

FIRE RESISTANCE OF SEISMIC JOINTS

Michael JAMES¹ And Andy BUCHANAN²

SUMMARY

This paper reviews the design, selection testing, installation and performance of fire rated seismic joints from first principles then compares this with current standards and codes of practice. It reviews generic seismic joint designs in use today and the problems that can arise during selection and installation. It makes recommendations for areas of improvement in standards based on the first principle examination of joint requirements and actual selection and installation experience. The problem of providing fire rating to gaps subjected to large movements is discussed.

SEISMIC JOINTS AND MOVEMENT

This paper is concerned with differential movement between buildings and between components within in buildings. Buildings of irregular shape such as an L shape are split up into simpler separate structures so that the different parts can move freely in an earthquake. This strategy of separate parts to a building is also often used when adding a new section to an existing building.

Within buildings, seismic joints are used for seismic frames around windows, gaps between external precast panels, thermal expansion joints on large slabs, and gaps between internal partition walls and the supporting slab above. Movement can occur in the horizontal, vertical, lateral and axial directions. Two parts of a building side by side can move towards and away from each other, move from side to side, or have a difference in height as they deform.

If access is required between two buildings or two separate structures in a building then a physical link is required between the two. This will require connections for walls, floors, ceilings and roofs. Floors of a building are generally fire separations which requires the floor to ceiling junction and any expansion joint to be fire rated.

Internal walls for separate fire cells, and safe path corridors are required to be fire rated. These are subject to differential movement where they cross a seismic floor joint. There will be differential seismic movement between the slab and the top and bottom of the wall, requiring a gap which must be fire rated. External walls often have gaps between the structural frame and the cladding of masonry or precast concrete. These gaps need to be fire rated to prevent fire spread to adjacent buildings or from floor to floor.

There is little published on the subject of fire rated seismic joints. The majority of information is contained in codes and standards. Most literature is devoted to fire rating of gaps in fire rated barriers. Gustafarro and Abrahms (1975) cover fire tests between precast concrete panels, O'Hara (1994) covers pipes and cables passing through fire rated walls and floors, Quigg (1988) and Richardson & Venasse (1989) cover fire rating of joints in gypsum board walls. Smith (1997) covers fire rating of joints and penetrations in heritage buildings. Botting and Buchanan (1998) summarise work on fire rated joints and Botting (1998) describes the recorded spread of fire after major earthquakes. Nicholas (1995) who summarises many draft standards on fire rated seismic joints carried out the most significant work. Williamson (1998) has reported on procedures to be used to evaluate the safety of building after a major earthquake based on experiences from recent major earthquakes. After the Northridge, California 1994 earthquake, all buildings were evaluated for their suitability for occupancy, and some buildings were classified as suitable for use on a structural basis but would have failed for fire safety reasons.

¹ *University of Canterbury, Department of Civil Engineering*

² *University of Canterbury, Department of Civil Engineering*

IMPORTANCE OF SEISMIC JOINTS

Fire rated seismic joints provide a fire barrier and fill a joint that can move during an earthquake. The question has to be asked whether they are important given the infrequent nature of earthquakes and fires and the many other fire safety features in a building. For life safety, prevention of smoke spread is the most important function of a seismic joint, which should be able to survive the most demanding earthquake. As a passive fire protection feature they are as important as any other passive fire protection feature in a building when considering that active systems such as detectors, alarms and sprinklers may not be operational after an earthquake.

There are three fire scenarios in which a fire rated seismic joint may be put to the test. The first is in a building which has not been subject to any earthquake movement. The second immediately after a large earthquake where other fire safety features such as sprinklers and alarms may be inoperable. The third is some time after an earthquake when building is back into normal operation.

Building not subject to an earthquake

In the early stages of a fire the prevention of the spread of smoke is of high importance for protection of life as shown by the MGM Grand Hotel fire in 1990 where the majority of people died on upper levels of the hotel many floors away from the seat of the fire on the ground floor. Unrated seismic joints were cited as a contributing factor by Best (1982). The ability of the joint to move is of no consideration in this scenario.

Immediately after the earthquake

Widespread fires have occurred after major earthquakes (Botting, 1998). Robertson and Mehaffey (1999) believe that the water supply systems will be inoperative or have insufficient capacity for multiple fires and the fire service will be overloaded. Botting and Buchanan (1998) describe problems with seismic restraint of sprinklers and other fire protection system. In a fire immediately after an earthquake, the ability of the joint to survive the movement and still have a smoke stop capacity for protection of people and fire rated capacity for protection of large scale spread of fire causing damage to people and property is paramount.

