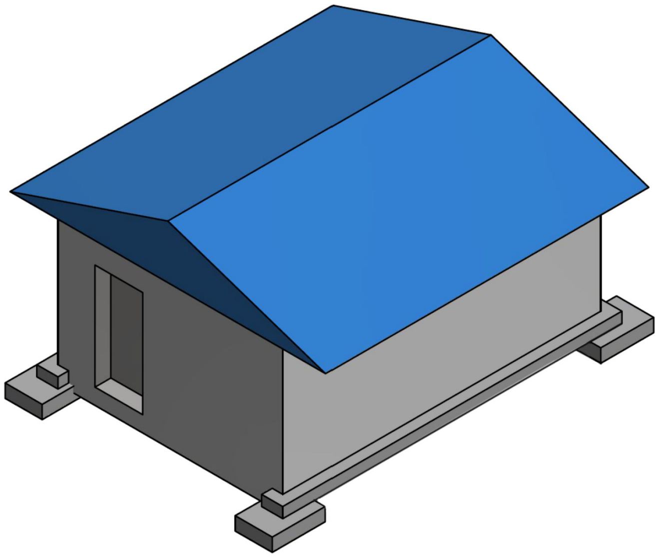
Rationale

A number of low income houses in the Philippines are constructed without a foundation system because of the lack of expertise and/or budget. As it is, the existing structure offers little resistance against lateral forces from earthquake and wind. It is therefore significant that a standard and validated retrofitting scheme be created considering the said conditions.

The proposed method can withstand the required gravity and special loads (earthquake and wind), accounting future incremental builds (two-stories) from the existing structure. Isolated reinforced concrete footings are placed on the four corners, and the longer side of the structure is connected by a plinth beam. Aside from adding the aforementioned resistance, this also adapts the foundation to different subsurface conditions, especially those that can cause differential settlement. For houses that fully rely on these walls (i.e., no existing columns), such differential settlement can induce cracks that can lead to failure. Detailed drawings and calculations are shown in the following sections.



Proposed foundation installed on a 6m x 4.25m one-story house

As shown, the proposed scheme is similar to the existing solutions. This is so it can be easily accepted and implemented by the locals and even homeowners.

During construction, concrete-filled bamboo props are used, which are not removed as concrete is poured. Treated and dried bamboo should be used in this process to prevent degradation. Concrete is filled inside the bamboo to further prevent its deterioration and add compressive resistance. The use of this method is both cost effective and safe (compared to the steel and coco lumber props currently used), enabling the dwellers to remain in their house during construction at a low cost - i.e., the concrete-filled bamboo should be able to resist the loads even before the concrete reaches its target strength.

The estimated cost of the project is USD 298 and the construction duration is within 12 days. The details are given in the succeeding sections.

Detailed Description

Materials

- Cement
- Sand
- Gravel (¾” to 1½” size)
- 10-mm steel bars
    - Steel reinforcing bars to be used shall consist of standard deformed bars meeting ASTM specifications. They should be free from rust and other coating which would destroy or reduce their bond with the concrete. Steel bars are tied together at each bar intersection with Gauge No. 16 GI wires.

- GI wires (No. 16)

- Treated Bamboo Props (3” to 4” diameter)
    - Bamboo props are to be used in lieu of metal jacks to act as support to the cornerpoint excavations. Props of length 500mm are to be filled with concrete before installation.

