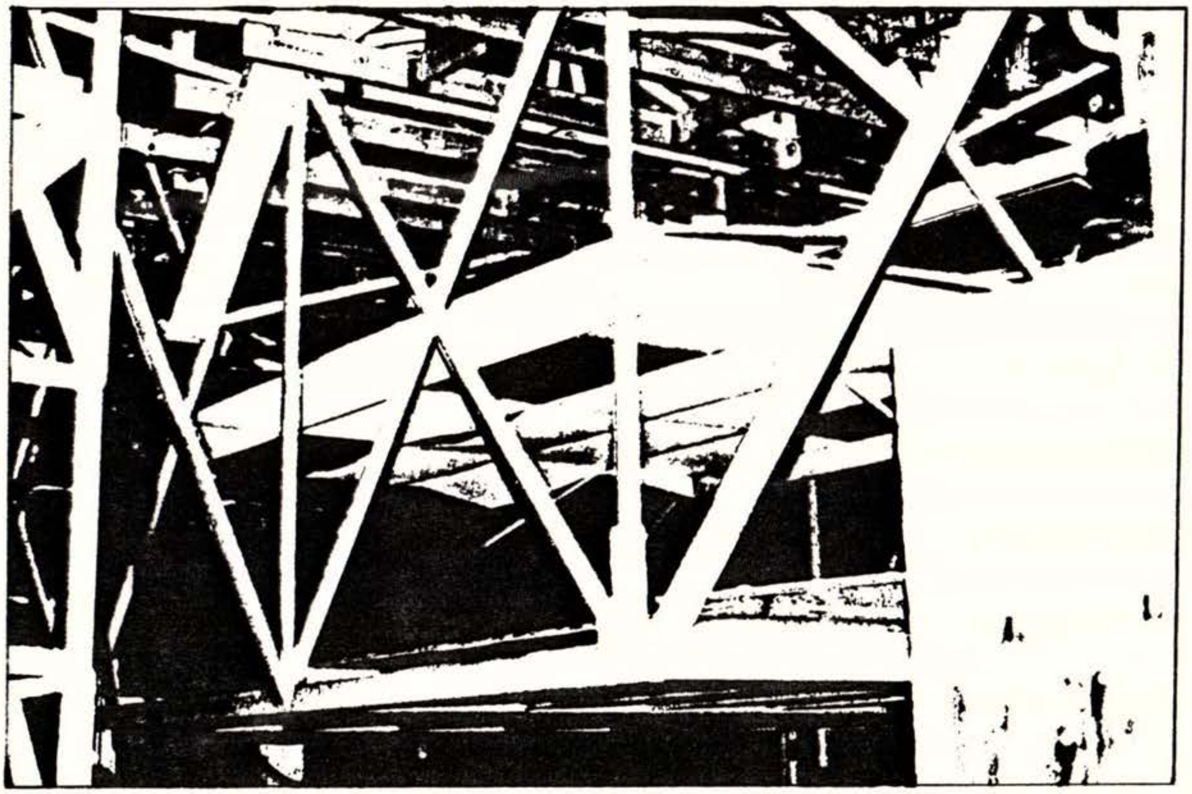
(1) the current code (UBC) provision requiring the installation of a vertical compression strut at splay wire restraint points do not appear to be justified;

(2) the wall perimeters with pop rivets placed for alignment purposes become defacto seismic restraints as the splayed wire bracing is too flexible;

(3) the use of safety wires on light fittings is effective in preventing drop-out and such wires are recommended for all fixtures, regardless of weight.

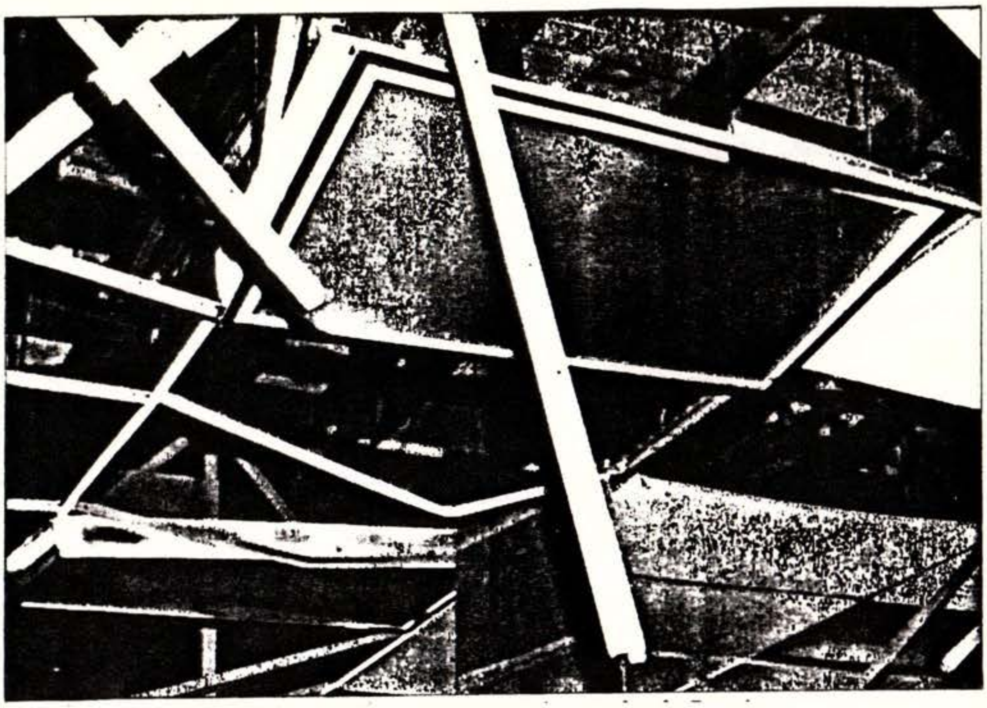


(a) Longitudinal view

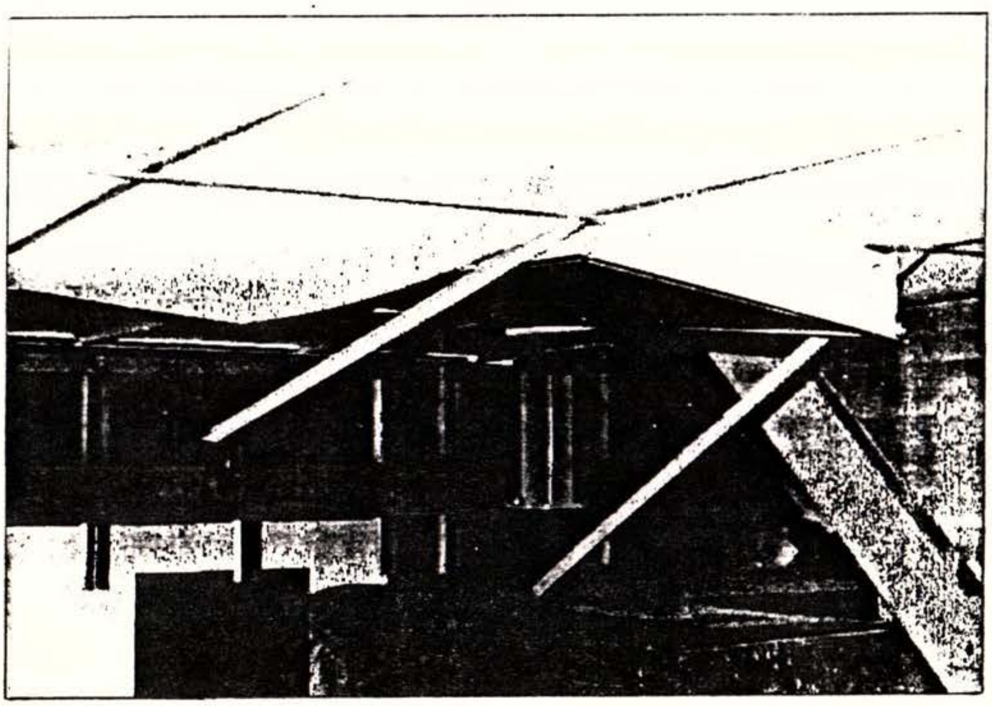


(b) Oblique view

Fig. 4.1: Overall Views of Test Ceiling During Fragility Test Series



(a) Light fixture adjacent to attached perimeter



(b) Light fixture adjacent to supported but unattached perimeter

Fig. 4.2: Demonstration of Drop-In Light Fixture Safety Wire Effectiveness during Fragility Test Series

4.2 Rihal and Granneman Testing (Ref. 11)

4.2.1 About the Report

The report is titled:

Interim Progress Report
EXPERIMENTAL INVESTIGATION OF THE DYNAMIC BEHAVIOUR OF BUILDING PARTITIONS AND SUSPENDED CEILINGS DURING EARTHQUAKES.

It was prepared for:

The National Science Foundation
Division of Civil and Environmental Engineering
Earthquake Hazard Mitigation
Grant No. CEE-81-17965

It was prepared by:

Dr Satwart S Rihal
Professor, Architectural Engineering Department
Dr Gary Granneman
Professor, ET/EL Department
California Polytechnic State University
San Luis Obispo
California 93407
USA

The report is dated June 1984.

4.2.2 Report Objectives

The following is a copy of Section 3 of the report headed "Scope and Objectives".

"The major emphasis of this research programme is to experimentally investigate the dynamic behaviour of building partitions and suspended ceilings including evaluation of fundamental dynamic characteristics, *e.g.* damping and natural frequencies.

The general objective of the dynamic testing programme is to assess the effectiveness of provisions of the Uniform Building Code (Refs. 8 and 9) other regulatory standards, *e.g.* State of California Title 21 and Title 24 (Refs. 15 and 16) and current practices governing the design, detailing and installation of building partitions and suspended ceiling systems (Refs. 14, 17 and 18).

The detailed objectives of the dynamic testing programme are to investigate:

1. The behaviour of unbraced and braced suspended ceilings without any partitions.

2. The behaviour of building partitions subjected to motions normal to the plane of the partitions.

3. The behaviour of unbraced and braced suspended ceilings with partial-height partitions including the interaction between these two components.

4. The behaviour of unbraced and braced suspended ceilings with full-height partitions including effects of perimeter detailing on overall component behaviour.

5. The behaviour of braced suspended ceilings with and without a vertical pipe strut at the point of bracing."

4.2.3 Test Procedures

A typical 4.88m x 3.66m area of tee rail suspended grid with lay-in tiles was used for testing. The grid consisted of main and cross tees at 1220mm and 610mm centres respectively. Testing also included partitions formed from metal stud and 16mm gib-board (gypsum board) each face. The partitions were both full and partial height. Partial height partitions are fixed to the ceiling grid while full height partitions pass through the grid to the structure above. The details of the ceiling specimens are given in Table 4.2.

Table 4.2: List of Specimens

	Partitions			Ceilings			
Specimen No.	Type	Facing Panels	Size (out of plane)	Type	Size (plan)	Ceiling Weight (kPa)	Bracing
1	N/A	-	-	vii	x	0.045	Nil
2	N/A	-	-	vii	x	0.045	xi
3	N/A	-	-	vii	x	0.045	xii
4A	i	iv	v	vii	x	0.099	xi
4B	i	iv	v	viii	x	0.106	xi
4C	ii	iv	v	viii	x	0.112	xi
5B	i	iv	v	viii	x	0.106	xii
6	i	iv	v	viii	x	0.106	xiii
8	iii	iv	vi	ix	x	0.054	Nil
9	iii	iv	vi	ix	x	0.054	xi
10	iii	iv	vi	ix	x	0.054	xii
9A	iii	iv	vi	ix	x	0.054	xiv

Notes:
- i. 92mm metal studs, 25 gauge at 610mm centres
- ii. As i but with bookshelves
- iii. Metal studs 64mm, 25 gauge at 610mm centres
- iv. Single layer of 16mm gib-board each side, screw spacing as per UBC Table 37-G
- v. 3.66mm wide by 2.44m high partial height partition
- vi. 3.66m wide by 3.05m high full height partition
- vii. Exposed tee grid with lay-in acoustical tiles
- viii. As vii plus light fixtures
- ix. As viii plus attached partition end and unattached at opposite end (soffit)
- x. 3.66m wide by 4.88m long
- xi. Splayed wire bracing, 4 wires (Sim 1988 UBC Std 47-18)
- xii. Splayed wire bracing with vertical strut (1988 UBC Standard 47-18)
- xiii. Two wire diagonal bracing at top of partition
- xiv. As xi but with vertical suspension wires at 203mm (8 inches) maximum at unattached perimeter, 2 vertical wires at point of splayed wire bracing.

The ceiling was tested by means of a shake table. The input motion used was sinusoidal and consisted of three dynamic tests.

1. Damping Test

   The loading grid was excited through one-half cycle of sinusoidal motion of 5 Hz frequency which was then allowed to decay. The peak command displacements were typically ± 19mm, 25mm or 32mm.

2. Sine Sweep Test

   For this test the peak displacement is fixed and frequency is varied. Initial test peak command displacements of 13, 19, 25, 38, 51 and 64mm were used. In all cases a fixed number of sinusoidal cycles at frequency between 0.2 and 6.5 were used, in steps of 0.2 and 0.5 Hz.

3. Block Cyclic Test

   For this test the frequency is fixed and specimens are subjected to several complete cycles of increasing peak command displacements. The levels of displacement chosen were 1.6, 3.2, 6.4, 9.5, 13, 19, 25, 32, 38mm and onwards in 6.4mm (¼ inch) increments, up to a maximum of 75mm (2.95 inches).

4.2.4 Test Results and Discussion

The following is a precis of Section 7 of the report titled "Discussion of Test Results and Conclusions".

"1. Results of dynamic tests to date have clearly shown that response and behaviour of building partitions and suspended ceilings is influenced both by acceleration and displacement levels and their frequencies.

2. Comparison of the response and behaviour of Specimen Nos. 1, 2 and 3 (suspended ceilings only) with those of Specimen Nos. 4A, 4B, and 4C (suspended ceilings with partial-height partitions) shows that:

   a. UBC provision of 45° splayed wire ceiling is satisfactory for providing stability to partial-height partitions, and this requirement should be enforced for all buildings.

   b. Test specimens with splayed wire bracing and a vertical strut seemed to be initially stiffer than the specimens without the vertical strut.

   c. Specimens with a vertical strut at point of splayed wire bracing had less observed ceiling uplift than those without the vertical strut.

d. For all test specimens, the behaviour was characterised by eventual slackening of the splayed wire bracing, observed uplift and some damage to ceiling main runners and their intersection with cross-tees at point of bracing.

e. Threshold level of damage to contacts (books on shelves) is given by results obtained for Specimen No. 4C. This damage occurred at a frequency of about 2 Hz and peak command displacement between 25mm and 70mm.

3. Examination of results from Specimen Nos. 8, 9, 10 and 9A clearly show that:

   a. Ceiling perimeter details (at partition and free end) are a predominant factor influencing damage to suspended ceilings and partitions.

   b. Extensive damage to suspended ceilings occurred at the unattached ceiling perimeter (free end) at frequencies between 4 and 4.8 Hz, and a peak command displacement of 25mm (Specimen Nos. 8, 9 and 10).

   c. Addition of vertical suspension wires at cross-tees (Specimen No. 9A) at 203mm (8 inches) maximum from the unattached ceiling perimeter prevented the ceiling tiles from crashing down, but damage was caused by pounding of the cross-tees into the perimeter angle. This perimeter damage occurred at a frequency of 3.6 Hz, and a peak command displacement of 64mm.

   d. In all tests, the only partition damage was loosening of some drywall screws caused by the input excitation of the test specimens.

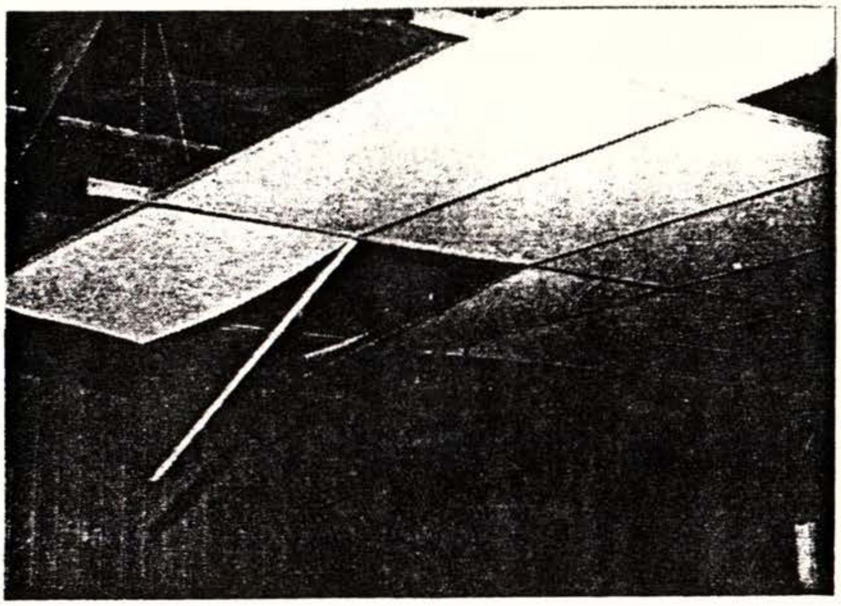
4. For all test specimens with available ceiling vertical acceleration data, the results show that the ceiling vertical acceleration had peak values ranging from 0.12g - 0.18g.