Building back to normal operation

In a building that has survived an earthquake and is back to normal operation the relative importance of the fire rated seismic joint is the same as in the scenario before an earthquake. Smoke stopping abilities are the most important. In buildings with sprinklers and alarms these features are more important than the fire rating ability of the joint for life protection. For a sprinklered building the risks are low. However in whatever capacity the joint is designed it must be able to withstand the earthquake without damage as joints are generally in concealed spaces and not inspected for damage.

TYPICAL SEISMIC JOINT CONSTRUCTION

Floor/ ceiling joints

The generic components of a floor joint are shown in Figure 1. They are a fire rated element, a load bearing element and a final surface finish element. The fire rated element and load bearing element are designed to take up the differential movement between the two structures. The surface finish is often assumed to be sacrificial and will have to be replaced after a significant seismic event.

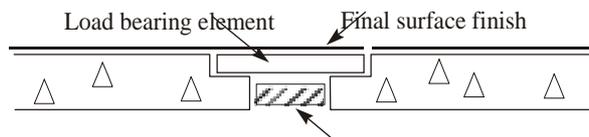


Figure 1 Components of Seismic Joint in Floor

The fire rated element can take the form of a board which may have extra insulation added dependant on the performance criteria and materials used. The board can be placed on the top of the joint if it is in a cavity where there are no load bearing requirements. The element is usually pinned at one side and allowed to slide on the other.

Intumescent layers sandwiched between foam layers are often used as the fire rated component in New Zealand but not widely used overseas. The strips are compressed into the seismic joint. During a seismic event the foam expands and contracts to take up the movement. In the event of a fire the foam also acts as a smoke seal until the intumescent strips expand to fill the gap. Another design is a fire rated blanket draped across the underside of the joint. Imported products consist of netting holding together an intumescent layer with a foil covering. Local products consist of a mineral wool fire rated blanket. Often the cavity is filled with mineral wool insulation to provide additional insulation.

Wall joints

Figures 2 and 3 show generic interior and exterior wall joints. They consist of a fire rated element and a surface finish element. The exterior wall also requires a waterproof element for the exterior wall.

A timber or metal stud wall clad with fire rated gypsum board can be designed to allow for axial movement. Where movement is in a lateral as well as an axial direction that would damage the integrity of the gypsum board, a fire rated element such as intumescent sandwich between foam strips or a fire rated blanket can be used to provide the fire rating.

Concrete walls are common firewalls and they are fitted with sliding steel plates on either side of the wall providing the fire rating and mineral wool in the centre provides the insulation rating. Sandwich layers of intumescent material and foam can also be used as the fire rated element. Another option is to use a fire rated blanket providing the rating either in the form of mineral wool or intumescent product on netting.

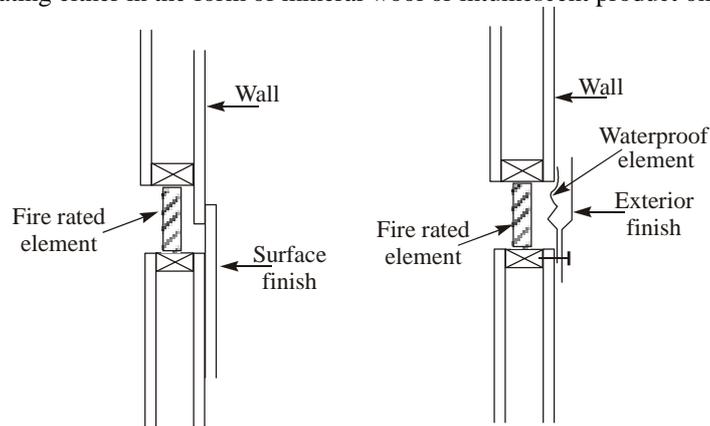


Figure 2 Interior wall joint (plan view)

Figure 3 Exterior wall joint (plan view)

Seismic joints must meet a long list of criteria to be of any use. These are cost, fire rating, ease of installation, dealing with movement in up to three planes, moisture and acoustic properties. There are three basic types of joint material, boards, intumescent strips and blankets.