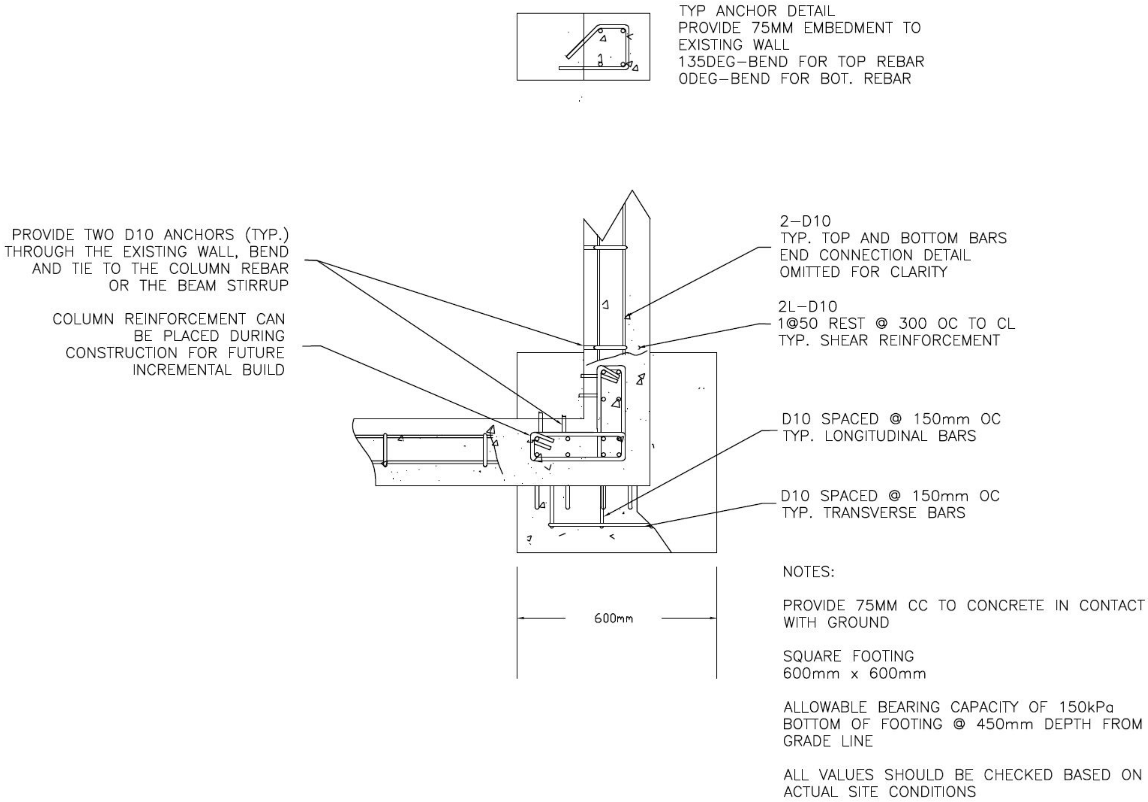
Retrofitting Instructions

Job Sequence

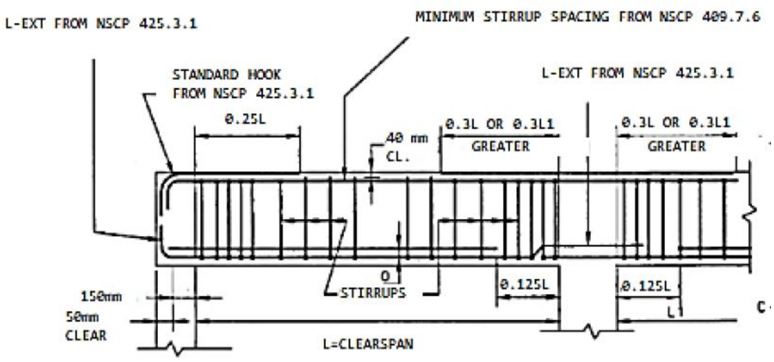
1. **Clearing the Site**

The immediate surrounding of the floor plinth slab and the walls must be cleared of rubbish, roots, and other degradable materials. Excavation lines should be staked out to establish reference points before excavation is started to minimize ground disturbance.

2. **Preparation of Rebar Cages for Column and Beam**



For the development, hooks, and splicing, refer to the figure below:

