AS 1170.4 Earthquake actions in Australia—Worked examples

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1. Summary

This paper provides a short guide and worked examples illustrating the use of AS 1170.4 *Structural design actions* Part 4: *Earthquake actions in Australia*.

The examples assume that at least a static analysis has been selected, and therefore, sets out the data required to calculate the base shear. Many structures do not require this level of design effort as there are conditions for which no further work is required by the Standard.

The key to understanding AS 1170.4 is that the performance of our building stock needs to take into account the unpredictable nature of earthquake activity in our low seismic environment. This approach arises from the small knowledge we have of earthquake risk in Australia coupled with the very low levels of earthquake risk we do currently expect. Therefore, the detailing requirements of the Standard are intended to provide some measure of resistance to earthquakes for all structures while the design levels for 1/500 annual probability of exceedance are intended for use mainly in the design of the seismic force resisting structural system and other components.

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2. Process of designing for earthquake actions

Earthquake actions are determined by considering the site hazard and the type and configuration of the structure. The Standard also provides the means for reducing earthquake loads on a structure by achieving set levels of ductility. Materials design Standards then provide detailing to enable the selected structural ductility to be achieved.

The aim is to avoid collapse. This requires the structure (and indeed the whole building) to be able to deform with the earthquake and absorb energy without vertical supports giving way. Therefore, it is not expected that a structure subject to the design earthquake would be undamaged, but rather that the damage had not progressed to collapse.

For Australian conditions, where we have scant knowledge of the earthquake activity, we design for a lateral equivalent static load, unless the structure is particularly vulnerable to dynamic effects. The standard also sets out minimum detailing requirements that aim to provide buildings with a reasonable level of ductility. In the event that a structure is subject to an earthquake, the ductility provided greatly improves its performance, regardless of the actual magnitude of the earthquake and the actual design actions.

The following paragraphs set out the sequence of steps required to determine the actions. Analysis of the structure is not covered.

3. Annual probabilities of exceedance

The AS/NZS 1170 series is as follows:

AS/NZS 1170 *Structural design actions*
- Part 0: *General principles*
- Part 1: *Permanent, imposed and other actions*
- Part 2: *Wind actions*
- Part 3: *Snow and ice actions*
- Part 4: *Earthquake actions in Australia (AS 1170.4)*
- Part 5: *Earthquake actions in New Zealand (NZS 1170.5)*

AS 1170.4 falls under the umbrella of AS/NZS 1170.0 and is for use with the BCA. As with all the parts of the series, Part 0 provides the annual probabilities of exceedance or, for buildings covered by the BCA, refers the user to those provided in the BCA.

As a starting point for the design of structures for earthquake, the BCA provides Tables B1.2a and B1.2b (see extract below from Part B1 of the BCA Volume 1). The Guide to the BCA provides comment on Table B1.2a, including the Table below giving examples of structures for the different Importance Levels.

Refer to the BCA and the Guide to the BCA to check on the latest versions of the following extracts.

Table B1.2a
Importance Levels of Buildings and Structures

Importance Level	Building Types
1	Buildings or structures presenting a low degree of hazard to life and *other property* in the case of failure.
2	Buildings or structures not included in Importance Levels 1, 3 and 4.
3	Buildings or structures that are designed to contain a large number of people.
4	Buildings or structures that are essential to post-disaster recovery or associated with hazardous facilities.

Table B1.2b
Design Events for Safety

Importance Level	Annual probability of exceedance			
	Wind		Snow	Earthquake
	Non-cyclonic	Cyclonic		
1	1:100	1:200	1:100	1:500
2	1:500	1:500	1:150	1:500
3	1:1000	1:1000	1:200	1:500
4	1:2000	1:2000	1:250	1:800

TABLE B1.2b from the BCA

Table B1.2a

A generic description of building types has been provided to which Importance Levels have been assigned. The 'Importance Level' concept is applicable to building structural safety only. More specific examples are provided in the following Table. The examples are not exhaustive.

Importance Level	Examples of building types
1	Farm buildings Isolated minor storage facilities Minor temporary facilities.
2	Low rise residential construction Buildings and facilities below the limits set for Importance Level 3.
3	Buildings and facilities where more than 300 people can congregate in one area Buildings and facilities with primary school, secondary school or day care facilities with capacity greater than 250 Buildings and facilities with a capacity greater than 500 for colleges or adult educational facilities Health care facilities with a capacity of 50 or more residents but not having surgery or emergency treatment facilities Jails and detention facilities Any occupancy with an occupant load greater than 5000 Power generating facilities, water treatment and waste water treatment facilities, any other public utilities not included in Importance Level 4 Buildings and facilities not included in Importance Level 4 containing hazardous materials capable of causing hazardous conditions that do not extend beyond property boundaries.
4	Buildings and facilities designated as essential facilities Buildings and facilities with special post disaster functions Medical emergency or surgery facilities Emergency service facilities: fire, rescue, police station and emergency vehicle garages Utilities required as backup for buildings and facilities of Importance Level 4 Designated emergency shelters Designated emergency centres and ancillary facilities Buildings and facilities containing hazardous materials capable of causing hazardous conditions that extend beyond property boundaries

Importance levels must be assigned on a case by case basis.