Fire rated boards are low cost and perform well when only subject to axial movement, but maintaining integrity at corners is difficult, on site joints are not as good as lab tests, transitions from one detail to another are difficult, and there may be insufficient space for the required movement of the joint. Intumescent strips sandwiched between foam layers are relatively easy to install and they deal well with corners and movement in all directions. The most common problem areas are when the width of the seismic gap does not allow for the thickness of the strip when it is at its minimum width or when the gap is larger than the joint is designed for. Fire rated blankets perform well under axial movement but have problems with shear movement. They also have problems with joints and corners. When they are installed it is important that they are selected and installed to take up the maximum axial movement. In New Zealand expensive imported systems are often specified but local products are most often used. Board systems are most common with intumescent foam strip products being second. Some critical buildings such as airports tend to have more expensive imported systems.

FAILURE ANALYSIS

Fire rated seismic joints always look good in catalogues and can be made to perform well under their respective fire tests however the reality of selecting, specifying and installing a product can often be less than ideal.

In New Zealand the fire rated seismic joint is often considered to come under the architect's package of design responsibility. The general procedure is to obtain the expected movement from the structural engineer then seek advice from a manufacturer or sometimes a fire safety engineer. If the manufacturer is solely relied upon there is the danger that the architect without sufficient knowledge is unable to choose the correct product from the range being offered. Further down the track when alternatives are offered by the builder or required for cost saving measures, the architect is offered further designs. Without a standard that specifically covers seismic joints it is difficult to choose between alternatives, even if they have test certificates of compliance with various standards. As will be discussed later, few standards cover the subject fully.

Problems encountered during the construction stage based on the author's observations and anecdotal reports are described by James (1999). The life cycle of the joint starts out with the joint manufacturer designing, testing, manufacturing and marketing a joint. Then the joint is specified and installed. After the building is complete, time passes, the building may be modified, maintenance work carried out, and the joint will be subject to environmental conditions such as temperature, moisture and sunlight. At some point the fire and smoke rating performance may be put to the test in one of the three scenarios discussed earlier.

Potential failure mechanisms for each stage of the life cycle are listed in table 1.

Table 1 – Potential Failure Mechanisms in Seismic Joints

Phase	Failure Mechanism
Joint manufacturer	Design standard not matching reality Testing standard not matching reality Incorrect application of products Manufacturing defects Damage during delivery Specification for supply or installation instructions inadequate
Joint specifier: Structural engineer Fire engineer Architect	Design features such as movement and smoke and fire rating not correctly communicated to the architect for specification. Incorrect joint selected for the application. Incorrect joint accepted when offered for approval by builder.
Builder/other contractors	Gap built larger than joint designed for. Different joint chosen on price. Damage during construction. Other services pass through the joint.
Joint installer	Installation instructions incorrect. Mistakes made during installation. Installer not advised of required design movement.
Building owner/ occupier	Joints fail due to: Walls built over joints. Joints damaged during refurbishment projects. Joints removed due to inadequate knowledge of their purpose.
Passage of time	Joint products deteriorate due to age. Building is used beyond the expected life of the joint products.
Maintenance teams	No Maintenance. Damaged while other activities carried out. Services penetrating joints are altered.
Environmental conditions	Temperature, moisture, exposure to sunlight, vermin.
Earthquake	Earthquake larger than joint designed for. Movement is in directions not designed for. Joints not checked after a large earthquake. Damaged during building repair work after an earthquake. Repairs after an earthquake inadequate.
Fire	Inadequate smoke seals. Fire rating less than actual fire. Sprinklers are not operational so fire burns larger and longer. Water from sprinklers affect the performance of the joint

HOW MUCH MOVEMENT

When buildings are subject to an earthquake they sway from side to side. The primary mode of vibration is in the direction of the earthquake and the secondary mode is at 90° to this. Factors that effect the amount of movement for a given size of earthquake are the foundation design, the soil type, (whether it is sitting on rock or soil), the building construction and stiffness. Frame buildings allow more movement than shear wall buildings. The frequency of the movements is dependent on the stiffness of the building so two buildings subject to the same earthquake will have different frequencies. The seismic gap between two buildings will expand and contract, and will also be subjected to shearing deformation.