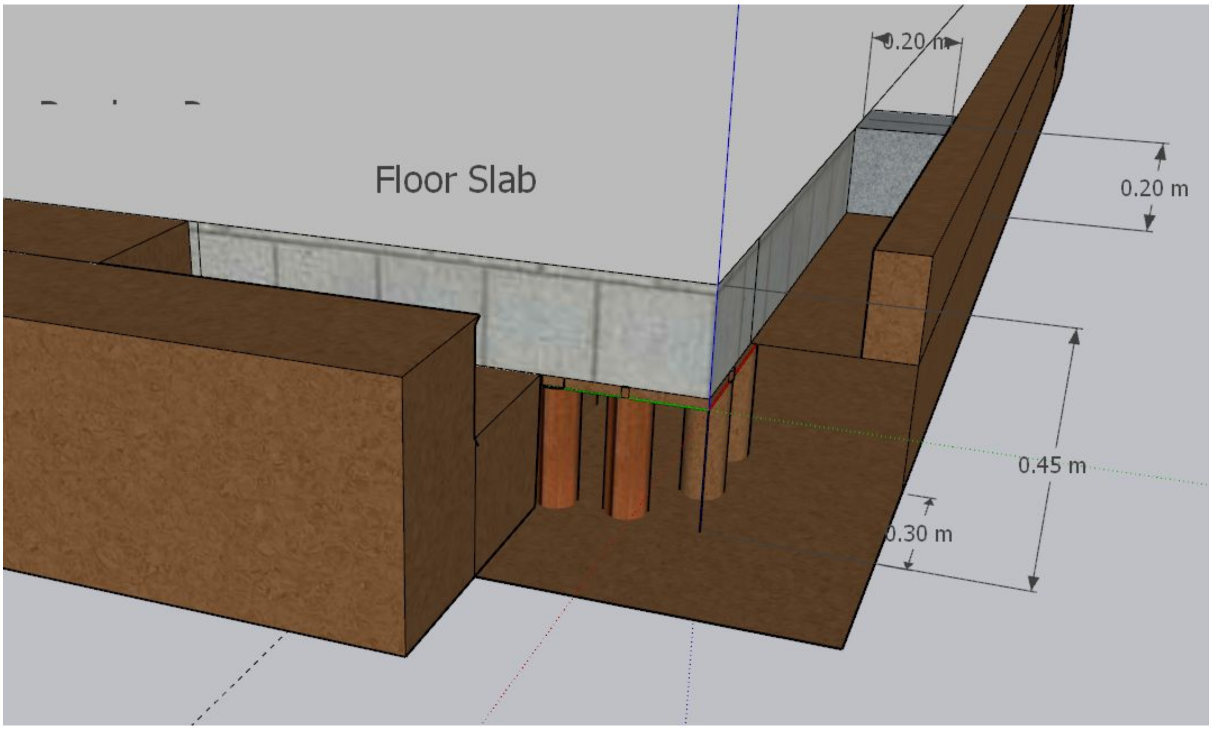


The preceding figure is based on the following provisions:

- Reinforcement continuity: 407.7.3.8
- Structural Integrity: 409.7.7
- Splicing: 425.5.1
- Hooks: 425.3.1

3. Corner Excavation

Excavate 1 meter along the perimeter on both directions starting from the cornerpoint. The depth of excavation for the wall footing is 200 mm. For the corner footing, excavate up to a depth of 450 mm.



4. Installation of Rebar Cages for the Corner Footing System

Rebar cages prepared in part number 2 are installed in the excavated ground. Bamboo props are set up to hold the overhanging corner of the slab.

5. Drilling of Anchor Rods to the CHB

Two sets of anchor rods are to be drilled on the exposed part of the slab. Sufficient grouting should be applied to secure the bond between the rod and the concrete hollow block

Top rod: Inclined 45 degrees
Bottom rod: Horizontal

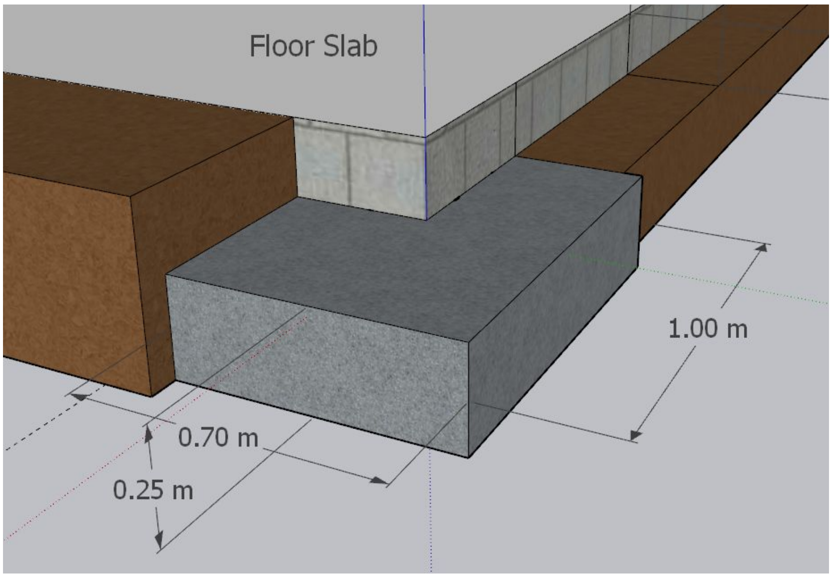
These rods will then be anchored to the rebar cages for the grade beam.