TABLE FROM GUIDE TO THE BCA

4. Quick paths to an exit

If you are designing one of the following structures, you can exit quickly to a simplified solution or even out of the Earthquake Standard altogether:

Importance Level 1 structures
Domestic house (Class 1 building)
Importance level 2 and h_n <= 12m

The examples below (Paragraph 12) ignore the simplified solutions in order to illustrate the use of the Standard.

5. Hazard at the site

Once the appropriate annual probability of exceedance has been determined, AS 1170.4 can be used to determine the value of k_p. The loads on the structure are then calculated based on this value.

The site hazard is determined from Section 3 of the Standard. The value of Z can be read from a Table or, for locations away from major centres of population, determined from the maps. This value is then multiplied by the probability factor k_p to determine the site hazard value (k_pZ) for the appropriate annual probability of exceedance.

6. Influence of site sub-soil conditions

The site sub-soil conditions are grouped into 5 categories (Class A_e, B_e, C_e, D_e or E_e) ranging from hard rock to very soft materials. The soil type is determined by a geotechnical investigation for taller (longer period) structures. The material in which the structure is laterally coupled to the ground provides the site class.

Generally, for short structures that are not of high importance, simply knowing whether the structure sits on rock or in soils of some depth (eg. more than 3m deep) would be enough to determine the appropriate value.

7. Selecting the analysis method

Once the annual probability of exceedance, the hazard value for the site, the sub-soil conditions and the building height are known, the required design effort can be determined using Table 2.1 (see copy from the Standard given below).

This paper assumes that at least a static analysis has been selected, and therefore, the remaining data required to calculate the base shear has to be determined. The Table below shows how for many structures, there are points at which no further work is required.

TABLE 2.1 FROM THE STANDARD
SELECTION OF EARTHQUAKE DESIGN CATEGORIES

<table>
<tr><th rowspan="2">Importance level, type of structure (see Foreword)</th><th colspan="5">Mapped hazard (k_pZ)
for site sub-soil class</th><th rowspan="2">Structure height, h_n (m)</th><th rowspan="2">Earthquake design category</th></tr>
<tr><th>E</th><th>D</th><th>C</th><th>B</th><th>A</th></tr>
<tr><td>1</td><td colspan="5">—</td><td>—</td><td>Not required to be designed for earthquake</td></tr>
<tr><td rowspan="2">Domestic housing as defined in Appendix A</td><td colspan="5" rowspan="2"></td><td>top of roof ≤8.5m</td><td>Appendix A procedure</td></tr>
<tr><td>top of roof >8.5m</td><td>Select design method as for Importance Level 2 structures</td></tr>
<tr><td rowspan="3">2</td><td colspan="2">≤0.05</td><td>≤0.08</td><td>≤0.11</td><td>≤0.14</td><td>≤12
>12, <50
≥50</td><td>I
II
III</td></tr>
<tr><td colspan="2">>0.05 to ≤0.08</td><td>>0.08 to ≤0.12</td><td>>0.11 to ≤0.17</td><td>>0.14 to ≤0.21</td><td><50
≥50</td><td>II
III</td></tr>
<tr><td colspan="2">>0.08</td><td>>0.12</td><td>>0.17</td><td>>0.21</td><td><25
≥25</td><td>II
III</td></tr>
<tr><td rowspan="2">3</td><td colspan="2">≤0.08</td><td>≤0.12</td><td>≤0.17</td><td>≤0.21</td><td><50
≥50</td><td>II
III</td></tr>
<tr><td colspan="2">>0.08</td><td>>0.12</td><td>>0.17</td><td>>0.21</td><td><25
≥25</td><td>II
III</td></tr>
<tr><td>4</td><td colspan="5">—</td><td><12
≥12</td><td>II
III</td></tr>
</table>

EDCI— Earthquake design category I is a simple lateral load applied at each level.

EDCII— Earthquake design category II requires a static analysis (dynamic can be used if desired). Section 6 sets out the method including the spectral shape factor, the structural ductility and performance factors, the natural period of vibration of the structure, etc. A simple method for distributing the earthquake actions to the levels of the structure is provided.

