Introduction

In many countries it is necessary to consider the effects of earthquakes when designing and constructing buildings. Earthquakes occur frequently but most are of insignificant magnitude. The larger earthquakes are less frequent but may be extremely damaging.

Building structures are designed to resist earthquakes as appropriate but the same attention is not always given to the design of cladding.

This Technical Note describes the behaviour of buildings during earthquakes, the effect on cladding and the risks associated with cladding failure.

Seismic design of building structures

In most countries affected by earthquakes building standards or codes exist. However, the type of earthquake and risk of occurrence vary and many regional or city building codes include specific earthquake requirements. For buildings that are small, of simple geometry and standard construction, the codes are applied as simple calculations. This leads to pseudo-static design methods in which equivalent horizontal forces are applied to the structure at each storey as static loads. The code will limit the permissible building structural movements, which are normally stated as allowable relative floor movements for any storey.

The effect of the earthquake depends not only on the form of the building and its geographical location but also on the site ground conditions. In pseudo-static calculations this is handled by factoring the horizontal loads.

For more complex building geometries, difficult ground conditions or buildings that have to survive (hospitals, utilities, etc.) it is normal to undertake a full dynamic analysis. If such an analysis has been performed then the displacements and accelerations experienced by the building frame will be available from the structural engineer.

Seismic resistance of structures

When designing buildings to resist earthquakes two strategies are possible:

- Flexible construction
- Semi-rigid construction

In the first case the structure is made comparatively flexible, Figure 1a, so that the structure attracts lower loads but experiences larger relative internal movements. The ground is then able to move during the earthquake while the mass of the building remains more or less static.

Semi-rigid designs are made stiff so that little relative internal displacement occurs, Figure 1b. The mass of the building then has to move with the ground and large forces are generated within the structural frame.

Building types

Buildings that are intended to flex during earthquakes are constructed as moment resisting
Cladding of buildings subject to earthquakes

(unbraced) frames of steel or concrete. This includes column and slab construction.

Semi-rigid forms of construction include load bearing masonry structures and concrete frames with shear walls. These may be provided as part of the service core or lift shaft.

**Structural movements**

The movements that affect cladding design are principally the shear that occurs with flexible building frames. Rigid forms of construction have limited relative internal displacements but may lead to high inertia forces on cladding components and fixings.

Flexible frames will exhibit different horizontal movement at each floor as a result of translational movement of the floors. The cladding has to accommodate these relative movements which appear as shear displacements on the face of the building.

Buildings that are not symmetrical on plan, or have a stiff component such as a lift shaft placed asymmetrically, are likely to show a torsional behaviour. Different rotation of each floor slab will lead to additional shear displacements on the face of the building.

Design displacements for the building structure should be determined by the structural engineer as part of the frame and foundation design. When considering the serviceability of the cladding these may be for a different magnitude earthquake than the one used for structural design.

**Cladding**

Cladding may be damaged in one of two ways by earthquakes. The principal cause of failure is due to the large relative displacements of cladding fixing points as the building structure moves.

The second cause of failure is due to the accelerations of the building frame, which will give rise to inertia forces in the cladding and fixings.

All but the most flexible of claddings will affect the stiffness of the structure and this may determine the failure mode of the structure. A particular problem occurs where the cladding differs greatly from floor to floor. The presence of lightweight cladding such as shop fronts and glazing screens only at the ground floor may make this a weak storey at which structural failure occurs. The structural engineer will normally be aware of these effects. However a cladding system may look the same from outside but be fixed differently at different floors.

**Cladding design principles**

Cladding should be designed on the same principle as the building structure with a proper consideration of the ultimate and serviceability states.

**Ultimate state** design considers the behaviour of the cladding at some maximum earthquake event. In practice there is no clear upper limit to the magnitude of the possible earthquake only a decreasing risk of being exceeded associated with larger earthquakes.

An upper limit earthquake will be set for the purposes of design and the building structure and cladding should remain safe during this event.

There are degrees of safety and it may be considered that the probability of glass falling from the wall can be greater than the probability of heavy concrete panels falling.

**Serviceability state** design considers the behaviour of the wall during some smaller earthquake and leads to a wall that is still serviceable after the earthquake event.

Serviceability generally includes:

- Watertightness
- Air leakage
- Operation of windows etc.
Accommodation of movement

Cladding that cannot freely accommodate the movement of the structural frame will become stressed and may break.

This is a major problem with stiff plates common in facade construction and breakage of glass is common during earthquakes. Falling glass is often a significant cause of injury in city centres during earthquakes.

