Defining importance levels for the design of retaining walls

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ABSTRACT

Retaining wall design does not typically differentiate between levels of importance, particularly for static design. Walls that are more important, for example supporting importance level four buildings, are often designed to the same safety margins as relatively unimportant walls. Indeed, it can be argued that using more sophisticated analysis and more geotechnical data for more important walls, that the overall level of safety may be lower than less important walls which typically require only routine and inherently more conservative methods.

Importance levels are commonly used in the design of buildings, as required by the Building Act 2004 and associated Building Regulations 1992. However, they are not typically used for retaining wall design except for in some limited load cases such as to determine seismic earth pressures. Whilst the design of retaining walls is subject to the requirements of the Act and Regulations, the importance levels definitions are intended for buildings and are not easily interpreted for retaining wall design. This paper provides a review of local and international practice in defining differing levels of importance to retaining wall and recommends a method of interpretation for New Zealand practice.

1 INTRODUCTION

The design of retaining walls does not typically differentiate on the importance of the wall. For example a wall supporting the foundations of a building required for post-disaster functions may be designed to the same level of safety as a relatively less important wall, such as a wall supporting a cut above a low use private road. The consequences of failure of these examples are significantly different. Should the more important wall be required to be designed to a higher standard?

Walls with higher consequences of failure are often designed with better information, such as higher quality geotechnical investigations and well defined geometry, and with more sophisticated methods of analysis. Whilst this improves the understanding of wall behaviour and reduces the uncertainties relating to failure, it is more likely that the wall design is optimised and value engineered, which may result in smaller margins of error against failure. The risk of failure is studied in reliability and probabilistic methods of analysis, but is more implicit in the more common deterministic methods of analysis. Retaining wall design is often governed by static design, particularly in low seismic hazard areas and for flexible walls where displacement in earthquakes can be tolerated, therefore the importance level classification makes little difference to the design of many retaining walls.

Importance levels are used to a limited extent in some aspects of geotechnical engineering. These are probably best understood when evaluating seismic hazard, where less likely but higher consequence earthquakes are considered in the design. This is typically simplified to a return period factor, where a higher factor (and therefore stronger ground motions) is used for more important structures.

Established standards such as the Building Regulations (MBIE, 1992), NZS1170 (Standards NZ, 2002) and Bridge Manual (NZ Transport Agency, 2016) provide some guidance on importance levels. These are typically for buildings and critical infrastructure. Therefore, interpretation is required for typical retaining walls.

2 EXISTING STANDARDS

2.1 Building Regulations

All building work in New Zealand, including retaining walls, must comply with the Building Act, Building Regulations and Building Code. Retaining walls would usually be classified as an ancillary building, i.e. not used for human habitation (Regulations, Clause 8). This classification allows exemption from some provisions such as amenity, but structural and safety aspects must still be complied with. Clause A3 of the Regulations sets out building importance levels. Whilst the clause describes building use and occupation, interpretation can be made for retaining wall design.

Table 1: Importance Level as defined by the Regulations (amended)

Importance Level	Description of building type
1	Buildings posing low risk to human life or the environment, or a low economic cost should the building fail. These are typically small non-habitable buildings, such as sheds, barns, and the like, that are not normally occupied, though they may have occupants from time to time. Examples: • Ancillary building not for human habitation • Minor storage facilities
2	Buildings posing normal risk to human life or the environment, or a normal economic cost, should the building fail. These are typical residential, commercial, and industrial buildings.
3	Buildings of a higher level of societal benefit or importance or with higher levels of risk significant factors to building occupants. These buildings have increased performance requirements because they may house large numbers of people, vulnerable populations or occupants with other risk factors or fulfil a role of increased importance to the local community of society in general Examples: • Where >300 people congregate in one area • Primary or secondary school or daycare (capacity > 250), college or adult education facilities (capacity >500) • Health care facilities (capacity >50) but not having surgery or emergency treatment • Jails and detention facilities • Any other building with >5,000 capacity • Power generating facilities, potable water and wastewater treatment facilities, and other public utilities facilities not designated as post-disaster
4	Buildings that are essential to post-disaster recovery or associated with hazardous facilities. Examples: • Hospitals and other health care facilities having surgery or emergency treatment • Fire, rescue, and police stations • Emergency shelters, preparedness, operation centres and response • Power generating stations and other utilities required as emergency backup facilities for importance level 3 structures

2.2 Building Code Clause B1 Verification Method VM4

The verification method B1/VM4 Foundations (MBIE, 2016) provides a design method by which compliance with the Building Code may be verified. It is very commonly used and referenced when designing retaining walls in New Zealand. The method does not provide any guidance on determining importance levels.