Based on this limited dynamic testing program, it can be concluded that suspended ceiling-splayed wire bracing and perimeter detailing provisions of the UBC standard 47-18 have been found to be effective and these requirements should be implemented in all buildings."

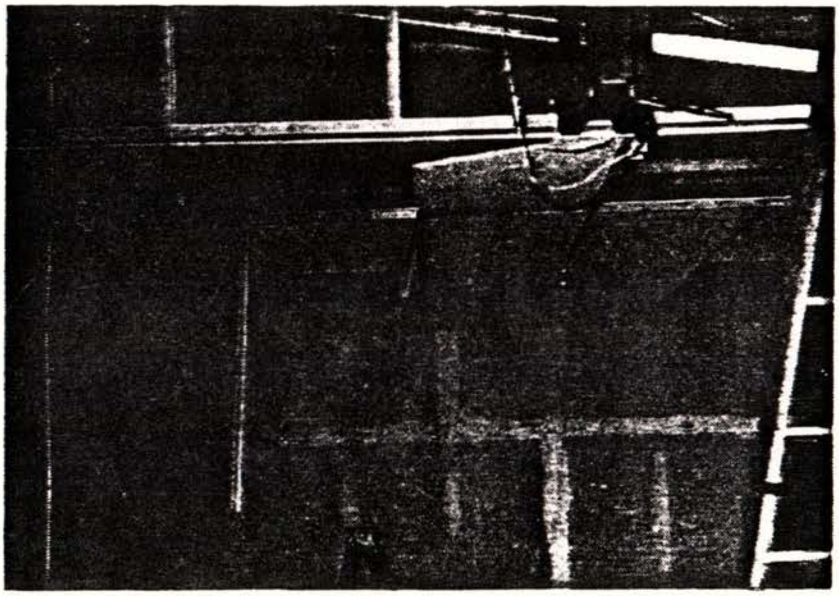
4.2.5 Report Conclusions

The shake table works well to identify the dynamic behaviour of building partitions and suspended ceilings, their dynamic characteristics and threshold levels of damage.

Rihal and Granneman note that the vertical strut increases the initial ceiling stiffness, i.e. pre-yield deflections are less, and reduces vertical ceiling uplift. Ceiling perimeter details, both where attached and unattached have a major influence on the damage to suspended ceilings. The addition of end hangers is an effective means of stopping tile drop-out of ends.



a) Test Specimen No. 9
Initial falling of cross tees and ceiling tiles



b) Test Specimen No. 9
Falling end cross tees and ceiling tiles

Fig. 4.3 Progression of Damage during Dynamic Test

4.3 Wyle Laboratories Testing (Ref. 12)

4.3.1 About the Report

The report is titled:

SEISMIC VERIFICATION OF THE CISCA RECOMMENDED STANDARDS FOR SEISMIC RESTRAINT : DIRECT-HUNG SUSPENDED CEILING ASSEMBLIES

It was prepared for:

Suspended Ceiling Manufacturers Association (SCMA).

It was prepared by:

Wyle Laboratories
Norco
California.

The report is dated November 15, 1972.

4.3.2 Report Objectives

The following is an edited copy of Section 2.1 of the report headed "Seismic Verification of a Suspended Ceiling".

In order to verify the seismic capability of a suspended ceiling installed under the CISCA Standard, a series of tests was conducted. As a starting point the SCMA Seismic Committee determined the first test should provide maximum penetration into the structural features of the CISCA Standard. To this end, a test fixture capable of being horizontally vibrated was installed in such a manner that a suspended ceiling could be mounted beneath it. This test fixture simulated primary building structure. A suspended ceiling was then installed by a CISCA contractor with the supervision of SCMA below the fixture according to the CISCA Standard, and SCMA ceiling installation procedures.

4.3.3 Test Procedures

A typical 3.66mm x 3.66m area of T-bar suspended grid with lay-in tiles was used for testing. The grid consisted of intermediate duty (ASTM C635, Ref. 14) main and cross tees at 1220mm and 610mm centres respectively. The typical ceiling weight was 0.088 kPa (1.84 psf) including four 14kg (30 lb) light fixtures.

The ceiling was tested by means of an overhead shake table. The input motion selected was a sine sweep of either ascending or descending nature.

Four tests were conducted with the same grid configuration. In all cases two sets of splayed wire bracing were used. Light fittings had two bolts to the main runners and a single slack safety wire. The differences between specimens are given in Table 4.3.

Table 4.3: Testing Details

Test No.	Compression Post	Testing in Direction of	Sine Sweep Test Details (Note 2)
1	No	Cross tee	0.2g, from 1 Hz to 40 Hz, 1 octave/minute
2	No	Cross tee	0.2g, from 40 Hz to 4 Hz, 1 octave/minute
3	Yes	Cross tee	0.2g, from 10 Hz to 2 Hz, 1 octave/minute
4	Yes (Note 1)	Main tee	0.2g, from 10 Hz to 1.3 Hz, 1 octave/minute

Note:
1. Also included, a simulated partition.
2. The testing is based on an early edition of the UBC which required a value of 0.2g as the suspended ceiling load level.

Test 4 included a simulated partition weighted to impart 0.034 kN/m (25 lb/ft) or 0.009 kPa to the ceiling. The main tees were each fixed with two screws to this partition.

4.3.4 Test Results and Discussion

1. Test One

Damage occurred at 1.2 Hz. One perimeter tile was dislodged due to a cross tee connection failure. Also the main tee buckled upwards at the splay bracing point and the wire connection holes exhibited tearing.

2. Test Two

No damage was noted.

3. Test Three

Damage occurred at 2 Hz. A cross tee joint failed adjacent to the splay bracing point. Testing was curtailed at this time.

4. Test Four

From 5 Hz down to 1.3 Hz, the splay bracing wires progressively slackened due to pulling of slack from the end connection windings and tearing of the main tee connection holes.

Movement of the simulated partition caused some buckling and tearing of the main tees where they were screwed to the partition.

4.3.5 Report Conclusions

No conclusions are drawn by the report writers although failure mechanisms are clearly described as above.

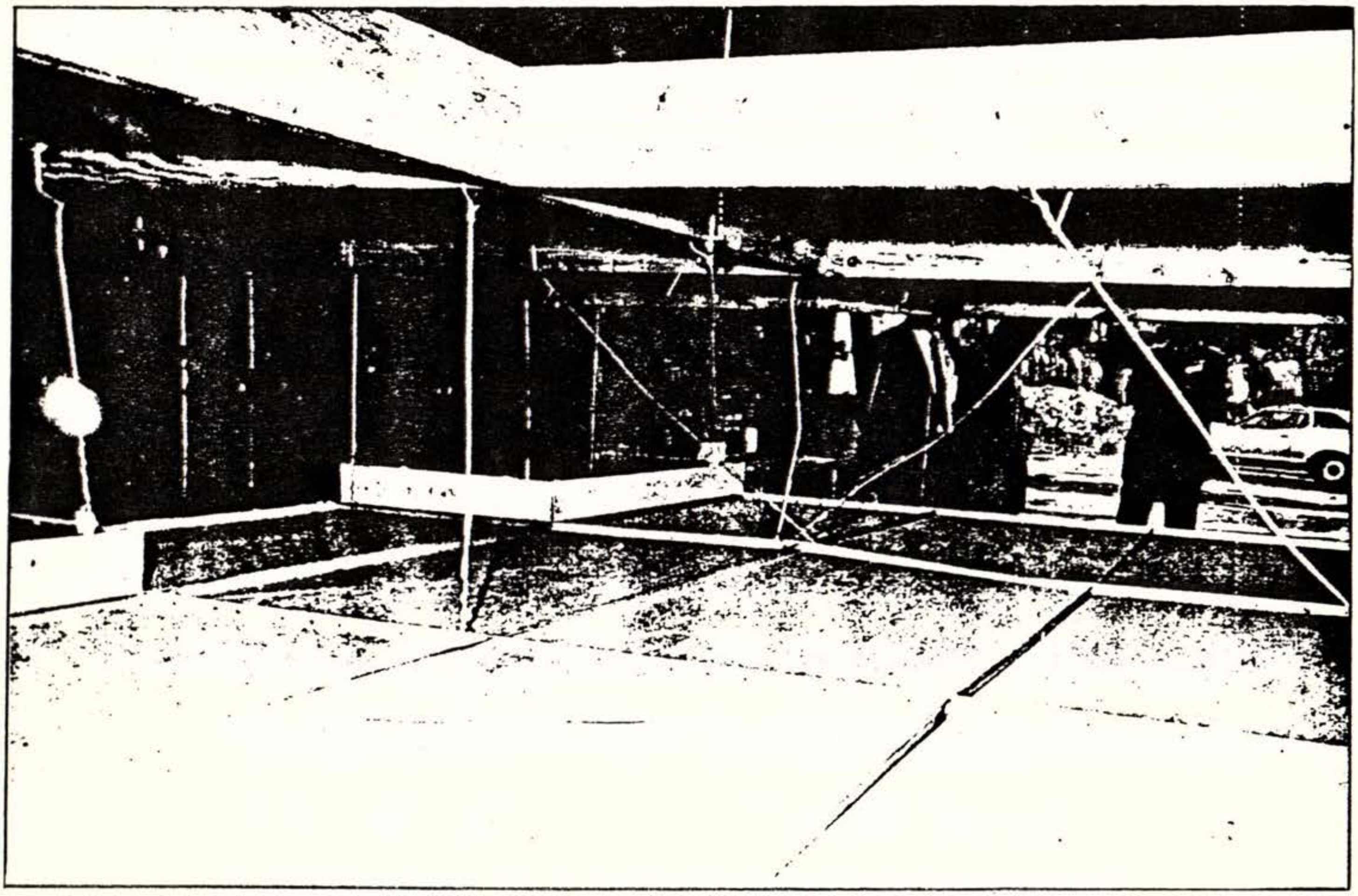


Fig. 4.4 Test Set Up after Dynamic Testing

5.0 Code Lateral Design Levels

Code requirements for suspended ceilings has a wide variation between countries both in design loads and details. The extent of detail in codes varies from nil to quite detailed minimum requirements.

This section of the report discusses the lateral load coefficients applicable to suspended ceilings in different countries. The detailed requirements of the codes are covered in Section 6.

Suspended ceilings are considered to be nonstructural elements. Many of the codes described below have specific requirements for suspended ceilings under the sections relating to parts or portions, or nonstructural elements of buildings. Other codes do not specifically mention suspended ceilings and seismic coefficients can only be estimated from these codes.

The terminology used in each country varies. For comparison purposes the values quoted here are in terms of C_p as used in NZS 4203 (Ref. 19), $F_p = C_pW_p$ for design of building parts and portions. Relevant provisions are summarised below.

5.1 New Zealand

1. **NZS 4203 : 1984** (Ref. 19)

$C_p = \alpha.K_x.Z.R.C_{pmax}$

Where:

α	=	h_{cg}/h_n
K_x	=	h_x/h_{cg} (but not less than 1)
h_{cg}	=	Height to centre of gravity of building
h_n	=	Height to the top of the main portion of the building
h_x	=	Height to the level under consideration
Z	=	Zone factor (A = 1, B = 5/6, C = 2/3)
R	=	Risk factor (1 to 1.6)
C_{pmax}	=	Basic seismic coefficient for ceilings (0.6)

C_p = 0.30 to 0.60 for R = 1 (normal buildings)
and Z = 1 (Zone A)

Maximum value of R = 1.6 for essential buildings:

2. **2/DZ 4203 : 1990** (Ref. 20)

$C_p = R_pC_{op}(T_p = 0.2, \mu_p).(0.4.Z + B.F_i/W_i)$

Where:	R_p	=	Risk factor for ceiling (1 or 1.1)
	$C_{op}(T_p = 0.2, \mu_p)$	=	Basic coefficient from design acceleration spectra at 0.2 seconds and ductility μ_p(0.67 - 0.8)
	μ_p	=	Ductility factor of ceiling
	Z	=	Seismic zone factor (A = 0.8, B = 0.6, C = 0.4)
	Wi	=	Seismic weight level at level i to which ceiling responds
	Fi	=	Seismic force at level i
	R	=	Risk factor for building.

The actual value of C_p is dependent on the building response at the given level and the ductility and natural period of the nonstructural components. General limits are not given, but a specific design is required. An estimate of the possible range of values is given below.

C_p = 0.14 to 1.41 for R = 1 (normal buildings)
and Z = 0.8 (Zone A)

The term F_i/W_i is dependent on R.

Maximum value of R = 1.3 for essential facilities.

3. **PW 81/10/1 : 1985** (Ref. 21)

This document refers to NZS 4203, but adds that seismically induced vertical loads should also be allowed for. No guidance is given as to the magnitude of these vertical forces.

5.2 United Stated of America

1. **UBC 1988** (Ref. 8)

$Fp = C_pZIW_p$

Where:	C_p	=	Basic coefficient for suspended ceilings (0.75)
	Z	=	Seismic zone coefficient (0 to 0.4)
	I	=	Importance factor (1 to 1.25)
	W_p	=	Weight of ceiling
	F_p	=	Lateral force.

Rewrite C_p = 0.75ZI

C_p	=	0.30	for $I = 1$ (normal buildings)
			and $Z = 0.4$ (Zone 4)

Maximum value of $I = 1.25$ for essential facilities.

2. **SEAOC 1990** (Ref. 22)

$$F_p = C_p Z I W_p$$

Where:	C_p	=	Basic coefficient for suspended ceilings (0.75)
	Z	=	Seismic zone coefficient (0.20 to 0.4)
	I	=	Importance factor (1 to 1.25)
	W_p	=	Weight of ceiling
	F_p	=	Lateral force.

Rewrite $C_p = 0.75ZI$

C_p	=	0.30	for $I = 1$ (normal buildings)
			and $Z = 0.4$ (Zone 4)

Maximum value of $I = 1.25$ for essential facilities.

The SEAOC code typically forms the basis for subsequent revisions of the UBC.

3. **California Administrative Code 1988, Title 24** (Ref. 23)

Based upon the UBC with specific additions for state owned facilities. Design levels are as UBC, but $I = 1.25$ is required for hospital buildings.

4. **OSA Title 24** (Ref. 15)

Generally as UBC. Specific values are listed:

Schools	(occupancy <300),	$I = 1.0$	$C_p = 0.3$
Schools	(occupancy >300)	$I = 1.15$	$C_p = 0.345$
Hospitals		$I = 1.5$	$C_p = 0.45$

5. **BOCA 1987** (Ref. 24)

$$F_p = C_p Z I W_p$$

Where:

C_p	=	Basic coefficient for suspended ceilings (0.3)
Z	=	Seismic zone coefficient ($1/_8$ to 1)
I	=	Occupancy importance factor (1.0 to 1.5)
W_p	=	Weight of ceiling
F_p	=	Lateral force.

Rewrite $C_p = 0.3ZI$

$C_p = 0.30$ for $I = 1$ (normal buildings) and $Z = 1$ (Zone 4)

Maximum value of $I = 1.5$ for essential facilities.

6. **NEHRP** (Ref. 25)

Cp = 0.9 for fire rated ceilings

= 0.6 for other ceilings.

7. **TRI - Services Manual** (Ref. 18)

Recommends the use of 2 times the C_p values of the UBC. Effectively requires an importance factor, I of 2.

8. **Veterans Administration** (Ref. 26)

C_p = 0.5 for base accelerations greater than 0.15g

= 0.2 for base accelerations between 0.1g and 0.15g.

9. **SF-DPW Code Ruling 73-8** (Ref. 27)

C_p = 0.2

Note: Refs. 9 and 10 predate the 1988 UBC and presumably have been, or will be changed to match.