6. Installation of Rebar Cages for the Grade Beam

Once the rebar cages are installed along the excavated perimeter, the anchor rods are tied to the rebar to integrate it to the rebarwork.

7. Concreting

The proportion of concrete to be used is Class A (1:2:4). Concrete mixture is to be prepared by adding together 1 part cement, 2 parts fine aggregates, and 4 parts coarse aggregates by volume, plus enough water to make the mixture into a pliable paste. It should be mixed thoroughly such that there is uniform distribution among the cement and aggregates. Concrete should be vibrated and the forms should be tapped as it is deposited to prevent formation of voids in the concrete members.



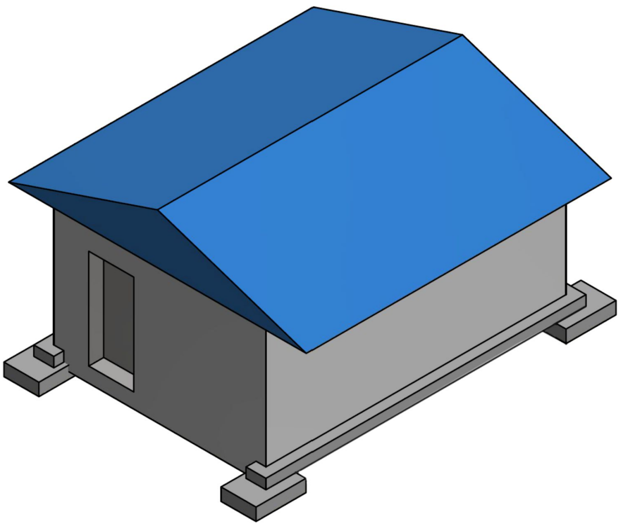
Do Steps 3-7 are done for all the corners. The same steps will be employed in excavating and concreting the remaining sides along the perimeter

8. **Excavate remaining midlength along the sides**
   The remaining sides that are yet to be excavated are dealt with here.
9. **Drilling of Anchor Rods to the CHB**

10. **Installation of Rebar Cages for the Grade Beam**
    Once the rebar cages are installed along the excavated perimeter, the anchor rods are tied to the rebar to integrate it to the rebarwork.

11. **Concreting**

12. **Backfilling**
    This is done once sufficient drying and curing as achieved.



Proposed Solution: Column Footing - Grade Beam Monolith

STRUCTURAL DESIGN CRITERIA
FOR THE SUPERSTRUCTURE AND PROPOSED FOUNDATION

I. PROJECT DESCRIPTION

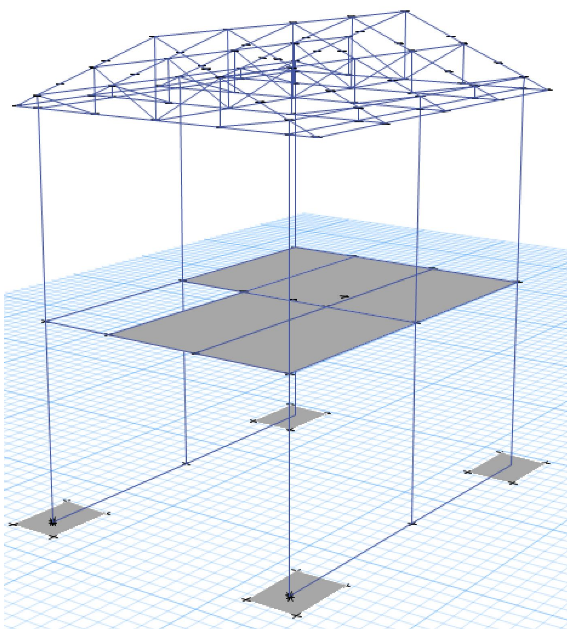
Validation of the proposed foundation as per project specifications. The model of the superstructure was based on the assumed retrofitted typologies given (refer to earlier sections). The following are the typical frame members used:

a) Girders	-	400mmx200mm
b) Beams	-	300mmx200mm
c) Columns	-	300mmx300mm
d) Roof element	-	75mmx50mm
e) Slabs	-	150mm
f) CHB walls	-	200mm (4”)

Rationale:

The existing typical beam depth is around 200-300mm. Retrofitting beams would constitute mainly adding on the depth, which can be around 100mm; the existing typical column is 200mm-square. Similarly, retrofitting would constitute an addition of 100mm; the rest of the elements are assumed to be the same as only the frame elements are retrofitted.

