FLEXIBLE BUILDING BASEMENT WITH MULTICOLUMNS

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SUMMARY

This invention is a passive seismic isolation system, which taking advantage of the resilience and flexibility that characterise modern steels, allows the use of MULTICOLUMNS in the buildings basement substituting the traditional columns.

INTRODUCTION

In order to allow the corresponding deformations of the MULTICOLUMNS, the basement or foundation caisson where they are installed, must not include any element opposing displacements between the ground, the foundation, and the structure of the building. For the said purpose, the following features must be taken into consideration:

1.The first level of the building — the one at street level — is separated from the upper part of the perimetric retaining walls of the basement or the foundation caisson.

2.All the basement, or the foundation caisson supports, are made up of MULTICOLUMNS, which in turn are sets of packets of steel straight vertical springs.

3.The building stairs, the elevators shafts, the non-structural walls, and the facilities, must be separated or articulated from the basement in order to allow certain displacements between the foundation and the building itself, by gravitating only on MULTICOLUMNS throughout the seismic event.

4.Seismic controls and shock absorbers can be built around the perimetric space between the first level, and the basement retaining walls — or the foundation cabinet. These devices could be of several types: granular, bar-tube, asynchronous or any other.

MULTICOLUMNS

MULTICOLUMNS are structural support elements for gravitational loads, consisting of packs of steel bars placed vertically. These columns are flexible and substitute the traditional rigid columns made of steel or reinforced concrete.

Packs of Bars

The packs of vertical bars can be set in different arrays, without affecting significantly the elasticity feature of such bars.

They can be formed in an orthogonal (rectangular), or hexagonal (regular hexagon) way. The latter presenting an extra advantage for every bar is confined by the other six surrounding bars; and the perimetral confining elements, such as hoops or clamps working under sole strain, adopt shapes close to a circle, which is the optimal shape for strain work.

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Hoops or Clamps

The vertical steel bars are confined firstly by hoops, clamps, rings, membranes, or any other element highly resistant to strain. The purpose of gathering these bars in packets is increasing its resistance against gravitational loads without bending. However, its characteristic flexibility proper of its thinness is present in case of any seismic event. Similarly, the steel-sheets work forming the suspension springs, also gathered by clamps.

Medial Cabinets for Embedding

The said MULTICOLUMNS may have one or more "medial cabinets for embedding", which are elements for lateral restraint for the bar packs, reducing its free height and allowing two or more moment inflection points to be formed in each MULTICOLUMN.

EXAMPLE: MULTICOLUMNS DESIGN AND ESTIMATION FOR A 60-STOREY BUILDING

The main features of the MULTICOLUMNS in the basements of a 60-storey building will be now determined. Such MULTICOLUMNS constitute basically a seismic isolation system.

Building Features

There will be clears of 10.00 m in both directions, and a weigh of 900 kg/m2 —600 kg/m2 of dead load and 300 kg/m2 of live load. The corresponding MULTICOLUMN is calculated in accordance with the central supports; this load is estimated as follows:

$$(UNL)\,(TA)\,(CF)\,(ST) = CENTRAL\ COLUMN\ MAXIMUM\ LOAD \tag{1}$$

Where: UNL= Unitary Load; TA= Tributary Area; CF= Continuity Factor; ST= Number of Storeys

$$(900\ kg/m^2)\,(10.00\ m)^2\,(1.21)\,(60\ storeys) = 6\,534\,000\ kg \tag{1}$$

This seismic isolation system reduces the horizontal displacements; for that reason the horizontal displacement being absorbed is the most important factor —in this case equals to 12 cm—. The inertial stiffness in the building base corresponds to a tenth of the gravitational weigh.
We will use CARBON STEEL (UNS 10950), with: Last stress to strain (LSS): 1380 MPa
Elastic limit to strain (ELS): 965 MPa Direct modulus of elasticity (E): 205 000 MPa [Aguirre, 1990]
We will also use 38.1 mm (1 ½")-diameter steel bars with an area of 1140 mm²
MULTICOLUMNS will be placed in the first and second basement of the building. All MULTICOLUMNS will have its own medial cabinet for embedding, allowing bars to have two free spans in each intermediate space between floors of 1200 mm each (*Figures 1 and 2).*