10. **LA - DBS, RGA 4-74** (Ref. 28)

$C_p \quad = \quad 0.2$

See <u>Note</u> to Item 9.

5.3 Japan (Ref. 29)

$C_p \quad = \quad Z.I.K_1.K_2.K_o$

Where:

$Z \quad = \quad$ Seismic zone coefficient (0.7 to 1.0)
$I \quad = \quad$ Equipment importance reduction factor (1, $^2/_3$)
$K_1 \quad = \quad$ Building amplification factor (1 to 10/3)
$K_2 \quad = \quad$ Equipment amplification factor (1, 1.5, 2)
$K_o \quad = \quad$ Standard seismic coefficient (0.3).

$C_p \quad = \quad 0.30$ to 1.33 for $I = {}^2/_3$ (general equipment)
and $Z = 1.0$

Maximum value of I = 1.0 for important equipment.

The above range of C_p values is for all nonstructural components and equipment. As most of the literature from Japan is in Japanese it is difficult to be any more specific.

5.4 Australia

AS 2121 - 1979 (Ref. 30)

$H_p \quad = \quad ZIC_pSW_p$

Where:

H_p = Horizontal ceiling force
Z = Zone factor (0 to 0.36)
I = Importance factor (1, 1.2)
C_p = Horizontal force factor (0.2)
S = Site-Structure resonance factor (0.5 to 2.5, 1.5 typ)
W_p = Weight of ceiling.

Rewrite $\quad C_p \quad = \quad 0.2ZIS$

$C_p \quad = \quad 0.11$ for $I = 1$ (nonessential facilities)

Maximum value of I = 1.20 for essential facilities.

Design coefficient, C_p applies only to the highest Seismic Zone 2. No requirements are given for other areas.

5.5 Mexico (Ref. 31)

$C_p = a(1 + 4c'/c)$

Where:

	a	=	Non reduced design acceleration
	c	=	Seismic coefficient (0.16 to 0.4)
	c'	=	c/Q
	Q	=	Seismic behaviour factor
	C_p	=	0.11 to 0.59 for appendages. Deemed to include suspended ceilings.

5.6 Switzerland

SIA 160 (1989) Chapter 19

For Class III (Hospitals, Lifelines, etc) facilities a "verification of safety and serviceability of suspended ceilings is required". But no further details are given.

5.7 Chile

No local code requirements. The seismic design of such structural elements is performed using foreign codes.

5.8 Turkey

The current effective earthquake design code contains only a veiled reference to similar items. The new version of the code, still under review also does not contain any explicit requirements for suspended ceilings.

5.9 China

China has no regulations for suspended ceilings. The seismic design of suspended ceilings mainly depends on the experience of engineers.

5.10 Greece

Neither the existing seismic design code, nor the first draft of the new regulations, address the subject of suspended ceilings.

5.11 India

Suspended ceilings are rarely used, and are generally considered unimportant by designers, although their damage could mean economic loss. The Indian Code on design and construction of earthquake resistant buildings cautions the designers and says:

> "Suspended ceilings shall be avoided as far as possible. Where provided they shall be light and adequately framed and secured".

5.12 Comparison of Load Levels

Summaries of the C_p values from Sections 5.1 to 5.5 are given in Tables 5.1 and 5.2

Table 5.1: Lateral Force Coefficients

Country	Code	C_p Values for Normal Buildings		Risk or Importance Factor	
		Minimum	Maximum	Normal	Maximum
New Zealand	NZS 4203:1984	0.2	0.6	1	1.6
	2/DZ 4203:1990	0.07	1.41	1	1.3
	PW 81/10/1:1985	0.2	0.6	1	1.6
United States of America	SEAOC 1990	0.15	0.30	1	1.25
	UBC - 1988	0	0.30	1	1.25
	CA Admin. Code	0	0.30	1	1.25
	OSA, Title 24	-	0.30	1	1.5
	BOCA 1987	0.04	0.30	1	1.5
	NEHRP	-	0.6	1	1.5
	Vet. Admin.	0.2	0.5	1	-
	SF-DPW	-	0.2*	1	-
	LA-DBS	-	0.2*	1	-
Japan	AIJ	0.21	1.33	2/3	1.0
Australia	AS 2121-1979	-	0.11	1	1.20
Mexico		0.11	0.59	1	-

Table 5.2: Maximum C_p Values including Risk or Importance Factors for Primary Zone

Recommendation	Ref	Normal	Schools <300	Schools >300	Important Facilities (Restoration) Period	Essential Facilities, Hospitals, (During EQ)
NZS 4203:1984	19	0.6			0.78	0.96
2/DZ 4203:1990	20	1.41			1.55	1.83
PW 81	21	0.6			0.78	0.96
UBC 1988	8	0.30				0.375
SEAOC 1990	22	0.30				0.375
CA Admin.	23	-	0.30	0.30		0.375
OSA Title 24	15	-	0.30	0.345		0.45
BOCA 1987	24	0.30			0.375**	0.45
NEHRP	25	0.60				0.90
Tri-services	18	-				0.60
Vet. Admin	26	-			0.50	
SF-DPW	27	0.20				
LA-DBS	28	0.20				
Japan *	29	1.33				2.00
AS 2121-1979	30	0.11				0.13
Mexico	31	0.59				

* These are maximum values for non-structural items, may not be directly applicable to suspended ceilings.

** Defined as greater than 300 endangered persons.

An anomaly arises when comparing both the C_p values and the Risk or Importance factors. The seismicity of Zones 3 and 4 in the USA are similar to that of Zone A in New Zealand and yet the New Zealand maximum C_p values are twice that for the USA. Also the increase for essential facilities varies between codes from nil to a 60% increase.

6.0 Existing Code Requirements/Recommendations

The following sections (6.1 to 6.8) are a summary of the minimum requirements of the codes and recommendations received.

6.1 Support and Clearance at Free Ends of Tees

When the terminal ends of cross or main tees are not connected to a wall angle certain conditions must be met. These vary between codes, but the items generally covered are the provision of an additional end hanger (within dimension a); clearance to walls (dimension c) and provision of a stabilizer bar (at dimension b)to stop spreading of the ends of the tee rails. Refer to Fig. 6.1 and Table 6.1 for these dimensions.

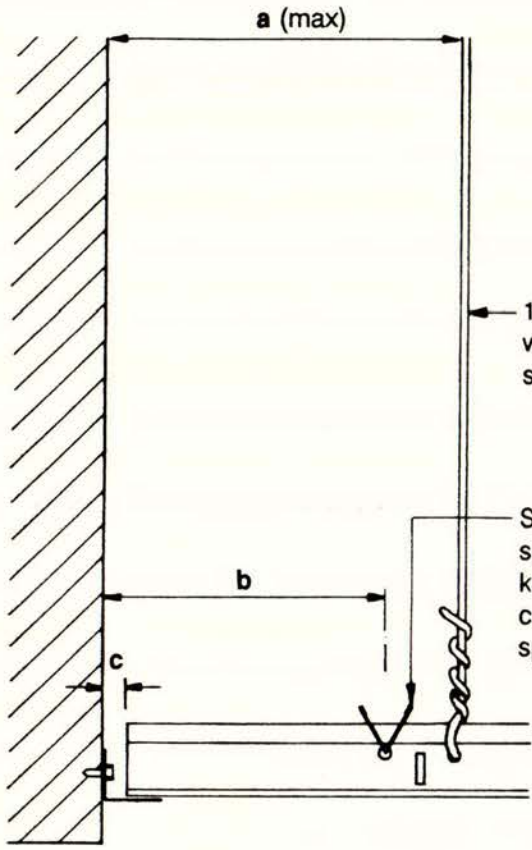


Fig. 6.1 Standard End Dimensions

Table 6.1: Tee Rail End Detail Requirements and Dimensions

Codes/ Recommendations	Extra Hanger	Max. a (mm)	Spacer Bar	Max. b (mm)	Min. c (mm)
NZ 4203 (Ref. 19)*	N	Nil	N	N	N
AIJ - Aseismic Design:Y Section 13 (Ref. 32)	150	Y	<a	15	
PW 81 (Ref. 21)	Y	100	N	-	5 (Note 1)
UBC-88 (Ref. 9)	Y	203	Y	610 (Note 2)	-
ASTM E580 (Ref. 17)	Y	203	Y	610	6.4
CISCA Zones 3 & 4 (Ref. 33)	Y	203	Y	<a (Note 3)	12.7
CISCA Moderate & Low Risk (Ref. 34)	Y (Note 6)	203	Y	-	9.5/13 (Note 7)
CISCA Zones 0-2 (Ref. 35)	Y (Note 6)	152	Y	-	9.5 (Note 8)
OSA Title 24 (Ref. 16)	Y	203 (Note 4)	Y	-	12.7
Clark & Glogau (Ref. 36)	Y	100	Y	(Note 5)	5 (Note 1)
EQE Engineering Inc. (Ref. 7)	Y	152	Y	(Note 5)	3.8
Rihal & Granneman (Ref. 11)	Y	152	N	-	-
US - Japan Co-op (Ref. 37)	Y	152	Y	-	-

* New Zealand Code does not have a specific requirement. Some NZ ceiling suppliers advocate appropriate valves.

Notes:

1. For unbraced and tension only braced ceilings provide a clearance equal to one-third of the ceiling plenum depth, or a vertical strut from the horizontal restraint point to the structure above.

2. California Administrative Code (Ref. 23) requires that ends of all main and cross tees longer than 305mm (12 inches) be restrained against spreading.

3. Applicable to cross tees only.

4. Minimum of this value and tee rail span divided by four (L/4)

5. Recommends the use of a closing runner or tee at free end.

6. Not required if support ledge is at least 22mm deep with a minimum of 9.5mm seating.

7. Values are for Zones 1 and 2 respectively, no seismic requirements for Zone 0.

8. Increase to 12.5mm for essential facilities.

6.2 Hanger Clearance to Services

A clearance of 150mm (6 inches in US documents) between unbraced services and ducts and hanger wires is specified in the following documents:

ICBO evaluation of UBC 47-18 (Sept 1989)	(Ref. 38)
OSA Title 24 (1989)	(Ref. 16)
NZS 4219:1983	(Ref. 39)

NZS 4219 waives the 150mm requirement when both the ceiling and services are braced, or the hangers are less than 200mm long.

6.3 Lighting

1. **NZS 4203** (Ref. 19)

    - Requirement as for tiles, that the distance between supports shall not increase by more than 5mm under the design load.

    - Fixtures shall be anchored to their supports against a net upwards force equal to one-third of their weight.

2. **NZS 4219** (Ref. 39)

    - Fixtures less than 10kg shall be positively clamped to the tee rails.

    - Surface mounted fixtures shall be mounted on the grid rails by at least two fixings.

    - Fixtures exceeding 10kg shall be fixed to the structure above. Such fixing shall not allow the equipment to drop by more than 100mm.

    - Pendant fixtures exceeding 10kg shall have two supports to a suitable structure.

3. **PW81** (Ref. 21)

- Pendant lights should not be used in essential facilities.
- For essential facilities provide additional hangers to fixtures whose weight is greater than four times the dead load of the ceiling alone.
- Provide independent support to all fixtures in excess of 25kg. Support shall not allow fixture to drop by more than 100mm, and should be designed with a factor of safety of 5.

4. **UBC-88** (Ref. 9)

- Attach fixture to grid for 100% of weight in any direction.
- Provide 2 no. 12 ga. slack wires for fixtures less than 25kg.
- Provide approved hangers for fixtures greater than 25kg.

5. **California Administrative Code** (Ref. 23)

- As for UBC.

6. **ASTM E580-78** (Ref. 17)

- As for UBC for recessed fixtures.
- Surface mounted fixtures require clamps around grid and slack wires from clamps.
- Pendant lights require a 9 ga. slack wire hanger.

7. **CISCA Zones 3 and 4** (Ref. 33)

- As for UBC, plus:
- Fix additional hangers to intermediate duty rails within 76mm of all four fixture corners.
- Earlier edition (1972) included clamps and slack wires for surface mounted fittings.
- Pendant lights require a 9 ga. wire hanger.

8. **CISCA Moderate & Low Risk** (Ref. 34)

- Independent support is required for fixtures in excess of 25kg.

- Attach fixtures less than 25kg with 2 no. 12 ga. wires to the structure above.

9. **CISCA Zones 0 to 2** (Ref. 35)

- Attach fixtures less than 25kg with 2 no. 12 ga. wire hangers to the structure above.

- Fixtures in excess of 25kg must be independently supported.

10. **OSA, Title 24** (Ref. 16)

- Attach fixture to grid for 100% of weight horizontally.

- Attach fixtures less than 25kg with 2 no. 12 ga. wire hangers to the structure above.

- 1.22m x 1.22m lights require 4 no. 12 ga. slack wires.

- Attach 4 no. 12 ga. taut wires to fixtures greater than 25kg, with a factor of safety against failure of 4.

- Surface mounted fixtures require two positive devices which surround the ceiling runner, and which are each supported by a 12 ga. wire to the structure above.

- Surface mounted fixtures in excess of 2.44m length require additional fixings.

- Pendant mounted fixtures require a hanging wire capable of four times the fixture weight.

11. **Clark & Glogau** (Ref. 36)

- As for PW81.

12. **BAREPP** (Ref. 40)

- Fix 12 ga. wires at each corner of fixtures, or at least diagonally opposite, or screws or clips to tee rail.

- Provide wire support to pendant fixtures.

13. **California Schools** (Ref. 41)

- Fix 12 ga. wires at each corner of fixtures, or at least diagonally opposite.

- For exposed fluorescent light bulbs or fixture lenses subject to falling, secure in place with 2 wires that wrap beneath the lens or bulb and attach securely to the fixture.

- Pendant lights require a wire bolted to the fixture and anchored to a structural member.

14. **SF DPW, Code Ruling 73-9** (Ref. 27)

- General compliance with the CISCA recommendations is required, plus

- Fixtures weighing less than 9kg require hanger wires to grid within 76mm of corners of fixtures.

15. **LA DBS, RGA 4-74** (Ref. 28)

- Attach fixtures to grid for 100% of weight horizontally and 300% vertically.

- Wire hangers are required to structure above for all recessed lights exceeding 25kg and pendant lights exceeding 9kg.

6.4 Other Fixtures

1. **NZS 4203** (Ref. 19)

- Fixtures shall be anchored to their supports against a net upwards force equal to one-third of their weight.

2. **NZS 4219** (Ref. 39)

- As for lighting.

3. **PW81** (Ref. 21)

- As for lighting.

4. **UBC-88** (Ref. 9)

- Positively attach fittings less than 9kg to the main tees, or to equal strength cross tees.

- Fittings of mass greater than 9kg but not more than 25kg shall also have 2 no. 12 ga. slack wires to structure above.

- Fittings in excess of 25kg shall have approved hangers from the structure above.

5. **California Administrative Code** (Ref. 23)

- As for lighting.

6. **ASTM E580** (Ref. 17)

- Fittings in excess of 9kg require positive attachment to the ceiling suspension system.

7. **CISCA Zones 3 and 4** (Ref. 33)

- As for UBC.

8. **CISCA Moderate and Low Risk** (Ref. 34)

- As for lighting.

9. **CISCA Zones 0 to 2** (Ref. 35)

- As for lighting.

10. **OSA, Title 24** (Ref. 16)

- As for lighting.

11. **Clark & Glogau** (Ref. 36)

- As for PW81.

12. **BAREPP** (Ref. 40)

- Positively attach fittings to rigid ducts braced to structure.

13. **California Schools** (Ref. 41)

- Provide anchorage for fittings.

14. **SF DPW, Code Ruling 73-9** (Ref. 29)

- As for lighting.

15. **LA DBS, RGA 4-74** (Ref. 28)

- As for pendant lighting, *i.e.* wires required for fixtures in excess of 9kg.

6.5 Partitions

1. **PW81** (Ref. 21)

- Make allowance for partition seismic weight of ceiling of 0.2 kPa in design.

2. **UBC-88** (Ref. 9)

- Make allowance for partition seismic weight, but no guidance given.

3. **ASTM E580** (Ref. 17)

- Make allowance for partition seismic weight in design, or provide extra bracing at the top of the partition.

4. **CISCA Zones 3 and 4** (Ref. 33)

- Make allowance for partition seismic weight in design of ceiling and connections.

5. **CISCA Moderate and Low Risk** (Ref. 34)

- Walls or partitions must be independently supported and not connected to the ceiling.

6. **CISCA Zones 0-2** (Ref. 35)

- Zone 1 and 2 ceilings may have partitions attached provided they allow the ceiling membrane to move laterally.

