DESIGNING EARTHEN BUILDINGS FOR SEISMIC FORCES PER NEW MEXICO EARTHEN BUILDING MATERIALS CODE AND NEW ZEALAND STANDARDS

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The New Mexico Earthen Building Materials Code regulates the design of earthen structures. "Table 1. Allowable Wall Heights for Earthen Structures" is a chart that describes the allowable maximum height of all earthen structures "whether adobe, burned adobe, compressed earth block, rammed earth or terron."

The parameters on the chart that define the maximum height are the wall thickness and the parameter 'Sds'. It is often asked what does 'Sds' stand for and how do you find out its value so you can utilize the chart. The value of Sds is dependent on the site location and the type of soil at the site. The greater the value of Sds the greater is the earthquake hazard at that location. It can easily be found by entering the project location address and site soil conditions to the online ASCE 7 Hazard Tool, (asce-7hazardtool.online). Another method is using the map in the IBC to determine Ss and calculating the value using the associated code criteria.

Table 1 ALLOWABLE WALL HEIGHTS FOR EARTHEN STRUCTURES

Maximum Sds	Wall Thickness	Maximum Height	Maximum Sds	Wall Thickness	Maximum Height
.25	10	120"	.3	10	120"
	12	128		12	128
	14	144		14	144
	16	144		16	144
	18	144		18	144
	24	144		24	144
.35	10	120"	.4	10	120"
	12	128		12	128
	14	144		14	144
	16	144		16	144
	18	144		18	144
	24	144		24	144
.45	10	104"	.5	10	96"
	12	128		12	112
	14	144		14	136
	16	144		16	144
	18	144		18	144
	24	144		24	144

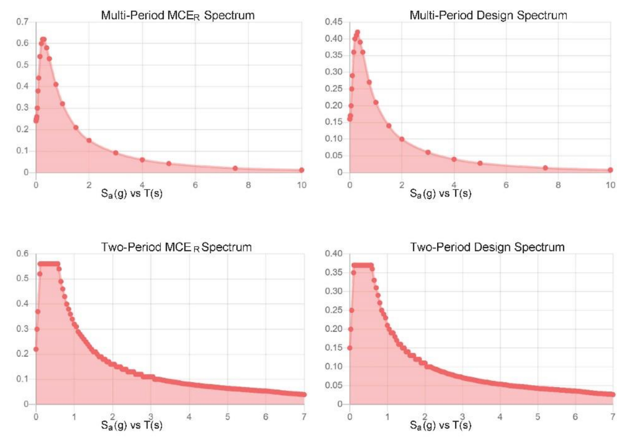
This table is based on two story maximum, one and two family residential with seismic soil site class D1.

[14.7.4.8 NMAC - Rp, 14.7.4.8 NMAC, 11/15/2016]

The following table is generated with the ASCE7 Hazard Tool

(Assuming site soil class D - stiff soil at all locations):

Location	Sds
Santa Fe, NM	0.38
Albuquerque, NM	0.38
Las Cruces, NM	0.30
Farmington, NM	0.13
San Francisco, CA	1.16
Los Angeles, CA	1.52
San Antonio, TX	0.05
NY, NY	0.20
Hilo, Hawaii	1.08
Anchorage, Alaska	1.08



Seismic

Site Soil Class:

Results:

PGA_M :	0.23	T_L :	6
S_{MS} :	0.56	S_S :	0.42
S_{M1} :	0.32	S_1 :	0.12
S_{DS} :	0.37	S_{DC} :	
S_{D1} :	0.21	V_{S30} :	260

MCER Vertical Response Spectrum

Vertical ground motion data has not yet been made available by USGS.

Design Vertical Response Spectrum

Vertical ground motion data has not yet been made available by USGS.

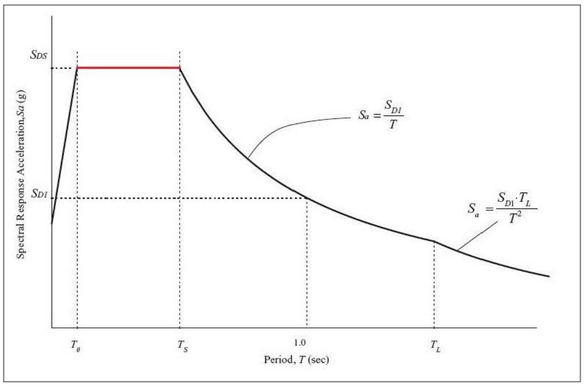
https://asce7hazardtool.online/ Page 3 of 5 Fri Jul 08 2022

