ARMADILLO™ 500R

COMPLIANCE WITH BUILDING CODE

Designed by www.cresco-group.com

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ARMADILLO™
FOUNDATION SYSTEM

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► Mr. Ian Smart

Genova, 15th of January 2014

Oggetto / Subject: Armadillo Floor System Structural Design

Dear Mr. Smart,

We have assessed the Armadillo Floor System with regard to the New Zealand Building Code section B1. The Armadillo Floor System consists of a voided biaxial slab with ribs having an average width of 150 mm and a height of 500 mm and with a concrete topping 85 mm thick.

1) Slab above Armadillo Pods

The concrete slab above the armadillo pods is 85 mm thick. For each design a specific calculation checks that the reinforced concrete section is able to withstand dead and live imposed load. Loads are in accordance with AS/NZS 1170 and may be summarized as follows:

Non Garage Areas:	Q (udl) = 1.5 kN/m^2	or	Q (point load) = 1.8 kN
Garage Areas:	Q (udl) = 2.5 kN/m^2	or	Q (point load) = 13 kN

The Armadillo slab is a two-way slab spanning from the ribs (span 750 mm in both direction).

Loads are spread trough the ribs to the ground. The Armadillo system may be generally applied with allowable bearing pressure greater than 50 kPa.

Verification method used to design the Armadillo slab and ribs are the following:

- B1/VM1	Loadings:	AS/NZS 1170
- B1/VM1	Concrete design:	NZS 3101
- B1/VM1 – B1/VM4	Foundations:	AS 2870

2) Ribs

Ribs are designed taking into account also the document "Repairing and rebuilding houses affected by the Canterbury earthquakes", clause 15.4.8 for relevellable concrete surface structures (key performances expectations, point 2); foundations shall withstand a maximum unsupported length of 4 m beneath sections or 2 m at the extremes of the floor. Deflection shall be limited to 5 mm at sls.

The other check that it is performed is during lifting condition: the whole dwelling is suspended on the perimeter beams that are supported on lifting jacks. In this condition, ribs are simply supported beams loaded by their own selfweight and by dead load of the building.

Verification method used to design the Armadillo system ribs are the following:

- B1/VM1	Loadings:	AS/NZS 1170
- B1/VM1	Concrete design:	NZS 3101
- B1/VM1 – B1/VM4	Foundations:	AS 2870

3) Perimeter footings

The perimeter footings are specifically designed as foundations using conventional methods of limitingsoil pressure on the ground. Each builing is designed to withstand the imposed dead and live loads .

Ribs are also designed taking into account also the document "Repairing and rebuilding houses affected by the Canterbury earthquakes", clause 15.4.8 for relevellable concrete surface structures (key performances expectations, point 2); foundations shall withstand a maximum unsupported length of 4 m beneath sections or 2 m at the extremes of the floor. Deflection shall be limited to 5 mm at sls.

The other check that it is performed is during lifting condition: the whole building is suspended on the perimeter beams that are supported on lifting jacks. In this condition, perimeter beams are simply supported or continuos beams (according to building geometry) supported on lifting jacking system and loaded by by their own selfweight and by dead load of the building.

Verification method used to design the Armadillo system perimeter beam foundations. are the following:

- B1/VM1	Loadings:	AS/NZS 1170
- B1/VM1	Concrete design:	NZS 3101
- B1/VM1 – B1/VM4	Foundations:	AS 2870

4) Functional requirements

Clause B1.2: the Armadillo floor system complies with this clause as it is specifically designed to resist the code loads and the design is based on site specific conditions.

5) Performance requirements

Clause B1.3.1: the Armadillo floor system complies with this clause as it is specifically designed to resist the code loads without rupturing or becoming unstable.

Clause B1.3.2: the Armadillo floor system complies with this clause as Armadillo™ 500 pods have been designed to bear the load of an operator (120 kg max) standing on top of them and to resist in wet conditions during the curing phase of the concrete. Armadillo™ 500 pods are sacrificial formworks without any relevant performance once the concrete has cured, therefore, even though when placed in a dry and confined space the HSC is very durable, they don't need to comply any requirements of durability.

Clause B1.3.3: the Armadillo floor system complies with this clause as all the physical conditions likely to affect the stability of the system are accounted for in the specific design. They include:

(a) self-weight,
(b) imposed gravity loads arising from use,
(c) temperature,
(d) earth pressure,
(e) water and other liquids,
(f) earthquake,
(g) snow,
(h) wind,
(m) differential movement,
(p) influence of equipment, services, non-structural elements and contents,
(q) time dependent effects including creep and shrinkage, and
(r) removal of support.