7. **ICBO Evaluation** (Ref. 38)

- Partitions may be braced by 45 degree 12 ga. wires at 2.44m along partition, or a separate design brace. Detail provided is applicable for partitions up to 3.05m high, not exceeding 0.72 kPa.

8. **OSA, Title 24** (Ref. 16)

- Allow for partition seismic weight, unless it is braced with wires at maximum 2.44m centres.

9. **Clark & Glogau** (Ref. 36)

- The connection between the top of the partition and the ceiling should allow movement in the plane of the partition.

- Make allowance for partition seismic weight of 0.2 kPa in design.

10. **SF DPW, Code Ruling 73-9** (Ref. 27)

- A minimum allowance of 0.024 kPa (0.5 psf) over the ceiling area is to be made for partitions.

- Partition seismic weights should be based upon 0.24 kPa (5 psf) minimum dead load on elevation.

6.6 Bracing Requirements

1. **NZS 4203** (Ref. 19)

- Avoid sudden or incremental failure, or excessive local or cumulative deformations that would release ceiling components likely to cause a hazard to the occupants.

- Primary and secondary support members shall have positive mechanical connections to each other and to the building.

2. **PW81** (Ref. 21)

- Provide either horizontal bracing of ceiling to walls, or;

- Provide bracing members between the ceiling plane and the structure above.

- Tension only bracing should incorporate vertical struts between each horizontal restraint point and the structure above, or an edge clearance equal to one third of the plenum height. (*See* also Note 1 to Table 6.1.)

- Bracing may be provided by four diagonal tension braces connected t the main runner within 50mm of the cross runner. Braces shall be splayed at 90 degrees, and at 45 degrees to the ceiling plane. Spacing shall be a maximum of 4m centres and 1m from perimeters. Vertical struts are also required in conjunction with the tension braces.

3. **UBC-88** (Ref. 9)

- Provide 4 no 12 ga., 45 degree splayed wires each within 51mm (2 inches) of cross/main tee intersection, or bracing point. Fixings shall have a design load of 0.89 kN with a factor of safety of 2.

- A vertical strut shall extend from the bracing point to the structure above.

- Bracing points shall occur on a 3.66m x 3.66m grid, not greater than 1.83m from all walls.

- Alternatively may provide substantiating calculations for an alternative system.

4. **California Administrative Code** (Ref. 23)

- As for UBC, but in hospitals bracing must be located on a 2.44m x 3.66m grid and the distance to surrounding walls may not exceed half of these values.

5. **ASTM E580** (Ref. 17)

- Ceilings of 13.4 m^2 or less surrounded by walls that connect directly to the structure above do not require bracing.

- Otherwise criteria are as for UBC.

6. **CISCA Zones 3 and 4** (Ref. 33)

- As for ASTM E580.

7. **CISCA Moderate and Low Risk** (Ref. 34)

<u>Document excludes Zones 3 and 4</u>:

- For all zones where the average seismic ceiling weight is less than 0.12 kPa fixing to two adjacent walls constitutes adequate bracing.

- Ceilings exceeding 0.12 kPa may be installed as for the 1988 UBC taking into account the design lateral force factor appropriate to the zone.

- Zone 1 requires a 19mm support ledge and clearance of 10mm for the terminal ends of numbers. Values for Zone 2 are 25mm and 13mm respectively. (*See* Table 6.1.)

8. **CISCA Zones 0 to 2** (Ref. 35)

- No bracing is required in Zones 0 and 1 except fixing to two adjacent walls. Similarly for Zone 2 where the average seismic ceiling weight does not exceed 0.12 kPa.

- Zone 2 ceilings exceeding 0.12 kPa may be installed as for the 1988 UBC, taking into account the design lateral force factor appropriate for Zone 2.

9. **OSA, Title 24** (Ref. 16)

- As for California Administrative Code.

10. **Clark and Glogau** (Ref. 36)

- As for PW81.

11. **SF DPW Code Ruling 73-9** (Ref. 27)

- Provide vertical struts at bracing points (main/cross tee intersection).

- Provide 4 no. 12 gauge, 45 degree splayed wires within 51mm of the bracing point, 2 of these wires should be connected to the vertical strut, or to the grid members where these are capable of transferring the induced load.

- Use 10 gauge wires when partitions are to be supported.

- Bracing points shall be at 3.66m centres and a maximum of 1.22m from walls.

- Where seismic ceilings weights exceed 0.19 kPa (4 psf) reduced brace spacing accordingly.

12. **LA DBS, RGA 4-74** (Ref. 28)

- Provide bracing wires and struts similar to UBC requirements.

- Ceilings less than 13.4 m^2 do not require bracing.

- Bracing points shall be at 3.66m centres and a maximum of 1.22m from walls.

13. **AIJ Aseismic Design, Section 14** (Ref. 32)

- Documents are in Japanese.

- Diagrams indicate the use of cross bracing in both the horizontal and vertical planes.

- Preference appears to be for both hangers and bracing to be steel rod rather than wire.

6.7 Seismic Ceiling Weights

The default bracing requirements in American codes such as the 1988 UBC, OSA Title 24 and ASTM E580 (Refs. 9, 16 and 17) are based upon an average ceiling weight of 0.19 kPa. The Veterans Administration (Ref. 26) code specifies that a minimum of 0.24 kPa be allowed as the average ceiling weight.

The CISCA recommendations (Refs. 34 and 35) for seismic zones other than Zones 3 and 4 suggest that for ceiling weights below 0.12 kPa bracing is ineffective and unnecessary.

PW81 and Clark and Glogau (Refs. 21 and 36) recommend an allowance of 0.2 kPa for the partitions in addition to the actual ceiling weight.

AS 2121 (Ref. 30) recommends a minimum value of 0.2 kPa should be used as the ceiling weight. Although AS 2121 prescribes loadings for suspended ceilings, AS 2785-1985 (Ref. 42) has no lateral design requirements.

SF DPW, Code ruling 73-9 (Ref. 27) requires a minimum lateral design load of 0.038 kPa (0.8 psf) which is based upon a C_p of 0.2 and a ceiling weight of 0.19 kPa (4 psf).

6.8 Minimum Requirements for Components

Table 6.8 summarises the minimum requirements of codes for testing of components.

Table 6.8: Values of Component Minimum Test Values

Recommendations/ Code (Note 1)	Member Strengths (kN)	Splice Strengths (kN)	Connection to.Structure (kN)	Bracing Structure (kN)	Vertical Strut (kN)
NZS 4203 (Note 2) (Ref. 19)	-	0.05	0.05	-	-
PW81 (Note 3) (Ref. 21)	1.0	1.0	1.0 (Note 10)	1.0/1.5 (Note 4)	75% (Note 5)
UBC-88 (Ref. 9)	0.80 (Note 6)	0.80 (Note 6)	-	0.89	(Note 7)
ASTM E580 (Note 8) (Ref. 17)	0.53	0.53	(Note 10)	-	-
CISCA Zones 3 & 4 (Ref. 33)	As for UBC-88				
CISCA Moderate & Low Risk (Ref. 34)	0.27	0.27			
CISCA Zones 0-2 (Ref. 35)	0.27	0.27			
OSA Title 24 (Ref. 16)			3.82/2.33 (Note 9)		
ATC29 Seminar (Ref. 43)	0.89	0.89	0.89	2.23	-
Clark & Glogau (Ref. 36)	As for PW81				
US-Japan Co-op (Ref. 37) (Note 6)	0.80	0.80	-	-	-
SF DPW, 73-9 (Ref. 27)	1.28	1.28	-	-	-
LA DBS, RG A4-74 (Ref. 28)	0.53	0.53	-	-	-

Notes:

1. All values are ultimate strengths and require a factor of safety = 2 to determine allowable loads, unless noted otherwise.

2. Design shear or upward reaction of one-third of the gravity load but not less than 50N.

3. These values apply in tension, compression and shear.

4. Values listed are for ceiling in-plane / out-of-plane bracing respectively.

5. Compression capacity shall not be less than 75% of the associated tension brace.

6. Or 2 times the calculated values based on 3 tests with a standard deviation not exceeding 10%. Test joints at 5 degrees or 1 in 24 out of alignment.

6.9 Vertical Accelerations

1. NZS 4203 (Ref. 19)

- Fixtures shall be anchored to their supports against a net upwards force equal to one-third of their weight.

2. PW 81 (Ref. 21)

- Ceiling tiles and ceiling mounted fixtures and fittings shall be built into the grid system to resist an upwards force which is the greater of one-third of their weight or a differential pressure of 0.3 kPa.

3. UBC088 (Ref. 9)

- Fixtures shall be attached to the ceiling grid for 100% of their weight in any direction.

4. California Administrative Code (Ref. 23)

- As for UBC.

5. ASTM E580-78 (Ref. 17)

- As for UBC for recessed fixtures.

6. CISCA Zones 3 and 4

- As for UBC.

7. Clark & Glogau

- As for PW 81.

7.0 Comparison of Requirements

Codes and recommendations vary in many aspects of both load levels and detailing as outlined in Sections 5 and 6. Some of the required details have been tested, both in dynamic shake table tests and in actual earthquakes. The following sections discuss how codes and recommendations compare with each other and with the testing.

7.1 Support and Clearance at Free Ends of Tees

7.1.1 Additional End Hangers

The use of an additional end hanger for tee rails not connected to the perimeter is now required by all recent publications received. The need for these hangers is reinforced by the falling of edge tiles observed in testing and in past earthquakes. (*Refer* Section 3.3.)

The effectiveness of end hangers is seen by a comparison of test specimens 9 and 9A damage observations in the Rihal and Granneman report (section 4.2.4.3.c). Despite the grid pulling away from the wall angle, the grid did not fall and so the tiles were also restrained.

Hole spacings in the main tee bulbs are typically 54mm. Therefore, a 100mm requirement would allow only one support hole to be used. 150 and 200mm dimensions will give the choice of 2 or 3 holes respectively. Along with the allowable 1 in 6 (maximum) out of plumb requirement for all vertical hangers, the two and three hole alternatives would provide increased construction tolerances.

The maximum dimension limitation given from the wall to the end hanger varies from 100mm to 203mm. OSA Title 24 (Ref. 15) requires 203mm maximum or one-quarter of the length of the rail, whichever is the lesser.

The one-quarter length of rail requirement is a logical extension of the end support criterion, as it ensures that the rail is stably supported.

7.1.2 Spacer Bars

Most United States and Japanese codes require the use of spacer bars between free ends of tee rails. Some recommendations call for end closers, others only require a spacer within 610mm of the terminal end, still others do not specify the exact position. The California Administrative Code (Ref. 23) requires only connection for ends of runners in excess of 305mm. The need for the spacer bars is to prevent the end tees from spreading apart and allowing edge tiles to fall out. Based on this, the positioning of the spacer bars would follow the same stability criteria as the end hangers.

However the phenomenon of spreading of spacer bars can only occur when the ceiling is not restrained in the direction perpendicular to the tees. This is a fairly common construction technique in the USA where fixing to two adjacent walls only is allowed. In the case of an unbraced ceiling fixed to four walls this requirement becomes redundant.

7.1.3 End Clearances

The values of end clearances vary widely between different recommendations. Values between 6.4mm and 38mm are mooted. PW81 and Clark and Glogau (Refs. 21 and 36) suggest that a ceiling without bracing i.e. allowed to swing freely, or a tension only braced ceiling should have clearances of one-third of the ceiling plenum height, unless a vertical strut is provided. This clearance is clearly difficult to achieve at the ceiling edges, if not impossible in most cases. Therefore tension only bracing normally could not comply with this requirement (e.g. wire splay bracing without the vertical strut). The large deflections suggested by the one-third requirement are also reflected in the ANCO Engineer's testing (Section 3.1).

The rationale for the clearances varies for some recommendations as they apply to different seismic zones. The purpose of these clearances is, however to prevent impact or pounding of the ceiling on the perimeter walls.

The magnitude of the separation is thus a function of the interstorey drift requirements, the ceiling plenum depth and interfloor height. Thus the recommended clearance, c (Fig. 6.1) between the end of the tee rail and the penetrations of the structure is:

$$c = d(h) * h_p/h$$

Where:
- $d(h)$ = interstorey drift, generally a function of h
- h_p = ceiling plenum height
- h = interstorey height

This form of calculation is based upon a straight line approximation of interstorey drifts and as such is conservative for deflections at the level of the suspended ceiling.

For a typical office building with an interstorey height of 3.7m and a ceiling height of 2.7m using NZS4203 interstorey drift requirements, the following results are obtained for Zone A.

h = 3700mm
$d(h)$ = 0.010 x h, nonstructural elements separated
h_p = 3700 - 2700 - 150 (floor)
= 850mm
therefore c = 0.010 * 3700 * 850/3700
= 8.5mm

The take up of load in bracing (especially splayed wires) results in deflection of the ceiling relative to its supporting structure. A further increment of deflection occurs as a result of rocking of the ceiling between bracepoints. No research has been done in these areas. An allowance of 5mm for these effects seems appropriate in the absence of test data.

The above type of analysis would be suitable as the basis for establishing minimum clearances for a braced ceiling. A suitable requirement for New Zealand would be to state that for ceiling plenum heights not exceeding 1.0m, the separation distance from penetrations of a braced ceiling shall be 15, 13 and 10mm for Seismic Zones A, B and C respectively. These values would be equally applicable for clearances to penetrations in an unbraced ceiling.

The conservatism of this approximate calculation should allow for the movement of the ceiling due to the elongation of the brace. This value would be 2mm for the above example. The question of slack in bracing connections is discussed in Section 7.6.

Many of the American codes allow braced ceilings to be connected to wall angles on a maximum of two adjacent walls, and the required clearances are to be provided to other walls. This allowance is to facilitate simpler installation procedures. As described in Sections 4.1.4.4 and 5, this causes a conflict as the connection acts as the defacto load resisting element until failure occurs. Then at failure there are no clearances to allow the bracing to resist the load, nor is there any end support of the tees to prevent tile drop-out. Hence this is not a satisfactory allowance.

7.2 Hanger Clearance to Services

Those recommendations which cover this topic all give a value of 150mm (6 inches in US publications) as the minimum clear distance between suspended ceiling hangers and unbraced services and ducts. In many ceiling spaces this clearance could be difficult to achieve due to the abundance of services within the ceiling plenum.

NZS 4219 allows the 150mm limit to be relaxed when hangers are less than 200mm long, or when both the ceiling and services are braced. Other codes also allow this by implication, but no guidance is given. A minimum clearance between braced services and braced ceiling components should be maintained, but 150mm is clearly excessive.

7.3 Lighting

All wire hangers required for light fixtures are required to be proportioned such that the required load can be carried with a factor of safety (FOS) of 4, except PW81 (Ref. 21) which calls for a FOS of 5. In the case of fixtures hung from two wires, in accordance with: UBC-88; OSA, Title 24; ASTM E580-78; California Administrative Code; CISCA, Zones 3 and 4; CISCA Moderate and Low Risk; CISCA Zones 0 to 2; BAREPP and California Schools (Refs. 9, 15, 17, 23, 33-55, 40 and 41), it would appear that each wire is capable of carrying the full fixture weight with a FOS in excess of 4. The requirement of each of the codes is for two 12 ga. wires, which are each capable of carrying 237kg (524 lb). However the reduction in strength of the wire due to bending around connections and through the tees is unknown.

1. Pendant Mounted Fixtures

Most recommendations require the use of slack wire hangers connected to the light fixture and to the structure above.

Where called up a No. 9 gauge (3.77mm) wire is specified for this purpose. Where 45 degree motion of adjacent fixture could cause impact this risk should be mitigated.

PW81 (Ref. 21) requires that pendant mounted lights be excluded from essential facilities.

NZS 4219 (Ref. 39) requires two supports for fixtures in excess of 10kg.

2. Surfaced Mounted Fixtures

Where recommendations separately mention fixings for surface mounted fixtures, a connection which surrounds the supporting tee rail is required. These clamps must positively lock closed. The clamps in turn must have 12 ga. slack wires from them to the structure above.

Generally, two of these clamps and wires are called for. OSA Title 24 (Ref. 15) requires additional hangers for fittings in excess of 2.44m long.

3. Grid Mounted Fixtures

Most recommendations require that all grid mounted fixtures be connected to the ceiling grid for 100% of the fixture weight. Some references go further and suggest that this should allow for 100% of the fixture weight in any direction.

Additionally fixtures less than 25kg (56lbs) require 2 no. 12 ga. slack wires connected to the structure above. Independent support or approved hangers are called for by some codes for fixtures in excess of 25kg.