Sds is a value of acceleration due to ground movement. It is expressed in terms of 'g' the gravitational constant. (The gravitational constant g= 32.2 ft/s/s or g=9.81 m/s/s.) Earthquake ground motion is often recorded as ground acceleration at a particular location. The acceleration of the ground generates the acceleration of the structure response. This produces earthquake forces that act on the structure. How a building responds to ground acceleration will vary over a wide spectrum corresponding to the period of vibration of the structure. Every system has an intrinsic set of frequencies in which it will tend to vibrate when set in motion by some sort of disturbance such as a wind or seismic event. This type of resonance is based on the mass and stiffness characteristics of the structure.

Over the years studies been made by engineers and scientists to record the response of structures over a wide spectrum of building forms to specific ground movements occurring during earthquakes. In addition, the potential of ground movements has been studied throughout the United States and other countries.

A basic tool and simplified method to aid in the design of structures to prevent damage due to earthquakes are the 'Simplified design response spectrum curves.' Spectral response acceleration is a function of the seismic hazard of the region and the 'period' (denoted as 'T') of the building. Period is the time interval required for one full cycle of a wave. Ground motion due to seismic activity occurs and the structure responds and moves in a direction. Then it comes back to its original position and keeps on moving, until it reaches the point where it starts to come back to its original position. That time interval that it takes for the completion of one wave cycle is the 'period' of the structure. The 'period' of a building is measured in seconds, 's'. A good estimate can be calculated based on the height of the structure and the structural system with which it is built.

For short periods the design spectral response acceleration is taken equal to Sds.



Low rise earthen buildings are very stiff and as such have a very short period. This is true of all earthen buildings, no matter where they are located. As can be seen from the simplified design response spectrum curve, short periods yield the highest Response Acceleration within the spectrum of possible building periods. The building's response acceleration generates forces that the structure needs to be able to withstand. The greater the value of Sds, the greater the potential earthquake forces that must be sustained.

One such force to be resisted is 'seismic base shear'. Sir Isaac Newton realized that when mass is accelerated force results. Hence the equation: Force equals Mass times Acceleration. **(F=m*a)**. This concept is one of the basic principles for the structural design of buildings due to seismic lateral forces.

A simplified method called 'the equivalent lateral force procedure' calculates seismic base shear; the force to be reckoned with applied at the ground level. The mass of the building is multiplied by a factor that takes into consideration the earthquake hazard at the location and the characteristics of the structure.

The seismic force is derived from the mass (i.e., weight) of a building times the seismic response coefficient (which takes into consideration the site hazard acceleration (Sds) and the ductility of the structure. The response modification factor denoted as 'R' in the IBC takes into account building ductility. Sds divided by R, yields the seismic response coefficient denoted as 'Cs'. (Cs=Sds/R). The stiffer and heavier the building the greater the seismic base shear. Unreinforced masonry buildings are very stiff and heavy. Seismic base shear denoted as 'V', is the seismic weight of the building (denoted as 'W'), multiplied by the seismic response coefficient 'Cs'. **V=CsW The force of Base Shear is a product of the weight of the building and the acceleration specific to the location and the building form.**

Adobe buildings are low rise, heavy, and stiff. The spectral value of Sds due to the very short period is high. Seismic base shear force is a percentage of the building overall weight. As a result, in areas of high seismic hazard earth buildings may not be viable or even allowed by code.

New Mexico has a rich tradition of vernacular earthen structures with a great deal of success. Stability is the ability to withstand force or stress without being distorted, dislodged, or damaged. One reason for the success of earthen buildings in New Mexico is that seismic hazard is low to moderate. Another factor is the arid climate. By providing continuity, connectivity and containment in new buildings or in the retrofit of older units, stability can be achieved. Continuity is the effective use of bond beams, diaphragms, judicious openings for windows and doors, and supporting walls know as shear walls. Connectivity between the ground and foundation, foundations and walls, walls and bond beams, bond beams and diaphragms are critical. Appropriate details and reinforcement are tools that can be utilized to overcome the risks in high hazard areas. Containment limits relative displacement across cracks or potential cracks in the walls. The earthen material could potentially continue to support loads if it is held in place preventing collapse.