A structural engineer determines the movement required of a seismic joint, using a structural analysis to determine the expected deformation. Table 2 gives maximum permitted deflections for varying building heights under the serviceability and ultimate limit state design, based on maximum interstorey deflections given in NZS 4203 (SNZ 1992) for a floor height of 3.5m. The ultimate limit state limit is 2% interstorey drift for buildings up to 5 storeys, reducing to 1.5% interstorey drift for buildings taller than 30m. The movements are for a single building therefore they need to be doubled to get the differential deflection between two adjacent buildings. These are the maximum possible lateral movements for buildings designed right to the limits of the Standard. Many buildings will have lower movements than these.

Table 2 – Building deflection

Number of Floors	Building Height	Ultimate limit state deflection (mm)	Serviceability limit state deflection (mm)
1(or single floor in taller building)	3.5	70	12
5	17.5	335	55
10	35	525	87
15	52.5	780	130
20	70	1050	175

It can be seen from Table 2 that designing fire rated seismic joints for the ultimate limit state results in very large movements. Due to the cost of producing joints for large movements the required magnitude is going always going to be a topic for debate. In New Zealand the minimum requirements in accordance with NZS 4302 is to meet the serviceability limit state for most buildings and the ultimate limit state for more critical buildings. Fire rated seismic joints would probably be classified under NZS4302 as category PI and PII parts (parts which could lead to loss of life and the continuing function is important) therefore would need to be designed for ultimate limit state movement for category I and II buildings i.e. buildings dedicated to the preservation of life and buildings containing crowds. For buildings other than category I and II a lesser value can be used which lies somewhere between the serviceability and ultimate limit state. Many fire rated seismic joints are hidden from view therefore it is impossible to determine whether they are damaged in a minor or moderate earthquake. This leads to an inherent danger in designing them for say the serviceability limit state when the building would be fit for use but not fire safe after a major earthquake.

Fire testing of joints is an expensive process. Testing a simple straight line of joint is the lowest cost test however most joints have changes in direction, splices and joints in them which need to be considered. Also after an earthquake the joints may not be in the neutral installed position due to building deformation. A testing protocol is being developed by James (1999).

SELECTION AND INSTALLATION

One of the fundamental requirements for a seismic joint to perform successfully is to select an appropriate joint and install it correctly. It sounds simple but in reality it involves a large number of people with varying technical abilities. The architect, structural engineer and fire engineer are involved in defining the movement,

fire rating, external appearance, durability and acoustic properties of the joint. The manufacturer must be able to convey how a joint meets these requirements and any limitations the joint may have particularly when it comes to variable site on site conditions. The manufacturer must also be able to communicate to the installer how to install the joint correctly, any limitations that site conditions may impose and common solutions to some of these such as services passing through joints or variations in the static width of the joint. After the building is complete, maintenance or fitout work may be carried out which could compromise the joint if the people involved do not understand the limitations or requirements of the joint.

A partial solution to this problem is to have a classification system for joints covering movement, fire rating, durability, surface finishes, and acoustic properties. Movement is the most difficult to comprehend so this would be ideally be illustrated with pictures and diagrams. The structural engineer could specify the structural part of the classification system, the fire engineer could specify the fire rating component and the architect could specify surface finishes, construction constraints, acoustic and durability constraints. With this generic information the manufacturer is able to offer the correct products to meet the requirements. Joints could then be installed with their classification system marked on them. This would ensure that everyone in the construction phase would be able to check up on the design requirements of the joints. Accredited installers could be trained in the installation methods and how to deal with variable on site conditions such as the gap being too large or services penetrating the joint

CODES, STANDARDS AND REGULATIONS

There are a number of codes around the world either in draft or completed form covering fire rated seismic joints. UL 2079 (UL 1997) covers floor joints, wall joints, splices, wall to floor interface and wall to ceiling interface. ASTM E1399-91 (ASTM 1991) covers cyclic movement of architectural joints, more aligned to thermal expansion and contraction rather than seismic movement. The ISO (1990) draft standard covers static joints and joints that are subject to thermal movement. AS 4072.1 (SAA 1992) covers method of testing sealing systems around penetrations through fire rated building elements such as pipes, cables and ducts and also covers control joints between building elements. See James (1999) for more details of codes and standards.

None of the codes address the problems associated with selecting and installing the correct joint, or bends, changes in direction or complicating factors such as services passing through a joint. None of the standards cover the transfer of smoke in the early stages of a fire when temperatures are low. Only ASTM 1339-91 covers the design of machines for testing for movement.