OSA, Title 24 requires that 1.22m x 1.22m (4 ft x 4 ft) fixtures have four slack no. 12 (2.68mm) wires. It requires also fittings in excess of 25kg are to have 4 taut wires, designed with a FOS of 4, to the structure above.

NZS 4219 (Ref. 39) does not require wire hangers for fixtures less than 10kg. However for fixtures greater than 10kg (with no upper limit) fixings are required to the structure above that do not allow the fixture to drop more than 100mm.

The ANCO Engineer's report concluded that safety wires are a simple and cost effective seismic hazard mitigator (*refer* Section 4.1.5).

7.4 Other Fixtures

Most recommendations do not distinguish between light fixtures and other ceiling mounted fixtures, or the requirements given are identical. One notable exception is the 9kg (20 lb) lower limit requiring additional wire supports, as given in the UBC and ASTM codes (Refs. 9 and 17).

7.5 Partitions

There are two types of partitions that affect suspended ceilings. The first is full height, or floor to floor partitions which are generally considered as a part of the structure providing lateral support to the ceiling. Therefore ceilings are fixed to them as limited by the applicable code.

Secondly, partial height partitions, or those which are attached to the suspended ceiling are the main subject of code requirements as these rely upon the ceiling for their stability. The rest of this section refers to partial height partitions.

Most references require that an allowance be made for partition weight in calculations. CISCA (Ref. 34) moderate and low risk area recommendations suggest that partitions should be independently supported and not connected to ceilings. This however is not how partitions are installed.

PW81 and Clark and Glogau (Refs. 21 and 36) require that an allowance of 0.2 kPa be made for the seismic weight of partitions. Only the weight of partitions perpendicular to the direction of loading need be considered as adding to the seismic weight.

The values specified by PW81 and Clark and Glogau are overly conservative when compared to typical partition installations. For a typical steel or timber 2.7m stud wall with 12.5mm Gib Board both sides, the face load is 0.3 kPa (compare 0.24 kPa, SF DPW:73-9, Section 6.5.10).

To achieve the value of 0.2 kPa partition allowance in PW81 would require walls perpendicular to the direction being considered spaced at 2.03m centres (based on C_p = 0.6 from Section 5.1.1). This is clearly not a realistic situation.

SF DPW, Code ruling 73-9 (Ref. 27) requires that a 0.024 kPa seismic weight over the ceiling area be allowed for partitions. Calculations of the actual weight contributed by partitions should be based upon partition weights of 0.24 kPa.

CISCA Zones 0 to 2 and Clark and Glogau (Refs. 35 and 36) recommendations require that partitions connected to the ceiling allow the ceiling membrane to move laterally. This requires that movement of the ceiling in the plane of the partition be allowed. Most proprietary ceiling systems are not detailed with any sliding connection to the ceiling.

OSA and ICBO (Refs. 15 and 38) recommend the use of 45 degree 12 gauge wires to brace the tops of partitions in addition to the typical ceiling bracing. The test results of Rihal and Granneman (*refer* Section 4.2.4.1a) indicate that the provision of these wires is satisfactory for providing stability for partial height partitions.

7.6 Bracing Requirements

Bracing of suspended ceilings is only specifically detailed in American codes. The requirements are generally given to apply to all ceilings unless other calculations or test data are provided. These requirements are based upon a seismic ceiling weight of 0.19 kPa (4 psf) and a C_p value of 0.3. The older codes such as the SF DPW and RGA4-74 (Refs. 27 and 28) use a C_p value of 0.2 but the same bracing is called for.

The bracing system consists of four 12 gauge wires splayed at 90 degrees to each other in plan and at not greater than 45 degrees to the ceiling plane, from a bracing point. A bracing point is a main/cross tee intersection. From this point most codes calls for a vertical strut up to the structure above. The wires are required to be fixed within 51mm (2 inches) of the bracing point.

The requirement for the vertical strut is addressed in both the ANCO and Rihal and Granneman test reports (*refer* Sections 4.1 and 4.2). Both conclude that the struts have very little effect upon the dynamic behaviour of the ceiling. The ANCO report concludes that the strut requirements do not appear justified (Section 4.1.5). Rihal and Granneman observed that the strut seemed to increase the initial stiffness (Section 4.2.4.2b).

A comparison of results given in Tables IV and V, Specimen Nos. 2 and 3, of the Rihal and Granneman report (Ref. 11) show that the introduction of the vertical strut causes a decrease in the ratio of measured acceleration versus input acceleration measured by nearly one half. In conjunction with this, the damping factor is doubled and the peak displacement of the ceiling is more than halved.

The observed damage at ceiling bracing points tends to be of three different types (*refer* Section 3.3.2). The first of these is stretch of the brace wire. In the pre-yield load zone this takes the form of straightening of the connection loops and tightening of the tying turns. Once the yield load is reached the wire will stretch inelastically.

The second observed failure is by tearing of the connection holes in the tee rail. The third failure mechanism is one of buckling of the main tee at the bracing point.

Addressing these last two items would appear to be the basis for the SF DPW, Code Ruling 73-9 requirement that the two brace wires, in the direction of the cross runners, be fixed to the strut. This however is not typically done, especially in the case of the proprietary spring struts which have a plastic bottom clip connection.

Vertical struts at bracing points serve in two other significant roles. The first of these is in the prevention of the phenomenon termed 'seismic bouncing'. This has been observed in large areas of suspended ceilings where the seismic action causes vertical waves in the grid system, dislodging tiles and damaging connections. The inclusion of vertical struts is quoted as a possible remedy for this (Ref. 34).

The second effect is an improvement of a construction related problem. Before vertical struts were used, ceiling installers always fixed the splayed wire bracing loosely to avoid pulling up the ceiling grid at the bracing points. This resulted in slackness in bracing wires which causes a jolting effect under lateral excitation (Section 4.1.4.1). With the vertical strut in place, the wire braces can be installed tight, providing a stiffer bracing system, with a reduced tendency to amplify input accelerations.

This splay wire bracing, even with the vertical strut still requires large deflections to fully mobilise the strength of the braces, often in excess of the minimum clearances. CISCA recommendations for moderate and low risk (Zones 0 - 2) seismic zones (Refs. 34 and 35) discourage the use of wire bracing and struts for all but heavier (greater than 0.12 kPa) ceilings in Zone 2 for this reason.

Also the bracing specified in the UBC-88 and related codes is not sensitive to zone factors, ceiling weights or heights within buildings. The 0.19 kPa ceiling (4 psf) on which the brace spacing is based corresponds to a moderate weight ceiling (*refer* Section 7.7).

However the greatest scope for improvement of ceiling bracing is in the area of specific design. The key area of concern, highlighted by the current UBC requirements, is that of deflections of the braced system. A stiffer system is less likely to result in pounding and its consequent damage.

PW81 (Ref. 21) also encourages the use of bracing in the plane of the ceiling. This is mentioned as one of the bracing alternatives. A specific design would be required for such a system.

Little consideration is given in design codes to the resistance of seismic loading by axial load in the grid members. Minimum component / connection requirements are given by most codes, but these are to comply with the need to transfer load to the braces. It is a simple extension of the same criteria to calculate allowable lengths of tee rails. EQE engineering alludes to this type of mechanism in their report (Ref. 7).

Most tiles are capable of providing the diaphragm action required to share loads and to distribute torsion. This fact is implicity assumed in the case of separate bracing points which require the tiles to act as a diaphragm between points of restraint. Thus a system of allowable tension and compression loads in the main and cross tees is a workable solution to the lateral restraint problem of suspended ceilings as any torsional effects are resisted by diaphragm action of the tiles.

The effectiveness of this mechanism is witnessed in both tests and earthquakes where the wall angle acts as the primary load resisting element until it fails. Often this occurs with no tee rail damage apart from pounding, indicating that the connection to the wall angle is the weak link.

7.7 Seismic Ceiling Weights

Recommendations for minimum ceiling weights vary enormously. An example of this is that the UBC (Ref. 9) restricts ceilings to a maximum of 0.19 kPa, while the SF DPW Code Rulings 73-9 (Ref. 27) imply that the 0.19 kPa value is the minimum design for bracing and higher values should be accommodated by reducing the brace spacing. OSA Title 24 (Ref. 15) only applies to ceilings not exceeding 0.19 kPa. No rationale appears to exist in many of the codes for the setting of a minimum design weight.

The CISCA recommendations (Refs. 34 and 35) go further to say that the standard UBC bracing is ineffective for lesser seismic zones, especially for lighter ceilings.

Actual ceiling weights vary significantly. An indication of the range of values is as follows:

- Very light tiles, small light fixtures, minimum partitions = 0.07 kPa
- Moderate weight tiles, typical light fixtures, typical partitioning = 0.19 kPa
- Heavy tiles, high intensity lighting, dense partitioning = 0.35 kPa

Care needs to be taken in applying the UBC-88 type of splay bracing, considering the data above.

7.8 Minimum Requirements for Components

Typical requirements in American codes and recommendations are in line with the UBC (Ref. 9) requirements for a 0.80 kN strength. This is to be applied in a test at an angle of 5 degrees or 1 in 24. SF DPW, 73-8 and PW81 (also Clark and Glogau) require 1.28 kN and 1.0 kN respectively. These values are to be applied without the angle requirements. The American codes predating the 1988 UBC have lower values corresponding to their lower C_p values. Other lower values occur in the USA recommendations for moderate and low risk (0 to 2) seismic zones, for the same reason.

A minimum component strength is given in conjunction with the minimum brace requirements in the American codes.

The requirement for a 5 degree or 1 in 24 misalignment is not consistent with the accuracy required of suspended ceiling grid installers.

When considering unbraced ceilings it is the minimum component strength that will determine the maximum unbraced length attainable. Full scale testing indicates that whole ceiling systems exceed their goal strengths (Section 4.1.1).

Failures, especially of cross tees, occurred in the recent Loma Prieta and San Fernando earthquakes, even when UBC ceiling bracing was installed. This suggests that either the limiting values are too low to prevent failure, or that these values are not obtained on site, or that some other load mechanism such as incidental wall connections may have caused the failure.

7.9 Other Miscellaneous Requirements

A number of requirements occur in the codes and recommendations which are peculiar to either a single code or to one country. One important item in this category is the question of tile clipping. This topic is covered more fully in Section 9. The following are some other items of this nature.

1. <u>5mm Extension</u>

   PW 81, NZS 4203, Clark and Glogau (Refs. 19, 21 and 36), all have a requirement that the ceiling support system be so designed that the distance between supports will not increase by more than 5mm under the design load. The reason for this requirement is somewhat unclear.

   If this clause is intended to restrict the movement apart of adjacent tee rails, then the reason would appear to be consistent with not allowing tiles to fall from the grid. In this respect it could be considered as an extension of the clauses in other codes, requiring spacer bars to stop spreading of tee rails at ends.

2. <u>Fixing to Two Walls</u>

   Most of the American codes allow a braced suspended ceiling to be fixed to wall angles, on not more than two adjacent walls. This however defeats the purpose of separating a braced ceiling by providing a defacto seismic restraint. The results are discussed in more detail in Sections 3.3.3, 4.1.4 and 4.2.4.

   The allowance is essentially to permit easier installation. The result however is at odds with the required seismic performance of the ceiling.

3. <u>Height Factors</u>

   NZS 4203 has a factor which is applied to the basic C_p which reduces for lower levels of the buildings. (*Refer* also 5.1.1.)

$\alpha = h_{cg}/h_n$

$K_x = h_x/k_{cg}$

Where: h_x = Height to the level in question
h_{cg} = Height to the centre of gravity of the building
h_n = Height to the top of the building
αK_x = 1 for single storey buildings
K_x cannot be less than 1 for multi-storey buildings.

Therefore the height factor is equal to 1 at the top of the building and reduces linearly down to hcg/hn at the height of the centre of gravity, hcg. All levels below this height have the same factor as at h_{cg}.

4. **Area Restrictions**

The California Administrative Code (Ref. 23) excludes the use of suspended ceilings in excess of 27.9 m^2 (300 sq. ft) in nurseries, emergency suits, laboratories and pharmacies, in hospital buildings.

8.0 The Clipping Question

8.1 Clip Description

Ceiling tile clips are snap-on attachments for the main tee rails designed to hold ceiling tiles down on the tee flange. Clips were traditionally formed from spring steel, though now injection moulded plastic clips are more commonly used.

Different clips are required for each tee type that has a differently shaped bulb at the top of the tee. Different clips are also needed for different tile thicknesses.

Each tile requires clips in four corners. Each clip fits over the rail and restrains the tiles on either side. Therefore on average a ceiling has two clips for each ceiling tile.

8.2 Current Code Requirements

8.2.1 NZS 4203 (Ref. 19)

- All suspended ceiling elements are to be positively anchored to the grid system for an upwards force equal to one third of their weight.
- Tiles which weigh less than 2kg and are of a shape and type that on falling would not be a hazard to occupants, need not have positive fixings.

8.2.2 PW81 (Ref. 21)

- As for NZS 4203, and
- Clips are also specified to resist a 0.3 kPa differential pressure between the lower and upper surfaces of tiles.
- The 2kg lower limit does not apply to exitways or essential facilities.

8.2.3 California Administrative Code (Ref. 23)

- All metal tiles and tiles weighing more than 0.024 kPa (0.5 psf) other than acoustical tiles shall be positively attached to the ceiling suspension runners. (This equates to a 1200 x 600 tile of 1.8kg mass.)

8.2.4 OSA, Title 24 (Ref. 15)

- As for the California Administrative Code.

8.2.5 Clark and Glogau (Ref. 36)

- Requirements as for PW81, plus
- Proposed details are given for reusable clips.

8.2.6 EQE Engineering Inc. (Ref. 7)

- The Installation guidelines include a clause calling for the provision of the manufacturers tile hold down clips, 4 per tile.

8.3 Need for Clipping

The New Zealand Codes require clipping for tiles in excess of 2kg and some American codes and recommendations are now including clipping requirements. However a consensus has yet to be reached.

The 2kg limit of tile weight, above which New Zealand codes require the use of clips is an arbitrary value which is intended to quantify the term "falling hazard". However it has been observed in earthquakes that debris on the ground in exitways, including suspended ceiling tiles are as great a risk as falling tiles. Regardless of weight, fallen tiles in exit ways restrict traffic flow and are thus undesirable. It would be prudent therefore, and in keeping with other requirements, to require all tiles in egress ways to be clipped regardless of their weight.

Some ceiling installers, architects and engineers are not convinced of the need for ceiling clips. Views range from tolerance of code requirements when insisted upon, through uncertainty of their effect, to adamant support.

Typically vertical accelerations measured in the dynamic testing or recorded in earthquakes do not exceed gravity yet a number of cases have been cited (Section 3.3.6) where ceiling tiles have fallen from the grid system which appears largely undamaged.

A number of explanations for this phenomenon are possible. Firstly the ceiling grid may amplify vertical ground motions, resulting in a net upwards force on the ceiling tiles. It is also possible that the upward component of the force induced in the bracing wire by the lateral load causes vertical accelerations in excess of the tile weight. This would occur mainly in the bracing systems without vertical struts, or where bracing wires are slack, causing impact type loads at the end of each motion (*refer* Section 4.1.4.1).

The use of clips on each tile is intended to provide the hold down force necessary to stop tiles from falling from the grid and to resist internal wind pressures. The effectiveness of clips designed to resist a minimum of one-third of the tile weight upwards is untested. Further research into this area may be warranted. However the appearance of clipping requirements in the California Administrative Code, OSA Title 24 and EQE Engineering Inc recommendations point to a realisation of their potential ability to mitigate this major falling hazard.

8.4 Use of Ceiling Clips on Site

The problems that surround the requirements for clips fall mainly into two categories. Firstly how many ceilings have clips actually in place. Secondly what purpose do the clips serve.

In order to answer the first question questionnaires were sent to ceiling installers, distributors and manufacturers throughout New Zealand (*refer* Section 8.4.1).

The question of clips also does not end after construction, many clips are dislodged during servicing. Experience of how clips perform in practice has not been gained, as yet.

8.4.1 Summary of the Clipping Questionnaire

Questionnaires (*refer* Appendix C) were mailed to 32 ceiling installers and 5 ceiling component manufacturers/suppliers in New Zealand (*see* Table 2.1). Three questions were asked of each of these firms.

1. *What percentage of ceilings have clips installed?*

   This question was broken down by seismic zone and the responses are listed in Table 8.1.