EDCIII— Earthquake design category III requires a full design with dynamic analysis. This is required for the highest hazard levels and tallest structures.

8. Period of vibration of the structure

The construction material, type of structure, and the period of the first mode of vibration all have an influence on the forces experienced by the structure.

In cases where a static or dynamic analysis is required, the first mode natural period of vibration of the structure is calculated (T_1). It is calculated by a simple equation given in Section 6 of the Standard. The equation is based essentially on the height of the structure, but includes an adjustment for material type.

It is acknowledged that the determination of this value is prone to error. The method of calculation given is the most reliable method available other than carrying out a full dynamic analysis and even then there are inherent modeling inaccuracies. Determining the period of an existing structure, however, is a simple exercise involving measuring its vibrations.

9. Spectral shape factor (site hazard spectrum)

The period is then used to determine the spectral shape factor ($C_h(T_1)$) for the building on the site. For dynamic analysis, the effects of a number of periods of vibration may be summed to determine the action effects in the members and, therefore, a number of spectral shape factors may be used in the analysis.

10. Adjusting for ductility

Once a design analysis is required, the structural configuration must be selected with resulting S_p/Mu values. *Mu* (the Greek letter) represents the structural ductility while S_p, the structural performance factor, is an adjustment made to calibrate the known performance of structure types to the calculated ductility.

As the S_p/Mu value reduces, the structure will absorb increasing energy and therefore is designed for less direct load but for more plastic capacity. For the lowest values (i.e., highest ductility, e.g., $Mu = 6$), dynamic analysis should be used and sophisticated methods are employed to establish the plastic capacity and ductility available at joints and designated hinges (usually only carried out in places such as New Zealand, California, Japan, etc.). Detailing rules to achieve these levels of ductility can be highly complex. At the other extreme, for the highest values ($S_p/Mu = 1.0$) the structure is designed to remain fully elastic under the full loads.

For Australian conditions, the earthquake actions are adjusted for ductility by selecting the value of S_p/Mu from Section 6. Once the value of *Mu* is selected the structure must then be detailed to achieve that selected ductility. For moderately ductile structures such as shear walls, ‘ordinary’ moment resisting frames, braced frames, and similar, there is no explicit design of plastic hinges. The ductility is achieved by applying the detailing provided in the materials design Standards currently in use.

In order to achieve the ductility assumed in design of the structure, it is essential that stiff elements should not impose themselves on the behavior of the seismic force resisting system. If they do, the structure will not exhibit the ductility required of it and will therefore attract a much higher load than that for which it is designed.

The Standard assumes that structures are irregular as the vast majority of structures in Australia fail to achieve regularity.

11. Calculating the base shear

For the vast majority of structures (low height, normal importance on firm or shallow soils) the next step is to estimate if the load is likely to be less than the wind load. This is done by calculating the base shear and then distributing the lateral force onto the various levels of the structure.

The base shear may be understood to be the percentage of the weight of the building to be applied laterally (eg. say 15% of ($G + 0.3Q$) for the building).

The base shear equation is—

$$V = [k_p Z C_h(T_1) S_p / Mu] W_t \quad (1)$$

All the variables in the equation are defined above.

Once the horizontal design action is calculated from the above information and the seismic weight of the structure, analysis can be carried out.

The materials design Standards are then used to design the members for the required resistance including achieving the ductility assumed in determining the loads. Finally, the parts of the structure must be tied together and individually designed to perform.

Inter-storey drifts should be checked to ensure that parts such as stiff walls do not interfere with the seismic force resisting system. Walls will usually require a check of the resistance to face loading.

The analysis and materials design is where AS 1170.4 differs most from NZS 1170.5. The Australian Standard provides for simplified analysis methods based on the low level of hazard. Also, as a result of the lower earthquake loads expected, the detailing required is minimal compared to that for such countries as New Zealand. Therefore, the materials design Standards are much simpler than those required in high hazard areas.

12. Worked examples

To illustrate the use of the Standard, following are some examples of the design required for various site conditions.

