

Earthquakes and structural risk

The issues raised by Auckland engineer John Scarry are part of a range of technical matters that have been examined by earthquake engineering experts over the last few years. New Zealand engineers and researchers have been at the leading edge of international best practice but there is still much to learn and to be done.

The experts note, for example that many existing buildings, particularly those built before 1976, have a lower level of seismic resistance than those constructed to more modern standards. They see this issue as of similar or greater concern than the recently raised questions about hollow core floors, because failure of one element in a building doesn't necessarily mean the whole structure will fail in an earthquake. The experts acknowledge that the performance of buildings in earthquakes is a complex and evolving area of building science.

Consequently, earthquake-resistant design standards must evolve continuously as the research develops. The BIA's response to Mr Scarry supports the call for further research into four specific structural issues but also identifies a general need for more relevant practical research to support theoretical structural design as it evolves. To reduce the probability of a building failing, structural engineering design standards must embrace, not only the best knowledge about tangible factors like materials, site and construction practices, but also the concept of earthquake risk. Designing for a major earthquake gives building structures considerable reserves of strength in everyday situations.

The concept of risk

Assessment of risk is a day-to-day decision-making process in a wide range of industries and professions where uncertainties must be considered before a course of action can be taken. Such consideration may be almost sub-conscious or may involve a more sophisticated methodical approach, but in all cases the outcome is aimed at assisting the decision-making process.

Estimates of risk involve an assessment and combination of two major variables:

- **The probability that a particular event will take place**
- **The severity of the likely result if it does take place.**

At one end, the lowest levels of risk apply to events that have very low probability of occurring, combined with little resulting effect if the event does occur. At the other

extreme, the highest risks are those for highly probable events that would have extreme consequences. In most cases, risks tend to fall somewhere in between.

There are various ways of estimating, weighting and combining these variables, and most disciplines have developed their own particular methods to suit the circumstances. An obvious example of this is the insurance industry, which has sophisticated calculations on which to base estimates of risk and, therefore, premiums. Structural engineering is no exception particularly in regard to earthquake design.

Structural design

Structural design involves the calculation of likely loads for a proposed building, and the design and detailing of the structure to withstand those loads. Engineers tend to classify loading into two broad categories:

- Those that occur constantly or relatively frequently. Examples of these types of loads are gravity (the weight of the building itself, along with its contents), snow, or wind loads.
- Those that occur relatively infrequently, such as earthquake loads.

The specific loads that are used in structural design depend on the proposed use of a building, its materials and design, and its location. For instance, Wellington buildings would not be designed to withstand snow loading, but would have to withstand wind forces.

Many areas of the world need only design for the first category of loads, if there is no history of earthquakes in the region. New Zealand buildings, however, must be designed to resist specific levels of earthquake loads.

Design for earthquake resistance

Earthquake resistant design is not a precise science, and no building should be regarded as ‘earthquake-proof’. Buildings are designed to **resist** a certain level of earthquake, to protect the occupants and to limit damage.

The concept of designing buildings that can resist earthquakes is relatively recent, and the knowledge that is used for design is continuously developing as more is learned about the nature of earthquake forces and the reaction of various types of buildings to these forces. New methods are always evolving, and the performance of these is not always easy to judge. The growth in understanding will undoubtedly continue into the future, meaning that the best of our current knowledge will in turn become outdated and superseded over time.

The process of arriving at a suitable design is not as precise as many people think. There are considerable uncertainties in assessing the earthquake forces that should be allowed for, and therefore conservative assumptions are made. There are also uncertainties in assessing the capacity of different materials and connections to resist these forces without dangerous deformation.

Earthquake risk assessment

The assessment of earthquake risk needs to be considered within the concept of risk as discussed earlier. In terms of assessing the overall risk to a building, the two relevant variables are:

- **The probability of an earthquake of serious magnitude happening within the life of the building**
- **The effect of those seismic forces on the building.**

Designing to meet the combination of these variables results in the overall earthquake resistance of the building. From the nature of both factors, it can be seen that a building cannot be termed “earthquake-proof”. The uncertainties involved are considerable and, even in the latest designs, there are conservative allowances or some additional structural capacity factored in.