2. *What is the estimated additional cost for a ceiling with clips, compared to one without clips ($\$/m^2$)?*

   These costs are listed in Table 8.2.

3. *Comment as to experience with clips being dislodged by Services Contractors.*

   This question is covered in Section 8.4.2.

Replies were received from 11 ceiling installers and 5 ceiling manufacturers and distributors. A summary of responses is given in Tables 8.1 and 8.2.

Table 8.1: Percentage of Ceilings Clipped

Seismic Zone (Note 1)		
A	**B**	**C**
100	100	15
100	100	100
100 (Note 2)	100	100
95	95	100
100		
100		
100		

Notes:
1. Each entry corresponds to an individual response to the questionnaire.
2. It was noted however that this applied only to mineral fibre and wood fibre tiles. Fibrous plaster tiles were not clipped.

Table 8.2: Costs of Clip Installation

Location	Cost ($\$/m^2$)	
Whangarei	0.18	
Auckland	1.25	
	0.50	(1.00)
	0.60	(1.50)
	1.00	
Hamilton	0.80	(Note 2)
Palmerston North	0.52	
New Plymouth	0.15	
Lower Hutt	0.38	
Wellington	1.05	
	2.88	(Note 3)
Christchurch	0.30	
Dunedin	0.62	

Notes:
1. Values in brackets ( ) are for 600 x 600 tiles.
2. Quoted by this respondent as 3% of ceiling cost
3. This is based on 4 clips per tile, *refer* Section 8.4.3 ($\$1.44/m^2$)

8.4.2 Questionnaire Comments Received

1. General Comment

From Table 8.1 we can see that most of the respondents do, in fact clip their ceiling tiles. However in the section allocated for comments a number of more revealing tales are told of "some businesses in the area" who do not clip ceilings. The following comments are based upon the responses received:

1. Only certain tiles are clipped to stop twisting.

2. Clipping of tiles is always done in high wind areas, such as entry foyers.

3. Clipping is done for seismic movement to assist diaphragm action.

4. Revealed edge mineral fibre tiles are best left unclipped.

5. All tiles are clipped, if possible.

6. All tiles are clipped in Wellington (even lightweight tiles) because of wind.

7. Clips are left out by some Sub-contractors to give a tender price advantage.

Comments 1 and 2 were repeated in a number of responses. The impression gained is that clips are more likely to be installed when required for reasons other than seismic code requirements.

The reason for not clipping mineral fibre tiles is that the clips can damage tile edges. This is especially the case if the tiles need to be removed.

2. Comments Relating to Loss of Clips

The loss of clips by the removal of tiles was the final issue addressed by the questionnaire. The answers received cover most of the issues surrounding clipping. A summary of the comments is as below.

Although some tile/clip combinations are designed for ease of dismounting, generally when a tile is removed the clips are dislodged and cannot be individually replaced. The only way to replace clips is to replace the clipping successively tile by tile back to a designated tile. If clips are dislodged, sometimes the Ceiling Contractor is resummoned to replace the clips. However more often the tiles are left unclipped.

The amount of tiles that are dislodged by service and Fitout Contractors varies widely. "Some Service Contractors are responsible while others could not care less". "The worst offenders tend to be airconditioning, telephone and computer installers".

The result is that typically random tiles or small areas of tiles are removed, and clips dislodged. However one Ceiling Contractor estimated that after fit-out as many as 40% of the ceiling tiles could be unclipped.

After the Ceiling Contractor has completed the installation of ceiling tiles, access must be restricted to marked access panels. These panels, which are left unclipped should not be more than 1 in 50.

One of the main problems is that the clipping of tiles is not adequately checked. This responsibility seems to fall between the Administering Council and the Architect/Engineer. Until clipping is more rigidly policed, the problems outlined in this section will continue.

To overcome the problem of dislodged tiles, it was recommended that all the tiles which have service penetrations could be installed with the balance of the tile installation left until after the ceiling space fit-out is complete. This would result in an increase in cost as the Ceiling Contractor must stop work, and then return. However, this procedure would eliminate the possible need to recall the Ceiling Contractor to reinstall clips which is even more costly, and would achieve the desired end product.

One final and revealing comment was made by a ceiling component distributor. In their coverage area they have only supplied clips, as requested, to one ceiling installer.

8.4.3 Comparison of Responses

The number of responses (16) compared to the number of questionnaires sent out (37) was a little disappointing, although not far below the 50% response considered normal for this type of survey. Also it is worth mentioning that two other questionnaires were returned as the addressee no longer existed.

The contents of Table 8.1 need to be viewed in light of the comments made in Section 8.4.2. Though almost all of the respondents say that they themselves always use clips, they indicate that others are not so responsible. Therefore it is difficult to ascertain what percentage of ceilings installed in New Zealand have the clips required by the codes (*refer* Section 8.2).

The second question dealt with in the questionnaire was the area of the additional cost of clipping. Full clipping of a ceiling requires an average of two clips per tile (*refer* Section 8.1). The plastic clips cost about 11 cents each to purchase, while the spring steel clips are slightly cheaper.

Based upon 1200mm x 600mm tiles an average of 2.8 clips/m^2 are needed for a ceiling. This equates to a \$0.31/m^2 cost of materials alone, and suggests that the values given in Table 8.2 which are less than this value may represent only the labour content, or alternatively the material cost. Therefore in order to arrive at an average cost of clipping it may be prudent to add \$0.31/m^2 to the 0.18, 0.15, 0.38 and 0.30 values in Table 8.2.

The value of $2.88/m2 given in Table 8.2 was based upon four clips per tile. This value should thus be halved. The altered costs per square metre are shown in Table 8.3.

Table 8.3: Adjusted Costs of Clipping Installation

Location	Adjusted Cost ($\$/m^2$) for 1200 x 600 tiles
Whangarei	0.49 *
Auckland	1.25
	0.50
	0.60
	1.00
Hamilton	0.80
Palmerston North	0.52
New Plymouth	0.46 *
Lower Hutt	0.69 *
Wellington	1.05
	1.44 *
Christchurch	0.61 *
Dunedin	0.62

Note: Values with an asterisk (*) have been adjusted as described above.

The average cost for installing tiles as derived from the raw data of Table 8.2 is $0.84/m2 with a sample standard deviation of $0.71/m2. From the adjusted data in Table 8.3 the average is $0.77/m2 with a sample standard deviation of $0.32/m2.

The Hamilton value of $0.80/m2 which is very close to the average indicated that this equates to 3% of the ceiling value. If this is the case then the economic basis for the omission of clips as a tender advantage can be seen.

The third part of the questionnaire, which also elicited the most response was that of clips dislodged by others. The extent of the problem as described in Section 8.4.2 varies depending on the degree of care of the Sub-contractor and the insistence and checking of the Council or Architect/Engineer that the ceiling is fully clipped.

8.5 Summary of Clipping

Clipping of ceilings should be performed in accordance with the requirements of PW81. The effectiveness of this type of clip at stopping tiles from falling from the grid needs to be tested. At such time the magnitude of upward forces to be resisted can be determined. At this juncture the value of one-third of the tile weight seems appropriate.

The fact that many ceilings may have not been fully clipped, or not clipped at all is of major concern. Clips need to be insisted upon by designers and checks need to be made on site that they are installed. Following that access must be restricted to designated access panels which should not be more than one of every fifty ceiling tiles.

At three percent of the total ceiling cost, clips are a reasonably inexpensive measure to mitigate what is a potentially extensive falling hazard.

9.0 Conclusions and General Recommendations

The following recommendations are based upon the comparisons drawn between different recommendations in Section 7. Where the reasoning of codes and the experience of tests and earthquakes concur these are recommended as minimum requirements. Other recommendations are based upon experience of the suspended ceiling industry and engineering principles.

9.1 Support and Clearance at Free Ends of Tees

1. <u>Additional End Hangers</u>

   End hangers are required to provide stability to the end section of tee rails when the wall angle no longer provides seating due to seismic movement. To achieve this the additional hanger must be near the free end of tee rail.

   A suitable definition of near the end of the rail is supplied by the OSA Title 24 requirements (Table 6.1) which state that the hanger shall not be located more than one quarter of the rail span nor 203mm (8 inches) from the perimeter wall.

   The rail span should be considered as the distance from the perimeter wall to the first typical hanger, or rail connection splice, whichever is the lesser.

   The limitation should not be so restrictive as to preclude any construction tolerances as provided by the regularly spaced connection holes.

   The most satisfactory requirement for end hangers would be that, where the terminal ends of tee rails are not connected to the wall angles to transfer the suspended ceiling seismic load, a hanger should be provided with 200mm, or one quarter of the rail length, whichever is the lesser.

2. <u>Spacer Bars</u>

   When the ends of tee rails are not restrained against spreading it is possible for edge tiles to fall from the suspension grid. This is effectively addressed by the introduction of a spacer bar. The spacer bar should provide a positive connection between the ends of rails.

   Tees can only spread when there are not fixings to sidewalls. Thus the need for spacer bars should only apply to braced ceilings with clearances around the perimeter.

   The position of the spacer bar, when required, should be as near to the end of the rail as is practical. Therefore the required distance should be defined as far additional end hangers.

3. End Clearances

There are basically two types of suspended ceiling restraint. The first is to connect the tees to walls, or other structural members, which, in turn transfer the seismic ceiling load to the building structure. These ceilings do not require separation from penetrations of the building structure as these provide the restraint.

The second major type of suspended ceiling restraint is that of bracing up to the structure above. Due to interstorey drifts these ceilings require separation from structural building elements. Suitable clearances (C, refer Fig. 6.1) for New Zealand Seismic Zones A, B and C would be 15, 13 and 10mm respectively. This allows 5mm for extension of bracing and ceiling rocking.

The allowance for connection of tee rails to wall angles on not more than two adjacent walls in American Codes causes this connection to act as the primary load distributing mechanism, by default. Typically the tee rail/wall connection acts as the ceiling reaction point until such a time as the connection fails, at which point the bracing is intended to carry the load. This mechanism allows both pounding of the ceiling and the falling of end tee rails and tiles which are no longer supported. Also it is possible, that a full floor to floor wall may place a demand for deflection on the ceiling that is beyond the pre-yield capacity of the bracing system causing premature failures.

In order to avoid this problem all suspended ceilings should be of one of two forms. A braced ceiling should be braced to resist the full seismic load of the ceiling in the direction of the brace, and given adequate end clearances on all sides and to all penetrations. Alternatively a ceiling may be unbraced but must have member and joint capacities, including connections to perimeters, adequate to transfer the seismic load induced. Two different bracing forms could be used in perpendicular directions or seismically separated ceiling areas.

9.2 Hanger Clearances to Services

The existing requirement of a minimum of 150mm clearance between all suspended ceiling hanger wires and all unbraced services and ducts has proved to be satisfactory. Guidance is required for the situation where both the ceiling and the services or ducts are braced. Under these conditions the value for clearance could be reduced to 25 mm.

9.3 Lighting

In line with the more common practice a factor of safety (FOS) on wire yield loads of 4 should be used. Pendant mounted fixtures with single wires should have a FOS = 5. These FOS values should also apply to end connections and tying of wires.

1. Pendant Mounted Fixtures

A 3.5mm wire should be provided to all pendant mounted fixtures. Fixtures in excess of 25kg shall have specifically designed hangers. All hanger connections shall be designed to have a capacity four times the fixture weight.

Fixtures which could impact when pendant mountings swing 45 degrees shall be avoided.

Care should be taken when detailing mountings of pendant lights to avoid excessive torsional loads being applied to tees due to pendulum action.

Pendant mounted fixtures may be used in essential facilities only when specifically detailed for this purpose.

2. Surface Mounted Fixtures

The recommendations of two clamps and slack wires for all fixtures should be continued. Allow for one additional clamp and wire for each 1.2m length of fixture in excess of 2.4m.

3. Grid Mounted Fixtures

From the collection of references there are three principles addressed. Firstly that all fixtures should be positively fixed to the grid system for 100% of the fixture weight.

Secondly there should be a lower limit of weight below which additional hangers are not required. An appropriate limit for this would seem to be the current NZS 4219 value of 10kg.

Thirdly there should be an upper limit of weight beyond which the additional support required should be specifically designed. This value would appear to be, by consensus, 25kg.

In summary, all fixtures should be positively fixed to the suspended ceiling grid system. All fixtures in excess of 10kg but not exceeding 25kg should be fixed to the structure above by two 2.5mm wires. All fixtures in excess of 25kg should have specifically designed hangers with a factor of safety of 4. No hangers should allow a fixture to drop by more than 100mm.

9.4 Other Fixtures

There should not be a distinction between lights and other fixtures. The falling of any type of fixture is of equal danger. Therefore Section 9.3 should apply to all fixtures mounted in the grid system.

9.5 Partitions

Full height partitions (from floor to floor) should be treated as other ceiling penetrations. Therefore in the case of a braced ceiling they should have standard end clearances. For an unbraced ceiling these partitions may be used to transfer ceiling loads to the structure above. Partitions terminating at ceiling height and fixed to the ceiling should be treated as follows.

The allowance for partition load should be based upon the actual partitioning to be installed. However as partitions are relocatable minimum requirements should be given.

A minimum value for seismic weight due to partitions of 0.05 kPa (compare 0.024 kPa, SF DPW:73-9, Section 6.5.10) should be allowed for all office type spaces. This equates to 2.7m stud walls at 8.1m average centres, or walls at 4m centres over one half of the office space, which allows for a mix of open plan and separate office spaces.

Partitions require detailing of connections to the ceiling grid that allow for the lateral movement of the ceiling system. Typical detailing to achieve this should include fixings which slide in the direction of the wall plane and fixings that are remote from wall junctions (Ref. 36).

9.6 Bracing Requirements

The bracing system described in the 1988 UBC (Ref. 9) and elsewhere is generally adequate, although generally too flexible, but needs to have its basis outlined i.e. limitations on ceiling weight. Consideration of zone factors, actual ceiling weights and other influences such as height-factors and flexibility should be included in the suspended ceiling design.

A bracing option which is stiffer than the typical splayed wire brace is preferable. A scheme which eliminates the tightening of end connection before load take-up would be the goal. This is partially able to be achieved by the introduction of the vertical strut. Also the system shown in Fig. 3.2(b) meets this criterion.

Consideration should continue to be given to the vertical component of the bracing reaction, *i.e.* the vertical strut should be kept.

The use of the axial load strengths of the tee rails, as an unbraced ceiling should be given further consideration (*refer* Section 9.8).

9.7 Seismic Ceiling Weights

Ceiling weights should be calculated, allowing for the tile weights; grid weight; lighting; partitioning and any other loads on the ceiling. The only factor of these that would reasonably be expected to change in the life of the ceiling and would significantly affect the ceiling weight is the partitioning. Thus a minimum only need apply to this term (*refer* Section 9.5).

9.8 Minimum Requirements for Components

Minimum component load capacities need to be tested and/or calculated for all grid systems. The magnitude of these values will affect the maximum brace spacing, and the maximum allowable unbraced ceiling length.

For a braced system to be specified, as in the UBC (Ref. 9), and other codes, a set of corresponding minimum component strengths are necessary. Otherwise the actual component strengths, which need not meet these minimum values, can be used in conjunction with brace strengths, to determine the brace spacing, or alternatively the maximum unbraced length for a tee rail.

9.9 Other Miscellaneous Requirements

9.9.1 5mm Extension Limit

If this value is used as a limitation on the end supports of an unbraced ceiling it has an unnecessarily conservative effect on the allowable unbraced length of the tee rails. This is particularly the case for light weight ceilings.

As a restriction of the spreading of adjacent tee rails, this clause needs clarification, or even deletion.

9.9.2 Fixing to Two Walls

This practice should be discontinued for braced ceilings to avoid the recurrence of edge damage to ceilings observed in recent earthquakes.

A ceiling should rely solely on braces with separation from all penetrations, or rely on penetrations for restraint, and have no additional bracing (*refer* Section 9.1.3).

9.9.3 Height Factors

The NZS 4203 factors allow a reduction in seismic coefficient which is based on sound engineering principles. It allows an economic saving also and should be permitted in ceiling design.

10.0 Proposed Code - Minimum Requirements

The following sections are a summary of the requirements for suspended ceilings that are considered necessary. Where existing code provisions have been demonstrated to be adequate they have been included. Other clauses are based on interpretation of test results and earthquake observations and engineering judgement. The requirements are based on Sections 5, 8 and 9 of this report.

It is intended that the clauses could be included in the lateral design requirements of a suspended ceiling code, or as part of a code such as NZS 4219 (Ref. 39).