TABLE 12.1
EXAMPLES OF TYPICAL STRUCTURES

Item	**Building example**			
	Commercial, 9.5m	**Residential, 4 floors plus ground floor and two basements**	**Golf Club, 3 storey**	**Public Hospital, 3 storey**
Annual probability of exceedance (based on probabilities similar to those given for wind, proposed by BD-006, see values given above by the BCA and explanation below)	1/500 (normal structure)	1/500 (normal structure)	1/1000 (assembly space holding >300 people)	1/2500 (surgery/emergency facilities)
Probability factor—k_p	1.0	1.0	1.3	1.8
Hazard factor—Z (mapped hazard)	Sydney—0.08	Morriset—0.10	Camden—0.09	Penrith—0.08
Site sub-soil class—A_e to E_e	C_e Firm soils (<25m deep)	A_e Basements supported laterally in rock (>50MPa)	C_e Firm/stiff soils (<30m deep)	C_e Soft/firm soils (<20m deep)
Number of (seismic) storeys	1 Piered to stiff strata	6 Ground floor not laterally coupled to soil structure	3 Raft slab	3 Piered to hard strata
Building height to top-most mass—h_n	9.5m	19.5m	9.5m	9.5m
Design effort required—Table 2.1 (simplified solutions have been ignored in the interests of illustrating the Standard; a higher method may always be used in preference to a simplified solution)	EDCII (static analysis required) [EDCI could be applied but is ignored here for the sake of illustrating the Standard]	EDCII (static analysis required)	EDCII (static analysis required)	EDCII (static analysis required) [if the height had been 12m or more, a dynamic analysis would have been required]

Building type (material and construction)	Concentrically braced steel frame, light roof and concrete slab on ground with sheet cladding	Concrete slabs and columns with limited ductile shear walls and tiled roof	Concrete slabs and columns with ductile shear walls and light roof	Concrete slabs and columns with intermediate moment-resisting frame and light roof
Period—T_1 (natural first mode of vibration)	0.34s	0.58s	0.34s	0.42s
Spectral shape factor— $C_h(T_1)$	3.5	1.22	3.5	3.0
Ductility and performance factors—S_p/Mu	0.38	0.38	0.22	0.22
Base shear— $V = [k_p Z C_h(T_1) S_p / Mu] W_t$	0.106 W_t	0.046 W_t	0.09 W_t	0.095 W_t
Position of masses and calculated forces on each level	see Table below			
	Apply the forces to the structural members, through the load paths to the foundation and also to the parts and components of the structure (eg, walls, cladding)			
	It is vital to apply the detailing required by the materials Standards to achieve the ductility that has been assumed for determining the loads			
	Check other requirements such as drift, pounding, action in two directions, torsion effects, connections, P-delta effects			

TABLE 12.2
CALCULATION OF ACTUAL FORCES

	Commercial, 9.5m			**Residential, 7 storey**			**Golf Club, 2 storey**			**Public Hospital, 2 storey**		
	m	W_i	F_i	m	W_i	F_i	m	W_i	F_i	m	W_i	F_i
Positions of masses and calculated forces as distributed to levels	0	—	—	0	—	—	0	—	—	0	—	—
	9.5	650	69	3	1300	21.7	3	1950	105	3	2400	127
				6	1200	41.2	6	1700	193	6	2000	211
				9	1180	61.8	9.5	500	85	9.5	1100	184
				12	1174	82.9						
				15	1160	103.3						
				19.5	423	49.5						
Value of k	1.0			1.04			1.0			1.0		

Comments

Higher ductility has been chosen to reduce the loads on the Golf Club and the Hospital. This will result in more effort in detailing to achieve the higher Mu assumed. Alternatively the higher loads could be designed for (with a lower assumed Mu) and less detailing would be required (ie, assuming fully elastic behavior at the ultimate loads). A similar approach to reducing loads (assuming a higher Mu value) could be used where Z is high.

The use of annual probabilities in the examples is based on recommendations to be proposed for adoption in the BCA at the time of adoption of the new Standard: IL3: 1/1000 and IL4: 1/2500. This is different to the existing values currently in the BCA of IL3: 1/500 and IL4: 1/800 (see copy of Table B1.2b above).

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Annex A—Function of AS/NZS 1170.0

AS/NZS 1170.0 *Structural design actions* Part 0: *General principles* provides the link between the limit states actions imposed on the structure and the design of materials for resistance. As background it should be noted that the format embodied in the new AS/NZS 1170 series of Standards (set out most comprehensively in Appendix F of Part 0 and it's Commentary) is founded on work done in the APEC TG1 Informal network. This was a group of loading experts from across the APEC region that met to create a means of establishing inter-changeability between the loading codes of different nations. The motivation for this move is the GATT agreement and the reduction of technical barriers to trade.

The basic aim is to state the design event in terms of the annual probability of the action being exceeded. The load is then defined for any annual probability of exceedance so that the design event is independent of the technical definition of the loads. This can be clearly seen in the wind Standard where AS/NZS 1170.2 is simply the technical solution that gives the loads independently of the annual probability of exceedance (design event) which is set elsewhere.

One of the fundamental principles of this approach is the removal of hidden factors through the provision of an umbrella document that defines the loading and resistance levels for design using the design event approach. This led to the development of Part 0.

This APEC work has been taken through to the ISO arena and will be embodied into the next generation of International Standards from ISO TC98 *Basis for design of structures*.

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