Dynamic Safety Factors

Total load (TL)=900 kg/cm² Dead Load (DL)=600 kg/cm² Live Load (LL) =300kg/cm²
Dead Load Factor (DLF)=1.2 Live Load Factor (LLF)=1.5
Steel Strength Factor (SSF)=0.90 Column Resistant Factor (CRF)=0.85

$$GLOBAL\ FACTOR = \frac{[(DL/TL)(DLF)] + [(LL/TL)(LLF)]}{(SSF)(CRF)} \tag{2}$$

$$GLOBAL\ FACTOR = \frac{[(600/900)(1.20)] + [(300/900)(1.50)]}{(0.90)(0.85)} = 1.70 \tag{2}$$

Static Safety Factors: Gravitational Load per Bar

Regarding the gravitational load per bar in repose, we will use 0.125 of the ELASTIC LIMIT TO STRAIN (ELS)=965 MPa

$$GRAVITATIONAL\ LOAD\ PER\ BAR = (ELS)(0.125)(area) \tag{3}$$

Critic Loads for Bars and for 19-Bar Packs

$$GRAVITATIONAL\ LOAD\ PER\ BAR = (965\ MPa)(0.125)(1140\ mm^2) = 137\ 512\ N \qquad (3)$$

The said bars will be gathered in hexagonal packets tied by metal hoops, with their extremes embedded. They will support the corresponding gravitational loads without bending. Since the hoops are separated from one another, this will also avoid the bending of the perimetric bars (*Figures 3 and 4*).

