CVNG 3014 DESIGN PROJECT

PRELIMINARY DESIGN OF STRUCTURAL MEMBERS

By R. Clarke

In the process of determining the economic feasibility of an engineering project the engineer must determine the cost of the engineering design. Since at this stage the objective is to study a number of possible alternative schemes and select the most cost effective one, detailed structural calculations are not necessary since the focus is the relative cost of each possible solution and the determination of a budget for the project. Therefore, it is necessary to estimate the member sizes and reinforcement content in order to determine the amounts of materials required hence the cost.

By making conservative assumptions it is possible to derive simplified calculations for both analysis and design. The former is called preliminary or approximate analysis, and the latter is called preliminary design. After the most cost effective scheme is selected and signed-off by the Client, the detailed calculations are performed on the selected scheme, and this phase is called the Final Design phase.

In the Caribbean, the design of structural members is typically controlled by the need for providing earthquake resistance to the structure.

The following provides a means of determining preliminary member sizes and reinforcement content for the most common elements. Preliminary earthquake loading is also presented for inclusion in the preliminary structural analysis.

EARTHQUAKE LOADING:

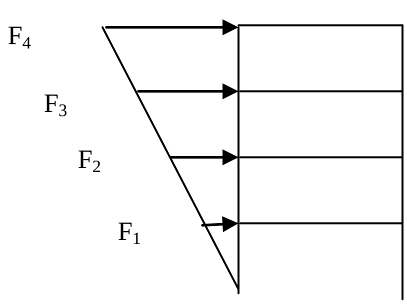
The total earthquake load on a building is called the Base Shear, V. Estimate this loading V as,

$$V = 0.1W, \quad \text{where W is the total weight of the building.,}$$

except as indicated otherwise below.

Remember that for earthquake analysis, you perform 2 analyses - one for if the earthquake is in the longtitudinal direction of the building (if viewed in plan), and the other analysis for the earthquake is in the short direction.

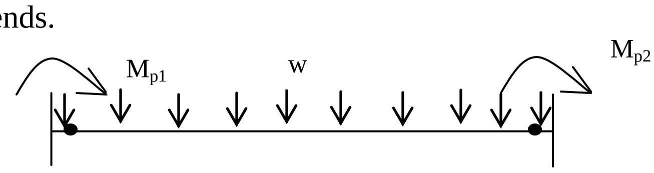
For preliminary structural analysis, distribute V vertically to each floor assuming a triangular distribution, so the point load on each floor is F_i and the sum of all the F_i equals V.

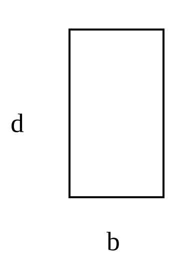


For example, for the 4-storey building at left, at each floor we get F_1 to F_4. To calculate F_1 to F_4, since V is known, and the floor heights are known, simple algebra gives F_1 to F_4.

REINFORCED CONCRETE SPECIAL MOMENT RESISTING FRAMES:

Step 1: Determine Initial Beam Sizes:
Reinforced concrete frame design is controlled by the need for the frame to be ductile. This means that the beams must form hinges at its ends.





Sizing:
For non-cantilevers: d (mm) = span (mm)/26 + 300, round the result to nearest 25mm.
For cantilevers: d (mm) = span (mm)/7 + 300, round the result to nearest 25mm.

For non-cantilevers:

If span < 6000mm, b (mm) = 300
If 6000 < span < 9000, b = 350
If 9000 < span < 12000, b = 400

For cantilevers, b (mm) = 300

Since the V and F's calculated are for the whole building, if you are using a plane frame analysis, then to get the F's on a particilar frame, divide the F's by the total number of frames, then do the analysis for the frame.

The earthquake analysis results are not used by themselves since other loads are always present but the chance of this occurring depends on the type of other loads. For the design of the members, to get the applied forces, you must therefore combine the results of the individual analyses.

For preliminary design, assume that in an earthquake the critical combination is when the earthquake load occurs together with the dead and the live loads, and use the following combination: 1.2 D + 0.5L + 1.0E

This means that you do the analysis of the structure for dead, live and earthquake loads separately, but for the design of the member, you get the moments, by multiplying the dead load results for the moments by 1.2, the live load moments results by 0.5, etc. Of course, you must also use the combination 1.4D + 1.6L.