10.1 Application of Code

The following sections shall apply to the Seismic Design and Detailing of Suspended Ceiling Grid Systems using inverted tee rails with lay-in ceiling panels, for use in New Zealand.

Note: Although not written for the purpose, many of the following sections may equally apply to suspended ceilings of other types.

10.2 Seismic Design Load Levels

1. The seismic coefficient, C_p ($F_p = C_p W_p$) for the ceiling shall be derived from the loadings code and for the zone and risk factors applicable to the building (NZS 4203:1984). The value derived should apply to the top of the building being considered.

   Where: F_p = Seismic force of ceiling
   C_p = Seismic coefficient
   W_p = Seismic weight of ceiling.

2. The value of C_p thus determined shall be multiplied by the term αK_x to calculate the seismic coefficient at the level of the ceiling being considered.

   Where: α = h_{cg}/h_n
   K_x = h_x/h_{cg} (but not less than 1)
   h_{cg} = Height to centre of gravity of building
   h_n = Height to the top of the main portion of the building
   h_x = Height to the level under consideration

   Note: For other countries, determine equivalent C_p and multiply by αK_x for the appropriate height.

10.3 Lateral Load Resisting Systems

The lateral load resisting system shall be such that the ceiling is either a "braced ceiling" or an "unbraced ceiling" (*refer* sections 10.3.1 and 2). Perpendicular ceiling directions may be considered separately.

10.3.1 Braced Ceiling

1. A braced ceiling shall have bracing members which transfer the load either horizontally or vertically to adequately designed structural components capable of receiving the load.

2. A braced ceiling shall have clearances to all ceiling boundaries including all penetrations which are not laterally supported by the ceiling. The clearances shall allow for inter-storey building movements.

3. The designer shall ensure adequate rigidity of the bracing system, or increase clearances at ceiling boundaries to avoid impact.

10.3.2 Unbraced Ceiling

1. An unbraced ceiling shall be designed such that the maximum length between lines of support will not allow seismic loads in excess of tee rail strengths to accumulate.

2. The maximum allowable load in tee rails shall be determined by testing or rational engineering calculation of component and connection strengths.

3. All ceilings with unrestrained tee rail lengths which exceed the allowable lengths based on prescribed loads shall be braced to the structure.

10.3.3 Testing of Components of System

1. Testing of components shall comply with AS 1538-1988, "Cold Formed Steel Structures Code", Standards Association of Australia, Sydney.

   Note: For other countries an equivalent standard may be used.

2. The weakest component of the seismic load resisting system shall have a working load factor of safety against failure, FOS=2/1.33 on the mean test value.

10.4 Support and Clearance at Free Ends of Tees

1. An addition vertical hanger shall be provided within 200mm of the end of tees with a span exceeding 400mm not connected to the ceiling perimeter. In no case shall the hanger be more than one quarter of the rail span from the perimeter. The rail span is the distance from the terminal end of the tee rail to the next hanger or tee rail splice.

2. Where it is possible for the terminal ends of tee rails to spread apart, provide a connecting spacer bar between the tee rails within 200mm, or one quarter of the rail span, of the terminal end of the rail.

3. Braced ceilings shall have minimum clearances at all boundaries and independent penetrations as follows:

   Zone A = 15mm
   Zone B = 13mm
   Zone C = 10mm

4. Increase these values where the plenum depth exceeds 1000mm by 10mm for each additional 1000mm of ceiling plenum depth.

   Note: For other countries similar requirements should apply for different seismic zones.

10.5 Connected Ceiling Perimeter

Where an unbraced ceiling system is used, connection shall be made at perimeters to members capable of distributing the induced load to the building structure.

10.6 Lights and Services

1. Separate all ceiling hanger wires and bracing components at least 150mm from all unbraced ducts, pipes, conduit and other services. Lightweight items such as single electrical conduit not exceeding 20mm may be supported from hanger wires.

2. Where both the suspended ceiling and the services are braced, the minimum clearance between hanger wires and bracing components may be reduced to 25mm.

3. For the purposes of Clauses 10.6.4 to 10.6.15 the term fixture shall apply to all lighting fixtures, air terminals, diffusers or other services fittings.

4. All ceiling mounted fixtures weighing less than 10kg shall be securely connected to the grid for 100% of the fixture weight in any direction.

5. All ceiling mounted fixtures shall be securely connected to the grid to preserve the diaphragm action of the ceiling.

6. All ceiling mounted fixtures weighing more than 10kg but less than 25kg shall have two slack no. 12 ga. wires from diagonally opposite corners of the fixture to the structure above.

7. Support all surface mounted fixtures by at least two fixing devices which surround the ceiling grid tee and which are each supported from the structure above by a no. 12 ga. slack wire.

8. Provide additional fixings as described in 10.6.6 for each 1.2m of surface mounted fixture length in excess of 2.4m.

9. All pendant mounted fixtures shall have a slack no. 9 ga. wire connected to the fixture and to the structure above.

10. Pendant fixtures which could impact when the pendant mountings swing 45 degrees shall be avoided.

11. Pendant fixture mountings shall be detailed to avoid pendulum induced actions applying excessive torsion to the supporting tee rails.

12. Pendant mounted fixtures may only be used in essential facilities when specifically designed for that purpose.

13. All fixtures (recesss, surface, or pendant mounted) weighing more than 25kg shall be supported directly from the structure above by approved hangers.

14. All fixture supports and connections shall have a minimum factor of safety against failure of 4.

15. Slack safety wires to fixtures shall not allow fixtures to drop by more than 100mm.

10.7 Partitions

1. Partitions which pass through suspended ceilings may be separated from the ceiling and be self supporting with clearances as detailed in 10.4.3 and 10.4.4.

2. Where the suspended ceiling is attached to a partition which passes through the ceiling plane, the ceiling shall be detailed as an unbraced ceiling. The partition shall be treated as a ceiling perimeter and connected in accordance with 10.5. Such partitions shall be designed to transfer the ceiling induced seismic loads to the building structure above and below.

3. Where the suspended ceiling system is required to provide lateral support to partitions, the suspended ceiling system, their connections and the lateral load resisting system shall be designed to resist the prescribed loads applied perpendicular to the face of the partition.

4. Partition connections to the suspended ceiling grid shall allow relative ceiling movement in the plane of the partition.

5. All ceilings that are likely to be required to provide stability to partitions shall be designed for a minimum partition seismic weight of 0.05 kPa.

10.8 Tile Clipping

1. All lay-in tiles shall be clipped into the grid system with a minimum of one clip per corner of tile. The clips shall be capable of resisting 0.3 kPa or one third of the tile weight in an upwards direction.

2. Except in exitways and essential facilities, ceiling tiles with a mass of less than 2kg each and of a shape and type that on falling would not be a hazard to the occupants need not have the tiles positively fixed against earthquake forces.

3. Designated tiles not exceeding one tile per 50 tiles shall be left unclipped for access to the ceiling space. Such tiles shall be clearly indicated.

11.0 Further Research

This report leaves a number of questions that are not fully answered. More work is required in the testing of these aspects and/or observation of future earthquakes to answer the questions. Some of the more important aspects are given below.

1. Lateral Force Levels

   These values vary widely between countries, even for areas of equivalent seismicity (*refer* Table 5.1 and Section 5.12). A relationship between the lateral loads of building floor levels and the related ceiling should be established. This could then be used to determine the acceleration amplification of different ceiling systems and thereby establish appropriate C_p values.

2. Spacer Bars

   Further testing is required to establish whether or not spacer bars are necessary to prevent tee rail spreading and consequent tile drop-out. This may be adequately served by the inclusion of end hangers.

3. 5 mm Extension Limit

   No absolute basis for this limit has been ascertained. The only purpose of the limit appears to be to restrict the unbraced length of tee rails in lighter ceilings.

4. Wire Strengths

   The strengths of wires used for bracing and for secondary support of light and other fixtures needs to be investigated. In particular, the effects of tying of the wires, tearing of the tee rails and failure of connections to fixtures and the supporting structure. The ATC 29 Seminar (Ref. 43) suggests test methods and set up.

5. Partitions

   The effect of partitions, connected to and terminating at the ceiling, on the ceiling performance in the plane of the partition needs to be investigated. This work should include investigation into the possibility of sliding connections in the plane of the partition and detailing at partition junctions.

6. Clipping

   The effectiveness of clips in preventing tile drop-out requires testing. Also the detail of a clip which allows tile removal and replacement without loss of clipping should be investigated.

7. Ceiling Deflections

Tests should be conducted to determine the amount of ceiling deflection that occurs as a result of tightening of the twist in bracing wires. Other tests need to be conducted to determine the size of ceiling deformations (racking) that occur within the ceiling diaphragm. These two items can then be used to refine the allowance for additional end clearances, which is recommended to be 5mm (*refer* section 7.1.3).

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Appendix A

List of Responses

Contacts that responded:	Nature of response:
The Manager Ace Ceilings Ltd 121 Ferry Parade Herald Island Auckland NZ	Questionaire filled out
The Manager Alotech Ceilings Ltd 24 Virginia Ave Eden Tce Auckland NZ	Questionaire filled out
The Manager Angus Ceilings and Linings Ltd 76 Kingsley St Sydenham Christchurch NZ	Questionaire filled out
Murray Holden Architectural Finishes Ltd PO Box 54 164 Mana Wellington NZ	Letter of reply, no questionaire samples, manuals, removable clips
John Little BCHF Limited NZ	Limited comments
Information Officer BRANZ NZ	Nil
Richard Eisner Bay Area Regional Earthquake Preparedness Project 1018th St, Suite 152 Oakland CA 94607 USA	Two publications, Database research.
Masaya Hirosawa Building Research Institute Ministry of Constr.1 Tatehara Tsukuba-shi Ibaraki 305 Japan	One English & three Japanese papers.

Contacts that responded:	Nature of response:
Building Seismic Safety Council Washington DC USA	Nil
Chris Arnold Building Systems Development 3130 La Selva Suite 308 San Mateo CA 94403 USA	Papers and other contacts given.
Donna Covarrubias, Librarian California Institute of Technology CA USA	One paper on Loma Prieta
Fred Turner California Seismic Safety Commission 1900 K Street, Suite 100 Sacremento CA 95814 USA	Letter, Regulations of State Architect, 2 report titles.
Dr Rodriguez Ciudad Universitaria Apartado Postal 70-290 Delegacion Coyoacon CP04510 Mexico	Nil
Librarian (Joanne) DSIR NZ	Nil - tried ICONDA database
Bob Falconer DSIR Auckland NZ	Nil
Prof Gulkon Earthquake Engineering Research Center Turkey	No publications, no regulations in current or draft codes.
Katherine Frohmberg Earthquake Engineering Research Centre 1301 South 46th Street Richmond CA 94804 USA	NISEE, Quakeline and Abstract Journal databases, test reports and papers.

Contacts that responded:	Nature of response:
Prof Bachmann Institute of Structural Engineering Eth-Hoenggerberg CH-8093 Zurich Switzerland	Design is required, but no details in code, no research.
John Swem International Science and Technology Consultancy Corporation China	Nil.
David Hopkins KRTA Manilla Phillippines	Use foreign codes.
Saburo Shimada Maeda Corporation Technology Research Institute Earthquake Engineering Section 1-39-16, Asahicho Nerima-ku Tokyo 176 Japan	No research, design recommendations given (in Japanese).
Mr M Brice NZNSEE Wellington NZ	Refered to the Directory for Earthquake Engineering Research.
David Morton Natural Hazard Research and Application Information University of Colorado Campus Box 482 Boulder CO 80309-0482 USA	Database search summary
Henry Lagorio National Science Foundation Suite 1130 1800 G St N.W Washington, D.C. 20550 USA	Two publications.

Contacts that responded:	**Nature of response:**
Office of the State Architect Seismic Program 400 P Street Sacramento CA 95814 USA	OSA regs, CISCA recommendations, UBC regulations.
The Manager Performance Ceilings Ltd 5 Wakefield St Lower Hutt NZ	Questionaire filled out.
Peter Radley Peter Radley Associates Auckland NZ	Limited comment.
The Manager Pinex Fixing Service PO Box 5186 Dunedin NZ	Questionaire filled out.
The Manager Pinex Fixing Service PO Box 897 New Plymouth NZ	Questionaire filled out.
The Manager Pinex Fixing Service PO Box 792 Palmerston North NZ	Questionaire filled out.
The Manager Pinex Fixing Service PO Box 12 643 Penrose, Auckland NZ	Questionaire filled out.
The Manager Pinex Fixing Service PO Box 50 209 Wellington NZ	Questionaire filled out.

Contacts that responded:	Nature of response:
The Manager Pinex Fixing Service PO Box 1351 Whangarei NZ	Questionaire filled out.
The Manager Potter Interiors Systems Ltd PO Box 13 336 Onehunga, Auckland NZ	Questionaire filled out.
Prof Ruitong Shanghai College of Architectural and Municipal Engineering No 71 Chi Feng Road Shanghai 20092 China	No regulations, based on Engineer's experience.
The Manager Suspended Ceilings (Wgtn) Ltd PO Box 30 723 Lower Hutt NZ	Letter, answers to questionaire and suggestions.
International Directory Service Telecom NZ	1 fax no. provided.
Prof. Ben Kato Toyo University Kujirai Kawagoe-shi Saitama, 350 Japan	Refers to Japanese regulations as others.
Information Officer US Information Service USA	Nil.
Elspeth Barclay US Information Service USA	Provided contacts.
Riley Chung US National Committee Decade for Natural Disasters National Research Council 2101 Constitution Ave Washington, DC 20418 USA	Given contacts: Henry Lagorio

Contacts that responded:	Nature of response:
Mr Neil Ridgway USG Interiors Pacific Ltd PO Box 11 155 Ellerslie Auckland NZ	Questionaire filled out. No information on % of clipping.
The Manager USG Interiors Pacific Ltd PO Box 2426 Wellington NZ	Referred to Auckland Branch.
Dr Hidalgo Universidad Catolica Chile	No local regulations, use foreign codes, no research.
Mr Spencer University of British Columbia Canada	Not aware of any research.
Prof Shepherd University of California, Irvine CA USA	Copy of report, qualification tests to follow???
Dr Anagnostropoulos University of Patros Greece	No publications, no regs in current or draft code.
Prof Jai Krishna University of Roorkee 61, Civil Lines Roorkee, 247667 India	No research, code recommends against it, not used much.
Librarian (Christie) WORKS Consultancy Wellington NZ	Advised costs.
The Manager Waikato Interior Installations Ltd 16 Monique Place Hamilton NZ	Questionaire filled out.

Appendix B

Document Abstracts

Appendix B : Document Abstracts

Contents

Appendix B : Document Abstracts

1. San Fernando Earthquake, February 9 1971 (Ref. 3)

"One of the most significant lessons learned from the San Fernando earthquake of February 9, 1971, was the magnitude and cost of the damage to nonstructural elements of buildings. Except for buildings in the areas subjected to violent ground shaking, most of the buildings in the Los Angeles area survived the earthquake without structural failures. Many of these same buildings, however, reported extensive damage to elevators, mechanical systems, lighting fixtures and ceilings, partitions, window glass and storage racks. Unfortunately, most of these nonstructural failures could have been avoided during the original design of the buildings at little or no added capital cost.

Nonstructural building elements by definition are not a part of the structural system or building frame - they actually are added to the frame in the last stages of construction. These elements are not designed to help the building frame resist the earthquake forces, so most of their installation details are not examined by the structural engineers. This detailing is left to architects, mechanical and electrical engineers, and quite often to the tradesmen in the field. The end result has been practically no consideration for earthquake-induced forces on nonstructural elements and heavy property damage after each earthquake. It is essential that these earthquake-tested buildings be studied to improve our knowledge of their behaviour under seismic forces and to develop recommendations for improvement to building codes, design practices, and construction techniques.

The lessons learned from this earthquake and the Alaska earthquake must be widely disseminated among the building design professionals, responsible governmental agencies, contractors, and manufacturers. All members of the design team - architects, structural, mechanical, and electrical engineers, cost consultants, and owners - must be made aware of the urgent need to consider earthquake-induced forces in the design, detailing, and installation of nonstructural elements of buildings. Hopefully, this study, prepared by mechanical and electrical engineers, will illustrate the need for an interdisciplinary attack on the problems of earthquake-resistive design of buildings."