2.3 AS/NZS1170.0:2002 Structural design actions, Part 0: General principles

NZS1170.0 specifies general procedures and criteria for the structural design of a building or structure. It is a widely used reference for design in New Zealand. The importance level is reflected in the acceptance of the probability of exceeding a limit state. This is determined using the annual probability of exceedance for actions. A 10% probability of exceedance in the life of the structure is commonly accepted, therefore 1/500 for earthquakes. This probabilistic approach is only used for the highly variable environmental actions, for example wind, earthquakes and snow. Other actions are determined deterministically including dead, live and earth pressure loads. Therefore, in some aspects, structural design does not differentiate between buildings of different importance.

2.4 NZTA Bridge Manual

The Bridge Manual (NZTA, 2016) sets out criteria for the design of bridges, culverts, earthworks and retaining walls. The manual is used for NZTA's state highways but other organisations often reference it, for example local council road controlling authorities. Similar to NZS1170, the manual follows limit state principles adopting a statistical approached to deriving loads. Specific guidance for importance levels is provided for retaining wall design. As NZTA's state highway network is typically of relatively high importance due to the high consequences of failure, use of the manual for private development and less important assets would generally be considered quite conservative.

Table 2: Importance level for retaining walls as defined by the bridge manual (from NZTA, 2016, amended)

Importance Level	Route security (typically supports road)	Protection to adjacent property (typically above road)
1	Not primary lifeline route and height <5m or area <50m^2 No-exit or loop rural roads and serving population <50 Where failure would not affect the use of the road	Failure would not significantly endanger adjacent property
2	Primary lifeline route and height <5m or area <100m^2 Not primary lifeline route and height >5m or area >50m^2	NZS1170.0 Table 3.2 Consequences >$1.3M
3	Primary lifeline route and height >5m or area >100m^2	NZS1170.0 Table 3.2
4	Critical to post-disaster recovery (for example where failure would close important roads)	Post disaster function NZS1170.0 Table 3.2
• Retaining walls associated with bridges determined based on that bridge • Retaining walls not defined above to be IL2 • Determination of height includes consideration of backslope		

2.5 AS4678-2002 Earth retaining structures

The standard sets out requirements and recommendations relating to the design and construction of structures required to retain soil, rock and other materials. The standard is widely used in New Zealand. Walls are classified as shown in the following table. The classification is used to vary some aspects of the design, for example lesser live load surcharge and less conservative strength reduction factors may be used for the lower classification walls. The standard also provides recommendations for different levels of construction monitoring. The principles of the approach in the standard are interesting, however the system is rather limited as most walls will be in the middle classification which would cover several importance levels in the NZ Building Regulations/NZS1170.0 system. The partial factors that vary for the classification are not necessarily critical to the design, therefore, there may be little difference in safety.

Table 3: Structure classification for retaining walls as defined by AS4678-2002 (amended)

Classification	Description	Examples
A	Low consequence for loss of human life, or small or moderate economic, social or environmental consequences	Where failure would result in minimal damage and loss of access. Areas rarely visited by people. Walls on private property supporting gardens.
B	Medium consequence for loss of human life, or considerable economic, social or environmental consequences	Where failure would result in moderate damage and loss of access. Walls supporting or above normal structures. Walls supporting minor roads. Walls above public spaces. Walls >1.5m height.
C	High consequence for loss of human life, or very great economic, social or environmental consequences	Where failure would result in significant damage or loss of life. Walls supporting, or supporting or above access for, structures identified for post-disaster recovery.