The resulting structure shown is a two-story, one-bay by two-bay concrete-frame with a 6m x 4.25m plan and story height of 3m.



ETABS model (walls not shown)

Note that unspecified pertinent site-specific details resulted in various conservative assumptions, especially in the wind and earthquake load parameters.

II. CODES AND SPECIFICATIONS

a) National Structural Code of the Philippines (NSCP) 2015 Volume 1, Buildings, Towers, and Other Vertical Structures, 7th Edition
b) Building Code Requirements for Reinforced Concrete, ACI 318-14, American Concrete Institute (ACI) [reference of NSCP]

c) American Institute of Steel Construction Inc., AISC-ASD/LRFD [reference of NSCP]
d) American Society of Civil Engineers (ASCE) 7-10 [reference of NSCP]
e) Uniform Building Code (UBC) 1997 Edition [reference of NSCP]

III. MATERIAL STRUCTURAL PROPERTIES

The following material strengths shall be used in the design and in the analysis of the structure.

g) Concrete – The concrete compressive strength is as follows:
   i. For Columns - f'c = 21MPa (3,000psi)

h) Reinforcing Steel Bars shall be deformed and shall conform with ASTM A615/A706:
   i. Grade 40 (10mm to 12mm diameter) - fy = 275MPa (40,000psi)

i) Roofing frame shall be constructed from coconut lumber
   i. For coconut lumber[1,2] - E = 9576MPa & f_crushing = 57MPa

IV. LOADS

The design loads are based on the critical combinations of the different types of loads – i.e., dead, live, earthquake, and wind – applied with the appropriate factors. These are experienced by the superstructure which are then transferred to the foundations.

The basic load types and their corresponding magnitudes are taken as follows:

A. DEAD LOADS

Dead loads (Section 204) are vertical loads from the weight of all construction materials which are permanently fastened thereto and supported thereby.

a) Material Weight and Density:

i.	Concrete	-	23.60kN/m^3
ii.	Structural Steel	-	77.30kN/m^3
iii.	Soil	-	18.90kN/m^3

b) Superimposed Dead Load:

i.	Finishing and topping	-	1.58kPa
ii.	Partition	-	1.2kPa
iii.	Ceiling	-	0.24kPa

B. LIVE LOADS

The live loads (Section 205) include loads that may vary in magnitude, and/or distribution during the life of the structure; not including wind load, earthquake, or dead load. The minimum values of these loads depend on the occupancy and are normally specified by the governing codes.

i.	Roof	-	1kPa
ii.	Residential area	-	1.9kPa

C. WIND LOADS

The design wind pressures are determined by the Envelope Procedure for Low-Rise Buildings (Section 207A.1.2).

Velocity pressure, q_z, evaluated at height z was obtained by the following equation

$$\mathbf{q_z = 0.613K_zK_{zt}K_dV^2}; \mathbf{V} \text{ in m/s} \qquad (207C.3-1)$$

[1] http://www.fao.org/3/W7731E/w7731e06.htm
[2] Masseat et al, Properties of Malaysian Solid Coco-Lumber, 2009

where

K_d = wind directionality factor
K_z = velocity pressure exposure coefficient
K_{zt} = topographic factor defined
V = basic wind speed

Below are the Wind Load Parameters used in the design of the structure:

i.	Exposure Category	:	C	(See Section 207A.7.2 and Section 207A.7.3)
ii.	K_d	:	0.85	(See Section 207A.6)
iii.	K_z	:	0.85	(See Table 207C.3-1)
iv.	K_{zt}	:	1.00	(See Section 207A.8.2)
v.	Gust-effect factor, G	:	0.85	(See Section 207A.9.1)
vi.	Basic Wind Speed, V (Occupancy Category: IV (Table 103-1))	:	200kph	(given)

D. SEISMIC LOADS

a) Static Lateral Force Procedure

Seismic forces were determined based on the equivalent static force procedure and computed following the provisions of the NSCP 2015. The structure is analyzed to resist the minimum total service forces assumed to act non-concurrently in the direction of each of the main axes of the structure.