6) Behaviour under soil liquefaction

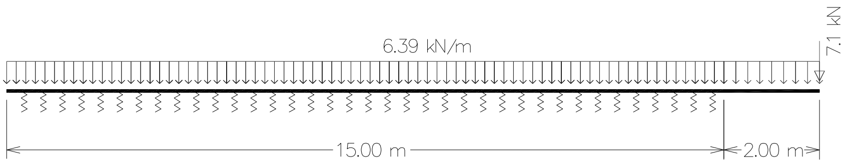
The behaviour of a foundation under soil liquefaction is dependent on a large number of factor, such as soil stiffness, superstructure load, amplitude of ground movement, differential settlements… Then, to evaluate the behaviour of the Armadillo foundation system the following hypothesis have been taken into account:

1. Building length of 17 m
2. Loads of a single storey medium weight cladding building
3. Loss of soil for 2 m on one side of the building (according to Canterbury Earthquake Guidelines)

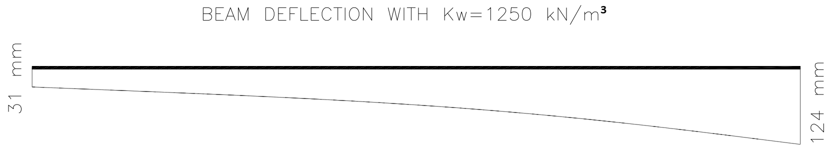
The soil has been modelled as an elastic continuum (Winker model). The value of the stiffness of the springs that model the soil has been changed in order to get different values of foundation settlement.

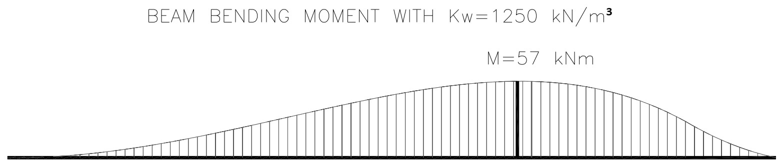
The values of the spring stiffness range from 250 To 10'000 kN/m^3. These values correspond to very poor soil characteristics (to simulate soil during liquefaction) to medium soil charactheristics.

The following picture shows the applied loads to a typical rib of the Armadillo foundation system.



The following pictures show the deflection and the bending moment of the beam under the here above loads and considering a Winkler coefficient Kw=1250 kN/m³.





Results are summarized in the following table:

Kw	**M**	**Max d**	**Min d**	**Diff. d**
kN/m³	kNm	mm	mm	mm
250	61	552	131	421
500	60	285	69	216
750	59	196	48	148
1000	58	151	38	113
1250	57	124	31	93
7500	46	30	8	23
10000	45	25	6	19

The values of the bending moments range from 61 to 45 kN/m³. Values are not very sensitive to soil stiffness, and all values are well below the design moment of the rib (ΦM = 75 kNm). Then the Armadillo foundation system is able to accommodate also very large soil settlements without cracking.

7) Stiffness

To prevent damages to a superstructure that relies entirely on the footing system, a raft footing system needs to be stiff enough to minimize its curvature. The value of the allowable curvature, depends on the type of superstructure that is supported. This value may be found on Australian Code AS 2870 (Residential slabs and footings -Construction), table 4.1 and on figure 4.1.

TABLE 4.1

MAXIMUM DESIGN DIFFERENTIAL MOVEMENT, Δ, FOR DESIGN OF FOOTINGS AND RAFTS

Type of construction	Absolute maximum differential footing movement, Δ, as a function of span, mm	Maximum differential footing movement Δ, mm
Clad frame	≤ L/300	40
Articulated masonry veneer	≤ L/400	30
Masonry veneer	≤ L/600	20
Articulated full masonry	≤ L/800	15
Full masonry	≤ L/2000	10

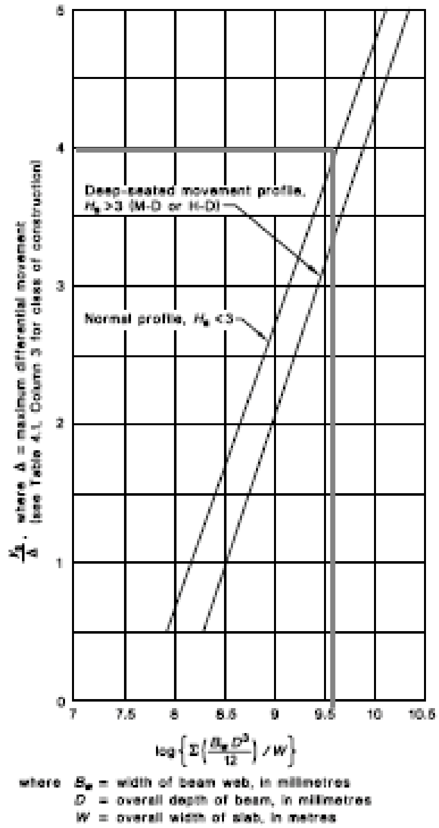


FIGURE 4.1 MOVEMENT RATIO VERSUS UNIT STIFFNESS

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The capacity of a foundation shall be evaluated trough the ratio y_s/Δ, where y_s is the maximum vertical displacement of the foundation and where ¤ is the permissible maximum differential movement given in column 3 of Table 4.1 for the appropriate construction. This value shall be compared with the value obtained from Figure 4.1 by mean of the stiffness unit value:

$$\log\left\{\Sigma\left(\frac{B_w D^3}{12}\right)/W\right\}$$

determined over all the edge and internal beams

where: B_w is the beam web width in millimetres (= 150 mm for the Armadillo system)
D is the overall depth of the beam in millimetres (= 585 mm for the Armadillo system)
W is the overall width of the slab in metres normal to the direction of the beams being considered (=0.75 m for the Armadillo system).

For the Armadillo system foundation, the stiffness unit value is 9.65, then the y_s/Δ value is 4.
This value is very high; for a clad frame building, where Δ=40 mm, with a vertical settlement of the ground of 160 mm, the superstructure will not be damaged.

On behalf of CRESCO
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