Step 2. Calculate Beam Longtitudinal Steel:

Assume a trial A_s and substitute in,

$M_i = 0.9\, A_s\, f_y\, (d - a/2)$

where d is the effective depth to the centroid of the reinforcement, and

$a = A_s\, f_y / 0.85\, f_c'\, b$, f_y is the yield strength of the bar (= 410 MPa for high tensile steel), f_c' is the compressive strength of the concrete in MPa (which you also select), and b is the beam width. Remember to use consistent units.

If M_i > than the critical moment at the section (i.e. M_u, which you get from the combined analysis results) then the selected A_s is safe. If not, then assume another A_s and re-do. For economical use of the materials, stop when M_i be just a little higher than M_u. Design for the two sections at the ends of the beam, and the section at mid-span.

Step 3. Calculate Beam Transverse Steel (Stirrups):

Calculate the shear force in a hinge from, $S = 0.75wL/2 + (M_{p1} + M_{p2})/L$

where w is the sum of the dead and live load on the beam (in force per unit length), L is the beam's span and,

$M_{p1} = A_{s,provided} \times 1.25 f_y \times (d - a/2)$

$A_{s,provided}$ is the area of the actual reinforcement you designed earlier; the calculation for M_{p2} is similar.

After you calculate S, the stirrpus required are determined by:

Select a trial reinforcement for the stirrup. Determine the values of A_v and s, where A_v is the area of the 2 legs of the stirrup, and s is the stirrup spacing which must not be greater than 100mm. Then substitute in,

$V_s = A_v\, f_{yv}\, d/s$, where f_{yv} is the yield strength of the stirrup steel.

The design is OK if V_s is just a little more than S; if not then try another spacing or rebar size and re-do.

Place the stirrups at a spacing s withing a zone 2d from the beam ends, but at a spacing of 2s outside of these zones.

Step 4: Determine Initial Column Sizes

For preliminary design use square columns.

If the building height is 3 stories or less:
If beam span < 6000mm, h (mm) = 300
If 6000 < beam span < 9000, h = 350
If 9000 < beam span < 12000, h = 400

If the building height is 4 to 9 stories:
If beam span < 6000mm, h (mm) = 400
If 6000 < beam span < 9000, h = 500
If 9000 < beam span < 12000, h = 600

Step 5. Calculate Column Longtitudinal Steel:

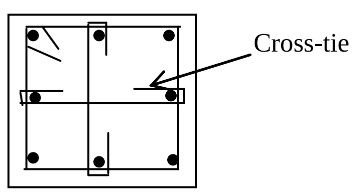
Consider 2 columns – the critical internal column, and the critical side column. You determine this by examining the analysis results. Use an equal amount of steel on each face of the column.

You will need the critical axial load, P_u, at the column's section, and the critical ultimate moment at that section, M_u (=P_u x e). However, first multiply the critical moment from your analysis, M_u, by 1.4. Then use the design chart included with this presentation. The total steel content msu be between 1 and 8% of the gross crossectional area.

Step 6: Calculate Column Transverse Steel:

If the building height is 3 stories or less:
Assume mild steel hoops at a spacing of 100mm and use additional hoops or cross-ties around the vertical steel if the distance between any legs of the hoops exceeds 350mm.

Place the hoops at the 100mm spacing within the top and bottom 1m of the column where the top of the column is considered to be from the bottom of the beam level; use the same spacing through the beam-column joint and through the foundation. In other zone use a spacing of 200mm.



If the building height is 4 to 9 stories:
Assume high tensile steel hoops at a spacing of 100mm and use additional hoops or cross-ties around the vertical steel if the distance between any legs of the hoops exceeds 350mm. Use the same spacing as above.

SPECIAL MOMENT RESISTING FRAMES WITH HOT-ROLLED I-SECTION MEMBERS

Determine the seismic load on the structure using the same method as for reinforced concrete special moment resisting frames (V=0.1W).