New Zealand has much more active seismic activity than New Mexico. In addition, it has a wet and windy climate. It is quite outstanding that they have put together a code that that tackles many different problems. It has beautiful and extensive details that explain how to build with earthen materials. It deals with structural issues as well as architectural. It deals extensively with the means and methods of earthen construction.

The New Zealand Standards consists of three volumes:

- NZS 4297:2020 Engineering design of earth buildings 48 pages
- NZS 4298:2020 Materials and construction for earth buildings 114 pages
- NZS 4299:2020 Earth buildings not requiring specific engineering design 153 pages

Summary of the structural requirements of the New Mexico Earthen Building materials code:

- Current code- Maximum wall height is governed by a chart that considers Maximum Sds and the wall thickness with allowable wall heights up to 144”. It defines the height of a wall “as the distance from the top of the slab or top of stem wall to the underside of the bond beam.”
- The old New Mexico Building Code (up to the 1997 edition) based the maximum wall height on a height to thickness relationship stated that the wall height of unburned clay units without lateral support shall be not more than ten (10) times the thickness of such walls.”
- Lateral supporting walls no more than 24 feet apart
- Foundation stem walls shall be at least as thick as the adobe walls they support. All adobe walls (except as noted) shall have a continuous footing at least eight inches thick and not less than two inches wider on each side that supports the foundation stem wall above.
- Concrete bond beams are allowed. Not specified how they are attached to walls. ” Roof and floor structures will be suitably anchored to bond beams.”
- Wood bond beams are allowed, no specification as to how they are attached. “Ends of wood bond beams are to be lapped a minimum of the width of the wall and fully nailed.”
- There is a schedule that governs lintels.

Table 2 ADOBE WALL WOOD LINTEL SCHEDULE

MINIMUM FIBER STRESS 850 psi

Wall Width	Max. Span	Size	Bearing length on earth wall	Load Capacity
10”	4'-0”	10” x 6”	12”	860 PLF
	6'-0”	10” x 8”	12”	1020 PLF
	8'-0”	10” x 10”	18”	1150 PLF
	10'-0”	10” x 12”	24”	1000 PLF
	12'-0”	10” x 14”	24”	1000 PLF
12”	4'-0”	10” x 6”	12”	860 PLF
	6'-0”	10” x 8”	12”	1020 PLF
	8'-0”	10” x 10”	18”	1150 PLF
	10'-0”	10” x 12”	24”	1000 PLF
	12'-0”	10” x 14”	24”	1000 PLF
14”	4'-0”	12” x 6”	12”	950 PLF
	6'-0”	12” x 8”	12”	1150 PLF
	8'-0”	12” x 10”	18”	1300 PLF
	10'-0”	12” x 12”	24”	1300 PLF
	12'-0”	12” x 14”	24”	1200 PLF

M. Concrete lintels. When an engineer’s drawing and seal is not provided for lintels, all concrete lintels shall conform to table 3 and have a minimum strength of 3000 psi.

Table 3 ADOBE WALL CONCRETE LINTEL SCHEDULE MIN. 3000 psi

Maximum Span	Minimum depth*	Reinforcing	Maximum Capacity per linear foot	Bearing length on earth wall
Less than 6’ - 0”	8”	2 - # 4	1500 lbs.	12”
6' - 0" to 10'- 0”	12”	3 - # 5	1500 lbs.	18”
11' - 0" to 16'- 0”	16”	3 - # 6	1500 lbs.	24”

* SIZE Wall width X depth of lintel

The following items are just a sample of the extensive and well described requirements found in the New Zealand Standards.

- NZ code requires that buildings are founded on 'Good Ground' which requires 'reasonable inquiry'.
- NZ code requires that you calculate the earthquake bracing demand. This requires calculating the seismic weight of the building and multiplying by 'Ke' which takes into account the response acceleration of the region, soil characteristics, and the response modification of earthen buildings. The New Zealand Islands have been divided into 4 different zones with increasing earthquake hazard. In NZ zone 4 earthen buildings are not permitted.
- NZS 4299 limits maximum earth wall height to 3.05 meters = 10 feet (120") in NZ zone 1 & 2 2.75 meters = 9 feet (108") in zone 3
- NZS 4299 permits a full height earth gable wall up to 3.6 meters = 11'-10"
- NZ requires overhangs.