2.6 Other international guidance

Eurocode 7 Geotechnical Design (BS EN 1997-1:2004) includes a three tier categorisation system which is based on the complexity of the structure. For example, Category 1 is for small and simple structure and Category 3 is for large or unusual structures or those in high seismic areas. The system does not require safer structures through mandated partial safety factors.

BS8006:1995 Code of practice for strengthened/reinforced soils and other fills included a partial load factor depending on the ramifications of failure. Three categories were defined. The system is similar to AS4678-2002.

Hong Kong's Geoguide 7 Guide to Soil Nail Design and Construction (GEO, 2008) describes a three tier system where the consequences to life and economy are to be considered with higher safety required for the more important structures. There can be quite a significant different (1.4 compared to >1.0) in the required safety between the most and least important structures.

3 POTENTIAL ISSUES WITH CURRENT PRACTICE

Two related potential issues have been identified with the determination and application of importance levels in the design of retaining walls in typical projects in New Zealand. These are inconsistency and the lack of relevance.

3.1 Inconsistent use of importance levels

There is a wide range of importance levels (IL) that can be applied to retaining wall design, particularly for private development. Many designers adopt an IL equivalent to typical buildings, i.e. IL2. However, the IL for a typical 5m high wall could be IL1, IL2 or IL3 based on the definition in the Regulations, a typical building or Bridge Manual respectively. The decision between these would largely be dependent on the subjective interpretation by the designer.

An example of where inappropriate selection of the importance level could occur is where a retaining wall is very close to a more important structure, for example a building with a post-disaster function which is therefore classified as importance level four. Collapse of the retaining wall could result in disruption to that building by blocking access or even cause significant structure damage. The Bridge Manual, however, requires that such "associated" structures be classified with equivalent importance as the more important structure.

3.2 Lack of relevance of the importance level in retaining wall design

It could be expected that more important structures be designed to be safer. However, if the only actions that increase due to a higher importance classification are not critical to the design, then there is no difference in safety of these structures. Research has indicated that earthquake design is not critical for many types of retaining wall where the design acceleration is less than 0.4g (Atik & Sitar, 2010). The following table indicates that for a typical flexible retaining wall there are few locations where the seismic hazard is high enough to be critical to the design.

Another comparison would be to consider the decrease in load factor for static design (F_E = 1.5) to seismic design (E_u = 1.0). As earth pressure is usually the critical action, it would need to increase by 50% due to earthquake acceleration even before other behaviours are considered like tolerable wall displacement. The coefficient of earthquake active lateral pressure (DK_{AE}) only exceeds 0.5 in very strong earthquakes.

Table 4: Comparison between return period factors and load factors

Importance Level	Return period factor (Annual probability of exceedance)	Hazard factor for k_h > 0.4g	Locations
1	R = 0.5 (1/100)	C0,1000 > 0.65	None
2	R = 1.0 (1/500)	C0,1000 = 0.58	Arthur's Pass and Otira
3	R = 1.3 (1/1000)	C0,1000 = 0.44	Woodville/Masterton/Wellington The north and west South Island (NW of Cheviot/Te Anau)
Assuming 50 year design life, Site subsoil class C, wall displacement factor 0.5			

4 RECOMMENDED DEFINITION AND USE OF IMPORTANCE LEVELS

The fundamental issue with considering the use of importance levels is whether it is desirable that more important retaining walls be safer than walls where the consequences of failure are less significant. If it is desirable, then it is necessary that importance levels are used to differentiate for all critical failure mechanisms, not only seismic actions as current practice. This could be achieved by applying partial safety factors based on importance level. These could be load factors or strength reduction factors, or both.

The importance levels defined by the Building Regulations are considered appropriate for use for retaining walls. The interpretation is critical. Too many walls are defined with an unnecessarily high importance level. Compared to buildings, which are usually occupied, failure of a typical retaining wall is unlikely to result in fatalities or high economic cost. Even locations such as high use car parks or city centre footpaths rarely have people standing at locations where failure would pose them an extreme risk.