Step 1. Select Beam Sizes:

1.1 If the analysis results are not available, consider $M_{max} = wl^2/8$ for udl, Wl/4 for point load; use factored loads for the D+L+E load case.
$Z_{reqd} \geq M_{max}/0.9F_y$; F_y = 345 MPa for ASTM A572M Grade 50; F_y = 250 MPa for ASTM A36M Grade 36, where Z is the plastic modulus and F_y is the specified yield strength.

1.2 Lookup in table.

Step 2. Check Beams for Local Buckling Stability:

Beam flanges b/t, max $\lambda_{ps} = 0.3\sqrt{(E/F_y)}$; beams web h/t_w, max $\lambda_{ps} = 2.45\sqrt{(E/F_y)}$. Note: b/t = $b_{flange}/(2t_{flange})$; re-do step 1 if check fails.

Step 3. Check Unbraced Length of Beam Flanges:

The unbraced length of the beam must be $\leq 0.086 r_y E/F_y$.
Note: It is typical to use composite deck flooring in which case the unbraced beam length is the spacing of the secondary beams supporting the floor.

Step 4. Determine Minimum Required Column Size:

Use factored loads or analysis results for the D+L+E load case.
Assume location of beam plastic hinge is 1.6 times beam total depth from the column center-line, ie.$x=1.6d_b$
$\sum M^*_{pc}/\sum M^*_{pb} \geq 1$ (1)

$\sum M^*_{pb} = \sum (1.1R_yM_p + M_v)$ (2)
R_y = 1.5 for ASTM A36M but 1.1 for ASTM A572M; Mp = plastic moment of beam = ZF_y
$M_v = V_px$
$V_p = 2M_p/(L-2x) + w(L-2x)/2$, where L is the beam's length to the columns' center lines, and w is the factored gravity load on the beam (force per unit length).
$\sum M^*_{pc} = \sum (Z_cF_{yc})$, where "c" refers to the column. (3)

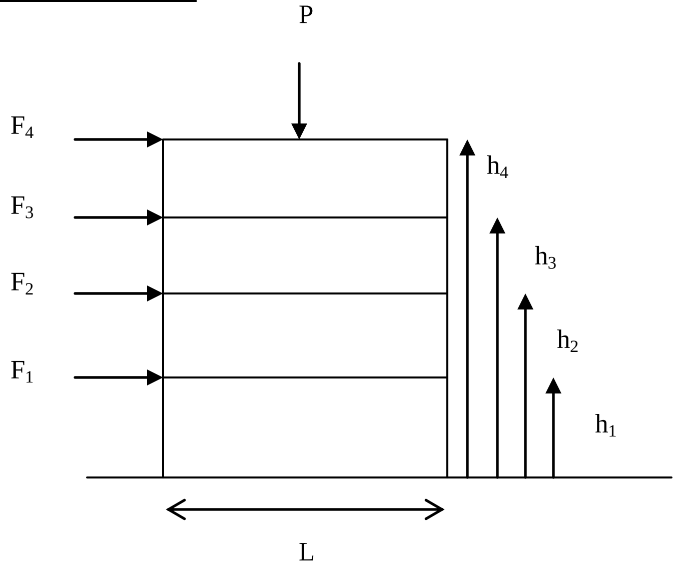
With Z_c as the unknown, substitute (3) and (2) into (1) and solve for Z_c; select an appropriate section from the table.

Step 5. Check the column for local bucking stability:
Column flanges b/t, max $\lambda_{ps} = 0.3\sqrt{(E/F_y)}$; column web h/t_w, max $\lambda_{ps} = 61.06$