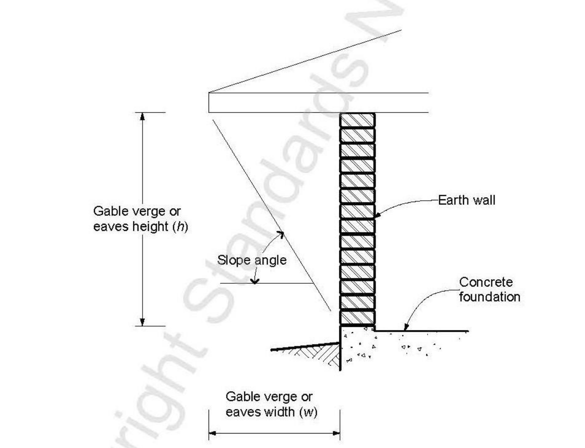


Figure 2.4 – Definition of eaves height and eaves width

Excerpt from NZS 4299. NZ code requires overhangs. In New Mexico buildings with parapets are the norm.

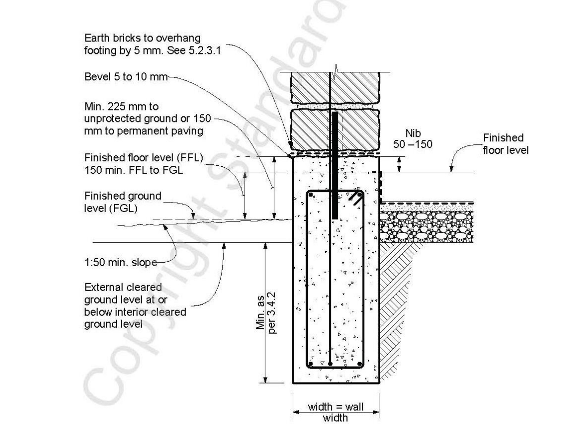


Figure 5.2 – Footing height clearances

Excerpt from NZS 4299.