It is also unnecessary to directly relate importance level to wall geometry such as area, or more significantly to height, rather than using a risk based approach. It is more likely that large walls are more important for other reasons, such as their failure could damage a nearby building.

However, a 10m high wall supporting a car park is not necessarily as important as a smaller wall supporting the foundations of a building.

The following table provides recommended guidance for determining importance levels for retaining wall design.

Table 5: Recommended definition of importance levels for retaining walls

Importance Level	Risk to human life and environment should the retaining wall fail	Comment
1	Low	Most retaining walls
2	Normal	Typically supporting, or above, area commonly occupied
3	High	Typically supporting or above area commonly occupied by a large number of people or where failure would have significant consequences to society
4	Very high	Retaining wall required for post-disaster function or associated with hazardous facilities

Notes:

1. Where failure of a retaining wall would pose a significant risk to a structure of higher importance level (i.e. the retaining wall is an associated structure), then the same importance level as that structure to be used. This includes where a retaining wall supports, or is above, access or emergency egress from that building.
2. For clients and asset owners that have specific requirements (for example NZTA), their definition of importance level to be used.
3. Risk of failure should be compared to a building of the same importance level.

Increasingly conservative safety factors are recommended based on importance level. This would require more important walls to be safer. The following factors have been derived from similar retaining wall standards used internationally and extrapolated to the New Zealand importance level system.

Table 6: Recommended safety factors for retaining walls considering importance level

Importance Level	Global factor of safety for static design	Load factor for static design	Strength reduction factor
1	1.4	1.0	1.00
2	1.5	1.1	0.95
3	1.6	1.2	0.90
4	1.7	1.3	0.85

Notes:

1. Global factors of safety are typically used for deep seated slope stability failure mechanisms. These should also be applied to associated slopes, for example retaining wall backslopes.
2. Load factor to be additional to those typically used for actions. For example for IL3, equation 6-4 of the NZGS Module 6 becomes $E_{d,dst} = 1.2 * [1.2G + 1.5 F_E + 0.4Q]$ for the gravity design case.
3. Strength reduction factor to be additional to those typically used when assessing resistance and capacity.

5 IMPLICATIONS IN PRACTICE

The improved definition of importance levels would allow a more rational basis for retaining wall design. There would be a clear difference between retaining walls where the consequences of failure are relatively minor compared to walls where failure would be significant. The use of specific safety factors would require more important walls to be safer for all failure mechanisms.

It is possible that the cost of more important retaining walls would increase. However, improved use of project based strength reduction factors (for example those defined in the piling standard AS2159-2009) and improved understanding of risk based design would result in more appropriate solutions. It is also likely that better definitions of less important walls combined with less conservative safety factors would result in more economic solutions for many retaining walls.

6 CONCLUSION

The existing use of importance levels in retaining walls design is inconsistent due to the lack of definition for how to interpret building standards. What guidance is available tends to be for assets of high importance and community value, for example state highways required for lifelines in post-disaster circumstances. Design practice only typically uses importance levels for seismic design which is often not critical to the design of walls, therefore the use of importance levels of little relevance to the final design outcomes. A specific design standard or guideline would likely improve the consistency and quality of retaining wall design.

The philosophy and intent of importance levels is potentially very useful. It would be straightforward to require more important walls to be designed to be safer. There are some examples internationally of additional requirements, for example for safer partial factors to be used. It is logical that walls required for post-disaster functions and where the consequences of failure are more significant that the probability of failure would be much lower.

Importance levels can easily be defined by the risk of failure. Most retaining walls have a relatively low risk compared to buildings, therefore most walls should be importance level one. Where the consequences are higher, for example where failure may result in significant damage to a building, then higher importance levels should be used. It is not necessary to define importance levels based on height or other parameters.

It is recommended that more conservative safety factors be used for more important walls. Specific partial factors have been suggested in this paper ranging from 1.4 to 1.7 for global stability, 1.0 to 1.3 for load factors and 1.0 to 0.85 for strength reduction factors. Use of such factors would result in a significant difference in safety between high and low importance retaining walls.

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