Step 6. Check column strength under each of factored D+L+E, and D+L load cases:
Calculate $\lambda_c = 1.1L\sqrt{(F_y/E)}/(\pi\ r_y)$, L is the column length between the beams, and let $Y = \lambda_c^2$.
Calculate $F_{cr} = 0.658^Y \times F_y$
$\varphi P_n = 0.8\ F_{cr}\ A$
$P/\ \varphi P_n \geq 0.4$, then in the following, use the overstrength factor Ω_0 in the determination of the design P for the *D+L+E* load case.
If $P/\ \varphi P_n < 0.2$:
Check $P/\ \varphi P_n + (1.2M_z/\ 0.8M_{nz}) + (1.2M_y/\ 0.8M_{ny})$ which must be ≤ 1. If not, choose a column section with larger Z.
If $P/\ \varphi P_n \geq 0.2$
Check $P/\ 2\varphi P_n + 8/9[\ (M_z/\ 0.8M_{nz}) + (M_y/\ 0.8M_{ny})\ ]$ which must be ≤ 1

In these equations P is the applied factored axial load, M_z is the applied factored moment in the column major-axis direction, and M_{nz} is the column moment strength = $Z_c\ F_{yc}$.

<u>REINFORCED MASONRY SHEAR WALLS</u>



For RM, V = 0.15W. If the wall has window or door openings, ignore them. As for the RC frames discussed above, to get the force on a wall, divide V by the number of walls supporting the floors and then analyse the wall. Consider the 4-storey wall above. The critical section is at the base and the applied moment there, M_u is $F_4h_4 + F_3h_3 + F_2h_2 + F_1h_1$. The shear force at the base, V_u, is obviously $F_4 + F_3 + F_2 + F_1$.

Step 1 Calculate Vertical steel:

In the Caribbean, the blocks are 400mm long, so to place the rebar at the center of the cell or core, the spacing must be in multiples of 200mm.

Try a block of thickness 150mm or 200mm; try n rebars each of area A_s evenly distributed along the wall length. The rebar must not occupy more than 4% of the area of the cell or core.

$M_n = 0.6\ [\ nA_s\, f_y + P]\ 0.8L/2$

P is the total dead plus live load that the wall is supporting including its self-weight; remember to include the weight of the grouted cells and omit the weight of ungrouted cells if you choose partial grouting..

The selected rebar is OK if $M_i > 0.75\ (F_4 + F_3 + F_2 + F_1)\ h_4$. If not, then try alternative combinations of bar size and horizontal spacing, block type, and block thickness, if possible.

Step 2. Calculate Horizontal Steel:

Select rebars each of area A_v and vertical spacing s.

The selection is OK if $V_u < 0.45\ A_v\ f_{yv}\ L/s$. If not, then try other combinations of bar size and horizontal spacing. The horizontal bar must not be placed in the mortar joint; cut the block's webs to accommodate the horizontal rebar, if depressed web blocks are not available. Since Caribbean blocks are typically 200mm in height, the spacing is typically a multiple of 200mm.

When finished (if appropriate reinforcement can be found), check the bearing strength of the wall using the procedures of CVNG 2006. This concludes the preliminary design of the RM shear wall.

REINFORCED CONCRETE SHEAR WALLS

If reinforced masonry cannot be used, as is possible if appropriate combinations of reinforcement and spacing cannot be found, then RC can allow thicker hence heavier walls, the use of 2 rebar across the thickness, and the rebar spacings need not be a multiple of 200mm.

Use the same formulae as for RM walls.

CONSTRUCTION COST NOTES (Oct 2013)

The following data can be used to estimate the construction cost of the facility (in Trinidad and Tobago) after the members have been designed and excluding any contractor's fees. For other English-speaking Caribbean countries, multiply the TT dollar amount by 0.8 to get an estimate of the cost ***in EC***, then convert from EC.

RC BUILDING STRUCTURES:

Cost of rebar per ton (2240 lbs) before VAT: 6520.00

Cost of Ready-Mixed Concrete per m^3 before VAT:

Grade 30 concrete within a 5 mile radius of the batching plant = 1130 without pump; 1297 with pump for first 21 m^3 and 1205 after.

Labour Cost = 65% of materials cost

Formwork cost = 25% material cost

STRUCTURAL STEELWORK STRUCTURES:

Cost of structural steelwork sections including fabrication and erection = 17.60 EX VAT per kg for simple construction, but 18.50 EX VAT per kg for complex construction.

Add 25% to cater for accessories (bolts, plates, welds, etc).

ARCHITECTIRAL AND BUILDING SERVICES COST:

Services = assume same as structural for office type buildings; 0.5 x structural for houses and apartments, and 2.0 x structural for hospitals.