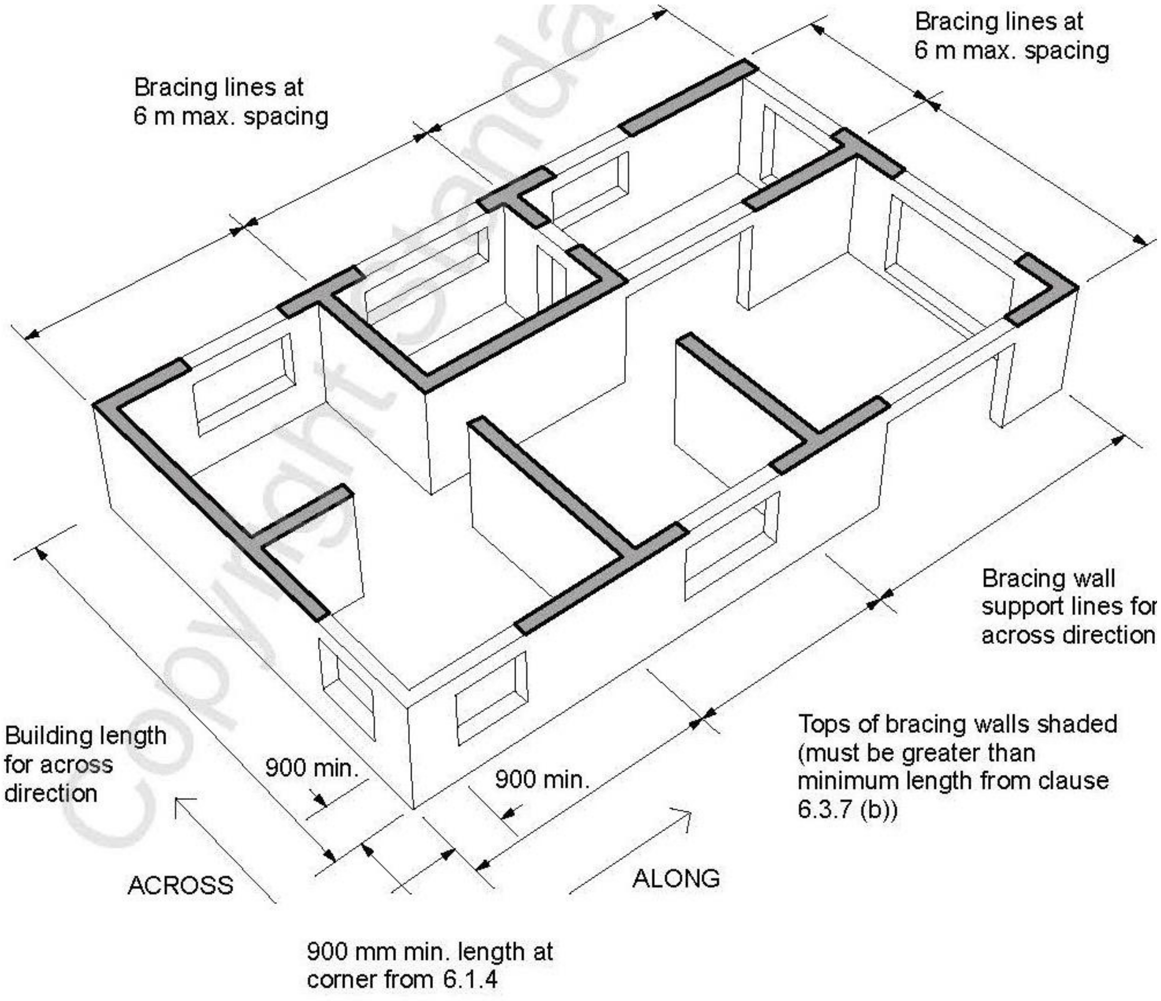


Figure 6.1 – Bracing line support system and openings at external corners

Excerpt from NZS 4299.

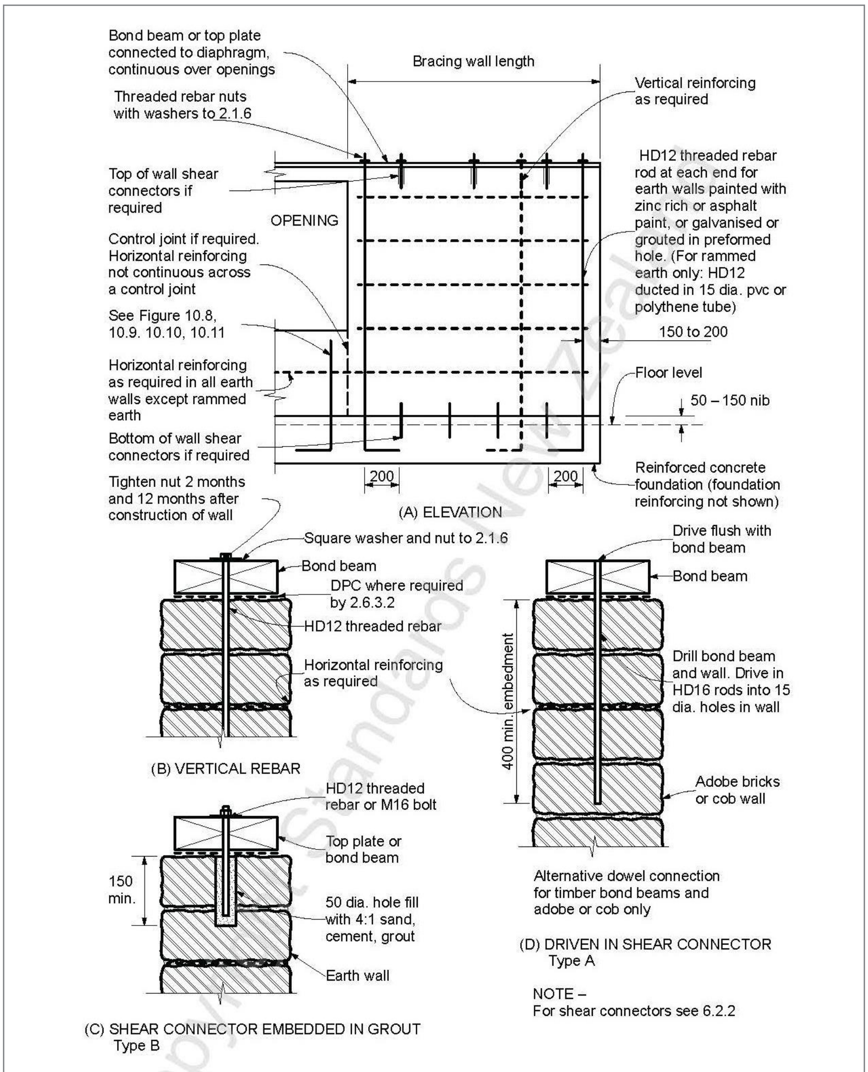


Figure 6.3 – Reinforcing and dowels for reinforced earth walls

REINFORCED EARTH WALLS PER THE NEW ZEALAND CODE
Excerpt from NZS 4299.