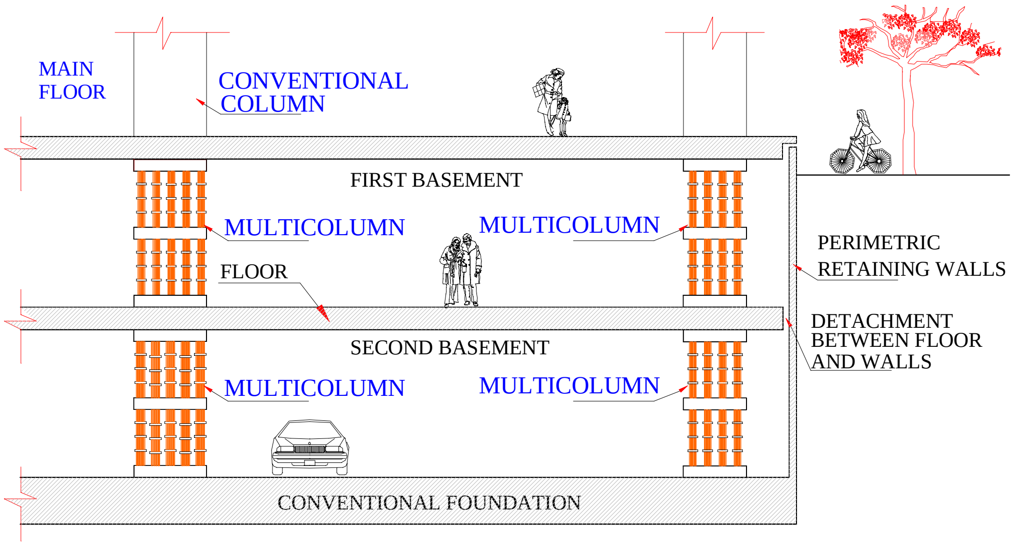

Figure 1. Two Basements with Multicolumns

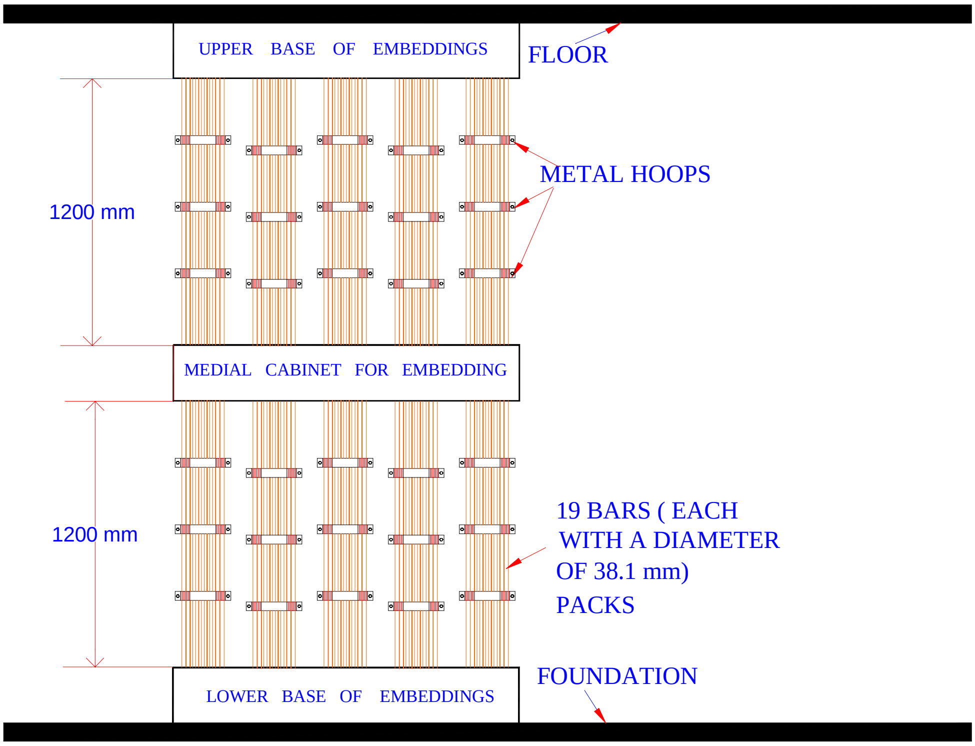

Figure 2. Multicolumn Elevation Detailed Scheme

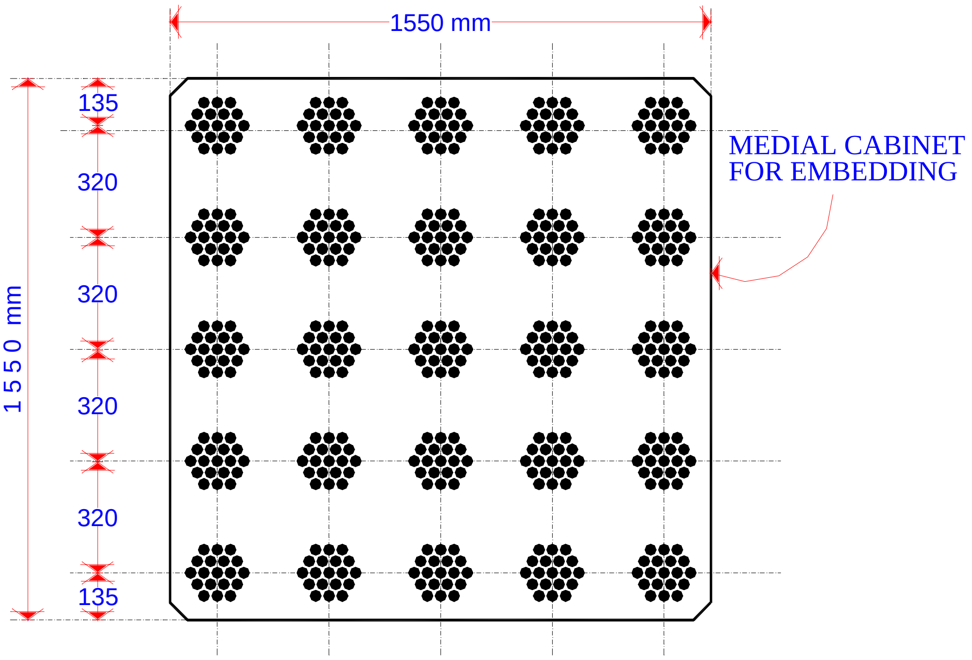

Figure 3. Multicolumn Plant with 475 Bars grouped in 25 Packs

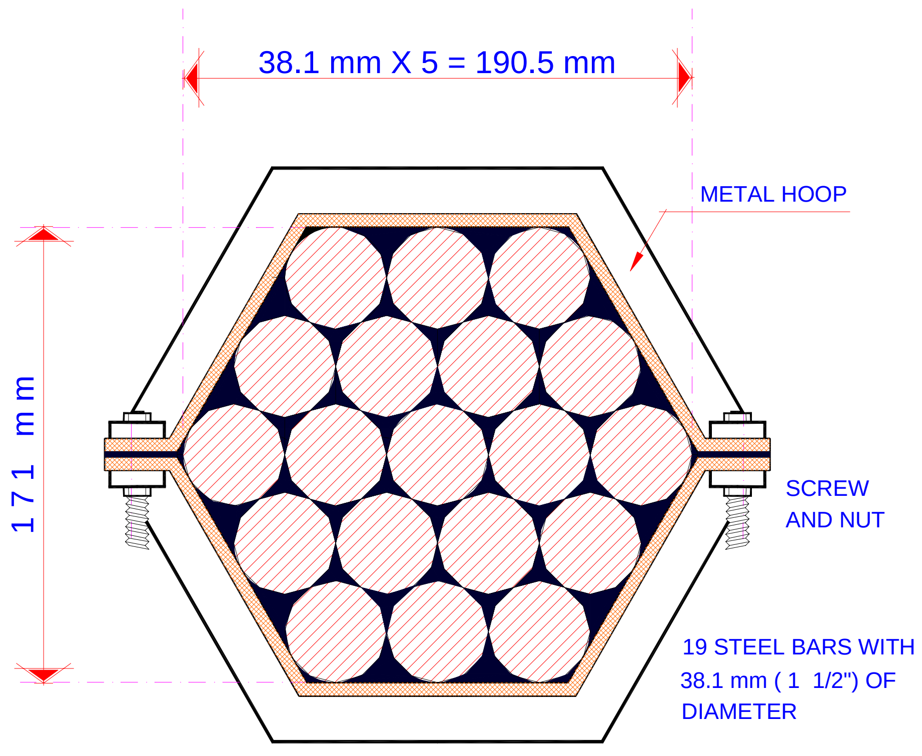

Figure 4. A 19-Bar Pack Plant with Metal Hoop

Bar Centroidal Moment of Inertia (I):

In the case of 38.1 mm-bar:

$$BAR\ CENTROIDAL\ MOMENT\ OF\ INERTIA(I) = \pi\ d^4 / 64 \qquad (4)$$

$$I = \pi\ (38.1\ mm)^4 / 64 = 103\ 434\ mm^4 \qquad (4)$$

Bar Section Modulus (S):

$$BAR\ SECTION\ MODULUS\ (S) = \pi\ d^3 / 32 \qquad (5)$$

$$S = \pi (38.1\ mm)^3 / 32 = 5429\ mm^3 \qquad (5)$$

Pack Centroidal Moment of Inertia (I):

IN THE CASE OF 19-BAR PACKS: PACK MOMENT OF INERTIA = I

$$I = 19\left(\frac{\pi\ d^4}{64}\right) + 8\left[\left(\frac{\pi\ d^2}{4}\right)\left(\text{sen } 60^0\ d\right)^2\right] + 6\left[\left(\frac{\pi\ d^2}{4}\right)\left(2\ \text{sen } 60^0\ d\right)^2\right] \qquad (6)$$