Architectural = assume 2.0 x structural for office type and hospital buildings; 2.8 x structural for houses and apartments.

MISCELLANEOUS ITEMS (EX VAT):

1 No. 200mm concrete block = 7.75
1 No. 150mm concrete block = 5.75
1 No. 100mm concrete block = 4.50
1 No. 100mm clay block grade 1 = 4.60
1 bag cement = 69.95
42" Aluzinc corrugated pre-painted 26g roof sheeting per ft = 18.00
25" Steel composite floor decking 20g per ft = 22.00
610 BRC x 100 ft = 449.00
6" Purlins 2"x6"x20' = 169.00

CONSTRUCTION COST NOTES (Oct 2008)

The following data can be used to estimate the construction cost of the facility (in Trinidad and Tobago) after the members have been designed. For other English-speaking Caribbean countries, multiply the TT dollar amount by 0.8 to get an estimate of the cost ***in EC***, then convert from EC.

RC BUILDING STRUCTURES:

Cost of rebar per tonne (2240 lbs) before VAT:

HTS:

10mm	12mm	16mm	20mm	25mm
8900	7261	7261	7700	7700

MS:

10mm	12mm	16mm	20mm	25mm
NA	7200	7200	7700	7700

Cost of Ready-Mixed Concrete per m^3 before VAT:

Grade 30 concrete within a 5 mile radius of the batching plant = 1130 without pump; 1297 with pump for first 21 m^3 and 1205 after.

Labour Cost = 77% of materials cost

Formwork cost = 28% material cost

STRUCTURAL STEELWORK STRUCTURES:

Cost of structural steel sections = 13.00 per kg for 400mm sections and less; 16.50 for > 400mm.

Cost of structural steelwork sections including fabrication and erection = Multiply by 1/(57%) for simple construction, but by 1/(44%) for complex construction.

Add 25% to cater for accessories (bolts, plates, welds, etc).

ARCHITECTIRAL AND BUILDING SERVICES COST:

Services = assume same as structural for office type buildings; 0.5 x structural for houses and apartments, and 2.0 x structural for hospitals.

Architectural = assume 2.0 x structural for office type and hospital buildings; 2.8 x structural for houses and apartments.

MISCELLANEOUS ITEMS (EX VAT):

1 No. 150mm concrete block = 8.35
1 No. 100mm concrete block = 6.91
1 No. 150mm clay block = NA
1 No. 100mm clay block = 5.00
1 bag cement = 43.43

CONSTRUCTION COST NOTES (Nov 2005)

The following data can be used to estimate the construction cost of the facility (in Trinidad and Tobago) after the members have been designed. For other English-speaking Caribbean countries, multiply the TT dollar amount by 0.8 to get an estimate of the cost in EC, then convert from EC.

For Building Structures:

RC BUILDING STRUCTURES:

Cost of rebar per tonne (2240 lbs) before VAT:

HTS:

10mm	12mm	16mm	20mm	25mm
6489	5806	5783	5715	6035

MS:

10mm	12mm	16mm	20mm	25mm
6148	5591	5660	5552	5893

Cost of Ready-Mixed Concrete per m^3 before VAT:

Grade 30 concrete within a 5 mile radius of the batching plant = 635 (including pump)

Labour Cost = 70% of materials cost

Formwork cost = 20% material cost

STRUCTURAL STEELWORK STRUCTURES:

Cost of structural steel sections = 6.58 per kg

Cost of structural steelwork sections including fabrication and erection = 10.80 per kg

ARCHITECTIRAL AND BUILDING SERVICES COST:

Services = assume same as structural for office type buildings; 0.5 x structural for houses and apartments, and 2.0 x structural for hospitals.

Architectural = assume 2.0 x structural for office type and hospital buildings; 2.8 x structural for houses and apartments.

MISCELLANEOUS ITEMS:

1 No. 150mm concrete block = 3.80
1 No. 100mm concrete block = 2.95
1 No. 150mm clay block = 4.75
1 No. 100mm clay block = 2.70
1 bag cement = 35.50