2. The Great Alaska Quake of 1964 (Ref. 4)

"The Alaska earthquake caused extensive damage to nonstructural elements of buildings such as facades, ceilings, partitions, elevators, lights, electrical systems, plumbing, ventilation and air-conditioning systems, heating systems, fire-protection systems, telephone and other communication systems, and furniture. In most cases the cost of repairing nonstructural damage was appreciably greater than the cost of repairing structural damage. Most of the nonstructural damage could have been avoided at little or no extra cost in the original design of the building. A study of typical nonstructural damage suggests recommendations for methods of avoiding such damage during future earthquakes.

In the past, earthquake-resistant design has been concerned primarily with the structural integrity of buildings, and very little attention has been given to the performance of the nonstructural elements of buildings. This procedure has been based on the philosophy that to design a building to avoid all damage during an earthquake is not economically justifiable; the structural system of the building is intended to be deformed by the seismic forces, and damage to some of the nonstructural elements is expected. The extent of this damage, however, and its effects on the safety of the building's occupants have never been fully evaluated, although the nonstructural elements often constitute more than two thirds of the total cost of a building. Greater knowledge and understanding is needed of the damage sustained by nonstructural building elements during an earthquake.

By definition, the nonstructural elements of a building are those materials that are not a part of the structural system. The structural system, or building frame, must be designed to withstand the live and dead loads of the building, in addition to wind and earthquake forces, without the assistance of the nonstructural elements. These elements are actually added to the frame in the last stages of construction of the building and include facades, ceilings, partitions, elevators, lights, electrical systems, heating systems, fire-protection systems, telephone and communications systems, storage racks, and even large pieces of furniture or portable equipment.

The final measure of a well-constructed building is the safety and comfort that it affords its occupants. If, during an earthquake, they must exist through a shower of falling light fixtures and ceilings, manoeuvre through shifting and toppling furniture, stumble down dark corridors and stairs, and then be met at the street by falling glass veneers, or facade elements, then the building cannot be described as a safe structure.

Aside from the loss of life caused by tsunamis, the number of people killed or injured because of vibrational damage to buildings during the March 27, 1964, Alaska earthquake was surprisingly small. Had more of the buildings been occupied at the time of the earthquake (5:36 pm), a great many more people would have been killed or injured because of failure of the structural and nonstructural building elements. The disaster would have been compounded if the earthquake had been followed by fires. In Anchorage, the fire potential was greatly reduced after landslides ruptured the gas mains and the electric power system failed. Even so, at least three deaths, numerous injuries, and considerable panic were caused by the failure of nonstructural elements.

The earthquake provided a rare opportunity to evaluate the performance of modern building construction under severe earthquake conditions. Anchorage, Alaska's largest city, is about 80 miles west-northwest of the epicentre of the earthquake; because of its size, it bore the burden of the majority of property damage caused by the earthquake. Anchorage is a young and growing city with new modern buildings, some as high as 14 stories. Most of these buildings were built under a code that required earthquake-resistant design and were constructed using up-to-date building techniques. Detailed studies of these earthquake-tested structures are essential as a basis for future evaluations of current design practices."

3. EQE Engineering Inc.
(Ref. 7)

"Suspended ceiling systems are a common architectural, nonstructural feature used to conceal the underside of the overhead structure containing utility components (conduit, ducting, piping, etc). Damaged ceiling systems in the form of fallen elements have been observed in past earthquakes. Casualties to occupants, impacting of sensitive life-safety related equipment components, and the blocking of egress corridors are potential seismic hazards posed by inadequately designed and installed suspended ceiling systems. Current studies into the performance of suspended ceiling systems during recent earthquakes suggests that the Uniform Building Code (UBC) Standard No. 47-18 can be enhanced to increase the seismic resistance of metal suspension ceiling systems. This conclusion is borne out of recent suspended ceiling performance data assimilated from the past Loma Prieta and Whittier Earthquakes, and shake table test results. This paper will review current seismic design and installation practices, their past performance, and present proposed strengthening techniques that expand UBC 47-18 requirements to enhance the seismic resistance of suspended ceiling systems during earthquakes."

4. ANCO Engineers Inc. Testing
(Ref. 10)

"Nonstructural damage resulting from an earthquake poses both life safety and economic hazards. Falling objects can cause human injury or death and inflict secondary property damage. Nonstructural damage can leave a facility's operation impaired or impossible for an extended period of time after the seismic event. This is a particularly critical consideration for essential facilities, such as hospitals and communication centres, but it can be economically disastrous for any business.

Earthquake engineering research to date has been focussed almost exclusively on aspects of structural damage. Although the types and extent of nonstructural damage have become increasingly documented in recent years, the earthquake effects on nonstructural components are not yet clearly understood. A structure can amplify the ground motion shaking and alter the frequency content of the motion which nonstructural components experience. Hence, research into nonstructural component behaviour during earthquakes is required to assess hazard potential and develop seismically resistant elements.

Ceilings and lighting fixtures are always one of the nonstructural elements noted during earthquake damage surveys.

In order for building codes to evolve, experimental work on the dynamics of ceiling and lighting fixture systems must be performed. The interdependence of these systems during building motion has been recognised, but specific movement patterns have not been studied. Using a shake table to simulate earthquake motion and accelerometers attached to a ceiling section including lighting fixtures suspended from the table, movement patterns can be obtained. The test program described herein is the first phase of such a study."

5. Rihal and Granneman Testing (Ref. 11)

"This report documents an ongoing experimental research programme being carried out to investigate the dynamic behaviour of building partitions and suspended ceiling systems during earthquakes. Under a previous research programme, static cyclic tests of building partitions were carried out under horizontal racking loads, to assess their behaviour and fundamental characteristics, *e.g.* stiffness, strength and energy absorption capacity.

Studies of observed building damage caused by recent earthquakes, *e.g.* Coalinga, California - 1983, San Fernando, California - 1971 and Anchorage, Alaska - 1964, etc, have clearly demonstrated that consequences of architectural (nonstructural) component damage are significant both in terms of their economic impact and the resulting hazard to building occupants, owners and to the public at large.

It is now recognised that cost of nonstructural building components is a significant proportion of the overall building cost. Thus, in recent years there has been increased interest in efforts to mitigate nonstructural component damage caused by earthquakes. Mitigation of such earthquake component damage necessitates efforts to increase our understanding of the dynamic behaviour of nonstructural building components under earthquake motions, including their fundamental characteristics, *e.g.* damping, natural frequencies, strength and stability.

Quantitative field and laboratory data is needed to systematically evaluate the dynamic characteristics of building components, their interactions, dynamic behaviour and relationship between input motion and threshold levels of damage. This quantitative data can then be incorporated into the building seismic design process, resulting in improved modelling of building systems and will eventually lead to safer building construction in seismic zones. The need for mitigation of building component damage during future earthquakes has been recognised.

Previous studies have shown that building component behaviour during earthquakes may be characterised by (i) acceleration effects, (ii) relative horizontal displacement (drift) effects, (iii) impact/pounding effects."

6. Wyle Laboratories Testing (Ref. 12)

"Seismic verification of a suspended ceiling.

In order to verify the seismic capability of a suspended ceiling installed under the CISCA Standard, a series of tests was conducted. As a starting point the SCMA Seismic Committee determined the first test should provide maximum penetration into the structural features of the CISCA Standard. To this end, a test fixture capable of being horizontally vibrated was installed in such a manner that a suspended ceiling could be mounted beneath it. This test fixture simulated primary building structure. A suspended ceiling was then installed by a CISCA contractor with the supervision of SCMA below the fixture according to the CISCA Standard, and the SCMA ceiling installation procedure."

7. Seismic Design of Architectural Elements (Ref. 13)

"The focus of this study is to survey and evaluate approaches to design, construction and installation of architectural components that will reduce casualties and economic loss due to earthquake damage. The major categories of nonstructural components can be defined as mechanical, electrical, plumbing, including fire protection systems, architectural, and contents.

Architectural components include partition systems (including doors, glazing, finishes), infill walls, ceiling systems (including light fixtures and air diffusion components), exterior systems, including curtain walls, precast panels, glazing, and facings of natural stone or built-up assemblies. Appendages such as parapets, sunshades and other exterior or interior ornamentation are also included, and staircases may sometimes be an important nonstructural element."

8. State-of-the-Art in Japan (Ref. 29)

"Recently in Japan, in the event of an earthquake, more investigations have been made into damage to building equipment, furniture and nonstructural components such as interior and exterior finishing and nonstructural walls rather than structural members, and there have been not a few reports on the analysis of such damage. Accompanied by this trend, seismic design guidelines for nonstructural components have been prepared under the supervision of the administrative organisations concerned and some of the guidelines have been used for actual construction.

In this paper, we will survey damage to these nonstructural components and members used for construction and introduce various related guidelines which have recently been prepared to reveal their goals and other principal contents."

9. CISCA Moderate and Low Risk (Ref. 34)

"The only installation guidance currently available for seismic restraint of suspended ceilings is contained in UBC Standard 47-18, which has its origins in a 1972 Ceiling and Interior Systems Contractors Association (CISCA) Recommended Standard for Seismic Restraint of Direct-Hung Suspended Ceiling Assemblies. The splay wire restraint requirements in UBC 47-18 were developed (and modified during the intervening years) for the lateral (earthquake) force design levels specified for Seismic Zone 4 (California). While the body of the UBC Code recognises lower lateral force levels for Seismic Zones 1-3, the implementation standard UBC 47-18 does not. The 1990 BOCA Code and 1988 SBC Code include lateral force factors (by seismic zone) for suspended ceilings, however, no implementation standards are referenced.

Many architects and ceiling contractors are just beginning for the first time to encounter seismic requirements in specifications for projects located in the traditional "non-seismic" areas of the United States. Building Code Officials and other governmental agencies are in a quandary as to what to enforce. Manufacturers are uncertain as to what to recommend in a market area where seismic provisions have been virtually unknown in the past.

Since splay wire restraints only function if ceilings have substantial displacement, it does not appear necessary to provide such restraint in moderate- or low-risk seismic areas (Zones 0-2). A ceiling system which is sufficiently unrestrained or free to accommodate the movement of a structure can provide the desired performance during a seismic event given that certain specified installation caveats are met. This paper discusses the background of the current ceiling restraint provisions and provides separate recommendations for ceiling installation in Seismic Zones 0-2."

10. CISCA Zones 0-2 (Ref. 35)

"The only installation guidance currently available for seismic restraint of suspended ceilings is contained in Uniform Building Code (UBC) Standard 47-18, which has its origins in a 1972 Ceilings and Interior Systems Construction Association (CISCA) Recommended Standards for Seismic Restraint of Direct-Hung Suspended Ceiling Assemblies. The splay wire restraint requirements in UBC 47-18 were developed (and modified during the intervening years) for the lateral (earthquake) force design levels specified for Seismic Zone 4 (California). While the body of the UBC Code recognises lower lateral force levels for Seismic Zones 1-3, the implementation standard UBC 47-18 does not. The 1990 Building Officials and Code Administrators (BOCA) Code and 1988 Standard Building Code (SBC) Code include lateral force factors (by seismic zone) for suspended ceilings; however, no implementation standards are referenced.

Many architects and ceiling contractors are just beginning to encounter seismic requirements in specifications for projects located in the traditional "nonseismic" areas of the United States and Canada. Building code officials and other governmental agencies are in a quandary as to what to enforce. Manufacturers are uncertain as to what to recommend in a market area where seismic provisions have been virtually unknown in the past.

Since splay wire restraints only function if ceilings have sufficient displacement, it does not appear necessary to provide such restraint in moderate- or low-risk seismic areas (Zones 0-2) where expected ceiling displacement due to seismic shaking is considerably less than expected in higher-risk seismic areas (Zones 3-4). A ceiling system that is sufficiently unrestrained or free to accommodate the movement of a structure can provide the desired performance during a seismic event given that certain specified installation caveats are met. This guide discusses the background of the current ceiling restraint provisions and provides separate recommendations for ceiling installation in Seismic Zones 0-2."

11. Clark and Glogau (Ref. 36)

"Traditional ceilings in rigid buildings generally caused few problems when under earthquake attack. The introduction of modern suspended ceilings with light metal grids and lay-in tiles or light fittings has created an entirely new situation. Increased flexibility of modern buildings has added to the problem, particularly with respect to the integration of ceilings and partitions.

The seriousness of the hazard was brought to the attention of New Zealand engineers in 1966, when as a result of the Gisborne earthquake, a heavy tile ceiling in a bank building fell some 8 m in the public space, fortunately vacant at the time. As a result, ceilings in new Government financed buildings were required to incorporate seismic resistant detailing. Additional evidence from other New Zealand and overseas earthquake damage, particularly at San Fernando 1971 and Managua 1972, led in 1976 to the introduction of specific loading requirements in the New Zealand Code NZS 4203.

The introduction of a wide variety of ceiling and partition systems has increased the complexity of the problem and consequently the need for professionally engineered, practical and relatively foolproof solutions.

The authors discuss the theoretical considerations of the problem and relate these to evidence from earthquake damage. Code requirements are reviewed and a number of typical solutions are presented.

Economics are briefly discussed and in conclusion the authors refer to a number of aspects not fully understood at present. Suggestions are made for further study and testing to clarify some dynamic aspects and fire barrier problems."

12. Wind and Seismic Effects (Ref. 37)

"A description of the methods of anchoring plaster, panel applied and T-bar ceilings against seismic forces is presented which is acceptable to the Structural Safety Section of the Office of the State Architect for public school and hospital buildings in California."

13. ATC-29 Seminar (Ref. 43)

"A series of tests devised to verify the strength of typical and suspended ceiling components are described. They involve establishment of the in-plane tension and compression capabilities of various section types and shapes and sizes. Also tests to determine the tensile strength of wire support-systems are outlined. The availability of simple and reliable testing techniques suitable for the seismic qualification of nonstructural ceiling elements is likely to promote their continued and expanded use in buildings and industrial structures with less seismic damage than has been experienced in the past."

Appendix C

Typical Literature Search Letter

Suspended Ceiling Questionnaire

KRTA Limited Engineers Architects Scientists Planners

25 Teed Street Newmarket Auckland New Zealand
PO Box 9806 Ph (09) 520 6069 Telex NZ 21385 KRTAAK Fax (09) 520 4695

150 Willis Street Wellington New Zealand
PO Box 3582 Ph (04) 847725 Fax (04) 852686

Please reply to **P O Box 9806, Newmarket**
Ref. P8513 SJWB:VMB

30 July 1991

Dear Sir

Clipping of Suspended Ceiling Tiles

KRTA Limited is a firm of engineering consultants based in Auckland, with particular expertise in earthquake engineering. We are currently engaged in a research project on suspended ceilings. The project is for the Earthquake and War Damage Commission.

One item of particular interest is the issue of clipping of tiles in New Zealand as required by NZS 4203. In practice it is found that some suspended ceilings, especially in Auckland, are installed without clips. Other ceilings have few clips left after the services contractors have completed their work.

To further our research work in this area, we would ask that you fill in the attached questionnaire and return it to us. We ask for the company name only for reference. None of the information that you provide will be published separately nor any reference made between the amount of clipping and your company name.

We are contacting other suspended ceiling installers/manufacturers also for the same information and will use only the collective results. If any of the questions are unclear we will be happy to assist with clarification.

Please find enclosed a stamped self-addressed envelope.

Thanking you in advance for your co-operation.

Yours faithfully
KRTA Limited

S J W Brinkman
Structural Engineer

P8513 SJWB

Questionnaire

Clipping of Suspended Ceiling Tiles

1. Company Name * ______________________________

   * This information is confidential.

2. | Areas of New Zealand where suspended ceilings have been installed | Percentage of ceilings where clips have been installed |
   |---|---|
   | Seismic Zone A | ________ |
   | Seismic Zone B | ________ |
   | Seismic Zone C | ________ |

3. Estimated additional cost for a ceiling with clips, compared to one without clips = ______ $/m^2

4. Please comment here as to experience with clips being dislodged by services contractors.

PO Box 9806, Newmarket
Ref: P8513 SJWB:esk

Dear Sir

Re: Seismic Design of Suspended Ceilings

KRTA Limited is a firm of engineering consultants based in Auckland, New Zealand with particular expertise in earthquake engineering.

KRTA has recently been awarded a research grant by New Zealand Earthquake and War Damages Commission to carry out a world wide literature search and appraisal on the subject of seismic design of suspended ceilings, primarily of the metal grid and lay-in tile type.

We would be most appreciative if you would be able to forward to us the titles and source of any research reports that you may be aware of on this subject. Also the title and source of any damage reports on earthquakes in the last 10 years with reference to suspended ceilings.

Any assistance you are able to give would be most helpful and very appreciated.

Yours faithfully
KRTA Limited

T.W. Robertson

T W Robertson
Structural Engineering Manager