A further problem may occur with joints and internal membranes, which may tear and rupture.

Seismic building codes generally limit inter storey drift to lie in the range 1/500 to 1/200 of the storey height.

Movement may be accommodated by:

- Rotation of panels
- Shearing of panels
- Sliding of panels

These are shown in Figure 2. The type of movement that occurs will depend on the configuration of the fixings.

When panels hanging (or standing) on individual fixings rotate, the load on each fixing will differ and the whole weight of the panel may be transferred through a single fixing.

Where the fixing system is redundant, it is possible for the panel to act as a structural component of the building frame and even higher forces will be experienced by the fixings. The use of rigid fixings to transfer dead load and flexible fixings to transfer only wind load will allow some movement accommodation at the fixings. This will limit the in-plane loads transferred to the cladding panels.

Small panels may be free to rotate if they are mounted in a glazing rebate. Glass and infill panels held between gaskets will be able to slide within the frame until they are restrained by the glazing blocks or panel to frame contact.

Panels that shear will move with the building without showing distress. These panels have to be flexible in shear to avoid the transfer of loads through the fixings. Flat panels are not generally flexible in plane but corrugated panels will often show a degree of flexibility in shear.

Sliding of panels past each other will allow relative shear of the floors to occur. Panels may be of storey height with sliding joints at each floor level. However panels can be smaller and the joints closer together. This is easily arranged for rainscreen cladding systems.

Concentration of movement

Where a cladding system contains panels of different stiffness within a single storey height then the movement will normally be concentrated within the weakest bands of the wall, Figure 3. This arises when ribbon glazing is placed between concrete spandrel panels.

Panel rotation may occur as the rotation of storey height panels or the rotation of smaller panels such as individual glazing panels.
Figure 3 Concentrated movement

Layered construction
Walls may be of layered construction with an outer rainscreen and an inner air barrier. A further inner layer may provide the internal finishes.

When designing cladding to resist earthquakes all layers of the wall should be considered and co-ordinated. The inner layers are often the most important when considering cladding serviceability.

Joints
Walls contain joints that may be open or sealed (gaskets and sealant joints). In general open joints perform well although care is needed to ensure that adjacent panels do not impact on each other. Some codes set minimum joint widths for this reason.

Sealed joints have to accommodate any relative movement of adjacent panels and should be designed appropriately.

Inertia forces
All parts of the building structure and the cladding will experience accelerations during an earthquake. These will lead to dynamic forces on the cladding panels and additional loads in the fixings.

Cladding is designed to carry wind loadings in the range 600 - 2400 Pa (N/m²) and greater. It is unlikely that such large loads will be generated normal to the plane of the wall, even for the heaviest cladding systems.

Horizontal inertia forces in the plane of the wall may also occur. However the resultant force on the fixings will comprise both the vertical and horizontal components and is unlikely to be more than fifty per cent greater than the vertical load alone.

Buildings may also be shaken vertically by an earthquake and additional vertical loads can occur. Particular attention should be given to hook on panels that may become detached.

Other components of the wall such as signage or open windows and vents will also experience inertia loads and these can lead to considerable damage to brackets, window hinges etc.

Testing
Cladding and cladding components can be tested for strength and additional loads arising from an earthquake can be applied during the tests.

Accommodation of movement can be tested by subjecting the cladding to a racking test (CWCT 1996).

To test for serviceability it is necessary to include a racking test in the general test regime for the cladding. The sequence of testing should then be:

- Air permeability
- Water tightness
- Racking
- Air permeability
- Water tightness

This will show any loss of performance as a result of an earthquake.

Note that the displacements forced during the racking test may well be of different magnitude when testing for movement accommodation and serviceability.

Summary
In many countries it is necessary to consider the effects of earthquakes when designing and constructing buildings.
Cladding may be damaged in one of two ways by earthquakes. The principal cause of failure is due to the large relative displacements of cladding fixing points as the building structure moves.

The second cause of failure is due to the accelerations of the building frame, which will give rise to inertia forces in the cladding and fixings.

References

CWCT, 1996, Standard for Curtain Walling, Centre for Window and Cladding Technology, University of Bath.

IAEE, 1984, Earthquake resistant regulations, A world list, The International Association of Earthquake Engineering.

Annex A Earthquake codes

The following countries have seismic building codes. Those shown in bold make specific reference to cladding.

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The International Association of Earthquake Engineering publishes ‘Earthquake resistant regulations, a world list - 1984’.