CONCLUSIONS

Seismic joints are an important part of the fire safety in a building relative to other features in earthquake prone locations. Immediately after an earthquake the likelihood of active fire suppression systems being operational is low. Therefore the passive fire protection features become very important. In terms of life safety the ability of the joint to stop the passage of smoke is the most important feature in the early stages of a fire when people are escaping.

For the successful selection and installation of a joint the method of communicating the performance requirements of the joint can not be ignored. The most appropriate method for assisting this may be a classification system of joints using pictures and diagrams to illustrate the movement requirements. This classification system would be branded on the joint in a similar way as fire rated doors are identified so that anyone at a future point in time could determine what the joint was designed for.

Standards and codes of practice for the design, selection, testing and installation of seismic joints are in their infancy. Most standards have a lot of detail on the actual fire test. Additional features that need to be covered are the number of movement cycles for tests relative to earthquake movement rather than thermal movement, movement in more than one plane or direction, passage of smoke in the early stages of a fire.

Durability of seismic joints is covered by standards related to general building products. Attention needs to be given to the fact that joints are generally inaccessible therefore may not be checked or replaced after a major earthquake or fire.

ACKNOWLEDGEMENTS

The authors wish to acknowledge useful discussions with Mr. John Fleming of Firepro Safety Ltd.

REFERENCES

ASTM 1991. ASTM E1399 - 91 *Test method for Cyclic Movement and Measuring the Minimum and Maximum Joint Widths of Architectural Systems*. American Society for Testing and Materials, Philadelphia, PA.

Best;R.; Demers,D.; 1982. *Investigation report on the MGM Grand Hotel fire, Las Vegas, Nevada, November 21, 1980*. National Fire Protection Association, Quincy, Maine.

Botting, R and Buchanan, A. 1998. *Structural Design For Fire After Earthquakes*. Proceedings, Australasian Structural Engineering Conference, Auckland, P 529 - 534.

Botting R 1998. *The impact of post-earthquake fire on the urban environment*. Fire Engineering Research report 98/1, June 1988. University of Canterbury, Christchurch, New Zealand.

Gustaferro, A. H.; Abrams, M. S. 1975. *Fire Tests of Joints Between Precast Concrete Wall Panels: Effect of Various Joint Treatments*. *PCA Research and Development Bulletin*. PCI Journal, 44-64, September/October 1975. Bulletin RD039.01B; PCA R/D Ser. 1539; 16 p. Portland Cement Association, Skokie, Illinois, U.S.A.

ISO 1990. ISO/TC92/SC2/WG6 N94, 1990, *Draft Proposals for a test for joints*, Fire Research Station, Borehamwood, Herts, England

James, M. 1999. *Fire Resistance of Seismic Gaps*. Fire Engineering Research Report (in preparation). University of Canterbury, Christchurch, New Zealand.

Nicholas, J.D. 1995. *Fire Resistive Joints – A History in the Making*. Fire Standards in the International Marketplace. ASTM STP 1163. PP 100-112. Am. Soc. For Testing Materials, Phoenix, Arizona

O'Hara, M 1994. *Understanding through penetration protection systems*. NFPA Journal Jan/Feb 1994 p54 - 61

Quigg, P. S. 1988 *Control Joints in Fire Rated Partitions*. Building Official and Code Administrator, Vol. 22, No. 3, 28-29, May/June 1988.

Richardson, L. R.; Venasse, R. G. 1989. *Fire-Resistant Joints in Gypsum Wallboard*. Fire and Materials, Vol. 14, No. 4, 139-143, 1989.

Robertson; Mehaffey, 1999. *Accounting for the fire following earthquakes in the development of performance based building codes*. Interflam 99. P 273 - 284.

SAA 1992. AS4072.1, 1992. *Components for the protection of openings in fire resistant separating elements, Part 1: Service penetrations and control joints*. Standards Australia, North Sydney

SNZ 1992. NZS 4203:1992. *Code of practice for general structural design and design loadings for buildings*. Standards New Zealand, Wellington.

Smith. R, 1997. *Compartmentation in a nutshell*. Fire Prevention 303 October 1997 pp 30 - 31.

UL, 1997. UL2079, 3 January 1997, *Tests for Fire Resistance of Building Joint Systems*, Underwriters Laboratories Inc., 333 Pfingsten Road, Northbrook, IL,

Williamson, R.B. 1998. *Manual of evaluation procedures for passive fire prevention following earthquakes*. Lawrence Berkeley National Laboratory, University of California, Berkeley California.