Probability of a serious earthquake

The greatest unknown facing earthquake engineers is whether an earthquake of serious magnitude will happen during the life of the building, and what intensity that earthquake would be, if or when it happens. It is impossible to predict these matters, so historical records and studies of seismic data such as tectonic plate movement are used to build up estimates of probability. This allows engineers to adopt a reasonably probable event for the basis of design, to allow for the possibility that an earthquake may happen at any time.

That reasonably probable event is known as the ‘design earthquake’, which is used as the basis for our design standards. In the NZ loadings standard, the design earthquake used has a 10% probability of occurrence in 50 years, or is likely to occur once in every 450 years. As can be seen, this design earthquake is conservatively based as it has a low probability of occurring.

The effect on a building

The actual occurrence of an earthquake that has an intensity equivalent to the design earthquake will not affect all locations in the same manner, as there is considerable uncertainty in terms of ground motions at any particular place. This increases the overall range of uncertainty for the structural performance of a building.

The likelihood that a building will suffer serious damage in an earthquake is affected by a variety of factors, including:

- **The limitations of accuracy in the design methods used:**
By their nature, design methods must rely on a variety of assumptions as to how a structure will behave under earthquake conditions. There are limits on the accuracy of those assumptions which then become part of the overall design.
- **Variations in properties of the materials used:**
This particularly applies to concrete, which is made up of many different ingredients from a variety of sources. This means that concrete is not an homogeneous material, and may therefore have variations in properties.

- **Properties of the site such as soil conditions, existence of fill and any geological peculiarities:**
Soil conditions can vary according to location, meaning that sites can react differently under similar earthquake conditions. In some instances, particular site conditions may even amplify earthquake effects.
- **The probability of errors in the construction process:**
Although every effort should be made to minimise construction errors, they are very hard to completely eliminate. Some possibility of errors, such as the steel not being placed exactly where the designer specified, is likely to remain even in the best-supervised project.

NZ standards make allowance for all such factors, based on the best information available at the time. Such information cannot be perfect and will develop over time in line with research and experience. Standards are regularly reviewed and updated to take this into account, which generally means that requirements are increased in line with new information.

Because of the inherent uncertainties involved in assessing the capacity of materials to resist movement or deformation, conservative assumptions are generally made. For example, the strength of concrete is usually taken as being well below the average expected.

Overall risk

Earthquake design is based on the best estimates of the likelihood that a serious earthquake will occur during the lifetime of a building. Design of structures to meet the requirements of the Building Code involves the application of NZ Standards that define the nature and size of the loadings to be applied.

Buildings must be designed for loadings that are appropriate to their use, and under such loads, must be shown not to exceed the limits set by the standards. These design standards are conservatively based on the best information available at the time. The resulting designs are therefore likely to have a degree of structural redundancy, or reserve capacity to carry other types of loads.

Overall structural performance

Earthquake design requirements are so high, relatively, that they tend to have a dominating effect on the sizes and strengths of structural components. Although of low probability, the design earthquake used to establish standards places significant demands on the structure.

The forces implied by the use of the design earthquake almost always govern the size and strength required of structural elements such as columns and beams. This means that buildings tend to have reserve capacity for carrying day-to-day loads, and are likely to meet or exceed the Building Code performance requirement to:

have a low probability of rupturing, becoming unstable, losing equilibrium, or collapsing during construction or alteration and throughout their lives.

Conclusions

Concerns regarding the seismic performance of some components, such as concerns regarding the performance of hollow core floors, need to be seen in the overall context of earthquake design, taking into account:

- The low probability of an earthquake of the magnitude on which the NZ Standards are based
- The imprecise nature of understanding and estimating the elements involved in earthquake design
- The continual expansion of knowledge and experience on the behaviour of buildings in severe earthquakes
- The numbers of existing older buildings that were built to meet standards current at the time of their construction, but which do not meet current earthquake requirements.
- The likelihood that current standards will become, in their turn, outdated in the future as requirements increase in line with new findings.