The total design base shear in a given direction shall be determined by the following equation:

$$V = [(C_V I)/(R T)] W$$ (See Section 208-8)

The total design base shear need not exceed the following:

$$V = [(2.5 C_a I)/R] W$$ (See Section 208-9)

The total design base shear shall not be less than the following:

$$V = 0.11 C_a I W$$ (See Section 208-10)

In addition, for Seismic Zone 4, the total base shear shall also not be less than the following:

$$V = [(0.8 Z N_v I)/R] W$$ (See Section 208-10)

Below are the Seismic Parameters used in the design of the structure:

i.	Seismic Zone Factor	:	0.4	(Table 208-3)
ii.	Occupancy Factor	:	1.0	(Table 208-1)
iii.	Soil Profile Type	:	S_C	(Table 208-2)
iv.	Seismic Source Type (M6.8)	:	B	(Table 208-4)
v.	Distance to Known Seismic Source	:	0.99km	
vi.	Near Source Factor, N_a	:	1.3	(Table 208-5)
vii.	Near Source Factor, N_v	:	1.6	(Table 208-6)
viii.	Seismic Coefficient, C_a	:	0.64	(Table 208-7)
ix.	Seismic Coefficient, C_v	:	0.896	(Table 208-8)
x.	Coefficient, R	:	8.5	(Table 208-11)
xi.	Coefficient, C_t	:	0.0731	(Section 208.5.2.2)

V. LOAD COMBINATIONS

Reinforced concrete and Steel sections shall be designed using the Strength Design or the Load and Resistance Factor Design method using the load factors and the most critical load combination from the following:

U = 1.4 (D + F)	(203-1)
U = 1.2 (D +F + T) +1.6 (L + H) + 0.5 (L_r or R)	(203-2)
U = 1.2 D + 1.6 (L_r or R) + (f_1L or 0.5W)	(203-3)
U = 1.2 D + 1.0 W + f_1 L + 0.5 (L_r or R)	(203-4)
U = 1.2 D + 1.0 E + f_1 L	(203-5)
U = 0.9 D + 1.0 W + 1.6 H	(203-6)
U = 0.9 D + 1.0 E + 1.6 H	(203-7)

where

f_1 = 1.0 for loads in places of public assembly, for live loads in excess of 4.8kPa, and for garage live load or,
= 0.5 for other live loads
D = dead load
E = earthquake load set forth in Section 208.6.1
F = load due to fluids with well-defined pressures and maximum heights
H = load due to lateral pressure of soil and water in soil
L = live load, except roof live load, including any permitted live load reduction
L_r = roof live load, including any permitted live load reduction
W = load due to wind pressure

For the foundation design, the soil bearing pressure shall be determined using the load factors equal to 1.0.

VI. DRIFT LIMITS

Structures or structural members shall be checked for drift limits as stipulated in Table 12.12-1 of ASCE-7.

STRUCTURAL DESIGN REPORT
SUPERSTRUCTURE AND FOUNDATION

I. SUPERSTRUCTURE

As required, the superstructure was designed to meet the specifications in the design criteria. This will not be written in detail as the focus will be on the foundation. Typical designs of the frame members are given below:

- Beam: 4-12M tension bars and 2-10/12M compression bars; minimum stirrups
- Column: 8-12M bars; minimum ties

Again, note that the design values can still be adjusted based on actual site conditions. It is reiterated that conservative estimates were made in the design criteria.

II. FOUNDATION

The proposed isolated footings were mainly analyzed using a spreadsheet program referenced from NSCP section 413 combined with ETABS. The applied loads are the governing reactions from the ETABS model. The solvers could have opted for a more complicated solution but focus was made on more straightforward industry-standard modeling techniques for future users. This is also the rationale why the embedded concrete-filled bamboo elements were not considered in the modeling. In addition, bamboo has a slightly higher compressive strength than concrete and neglecting not only simplifies the analysis but also is more conservative.

Beam

The beam was analyzed and designed using ETABS. As it rests on ground and also transfers its load on the column connected to the footing, the design loads are very small, only requiring the minimum reinforcement

- Typical and minimum flexural bars: Top & Bottom 2-10M
- Typical and minimum stirrups: 2L-10M; 1 bar at 50mm, the rest at 300mm O.C. TO C.L.

Foundation

The unfactored sum of pressures were obtained from ETABS. A soil capacity of 150kPa was used.

The governing design, flexure, yielded a detail consisting 10M bars @ 150mm C/C. This configuration is safe against one-way and two-way shear. From the combinations of assumptions and typical values, it is therefore recommended that the minimum and typical flexural reinforcement be as follows:

- Typical and minimum footing bars: 10M bars @ 150 C/C

Lastly, note that the grade beam is modelled as supported by the column footing – i.e., negligible pressure is exerted upon the soil.