$$If \ldots d = 38.1\ mm\ then \ldots \qquad I = 41\ 684\ 000\ mm^4 \qquad (6)$$

Euler´s Equation:

$$CRITIC\ LOAD = \frac{\pi^2 EI}{L^2} \qquad (7)$$

$$BAR\ CRITIC\ LOAD = \frac{(\pi^2)(205000\ MPa)(103\ 434\ mm^4)}{(350\ mm)^2} = 1\ \ 708\ 373\ N \qquad (7.1)$$

$$PACK\ CRITIC\ LOAD = \frac{(\pi^2)(205000\ MPa)(41\ 684\ 000 mm^4)}{(1200\ mm)^2} = 58\ \ 568\ 288\ N \qquad (7.2)$$

Static Safety Factor

$$CRITIC\ LOAD / WORK\ LOAD = SECURITY\ FACTOR \qquad (8)$$

$$\frac{BAR\ CRITIC\ LOAD}{BAR\ WORK\ LOAD} = \frac{1\ 708\ 373\ N}{137\ 512\ N} = 12.42\quad SATISFACTORY \qquad (8.1)$$

$$\frac{PACK\ CRITIC\ LOAD}{PACK\ \ WORK\ LOAD} = \frac{58\ 568\ 288\ N}{(137\ 512\ N)(19\ bars)} = 22.41\ \ SATISFACTORY \qquad (8.2)$$

By means of the MEDIAL CABINET FOR EMBEDDING, as well as the intermedial metal hoops, the pack works like a short column.

Deflection Bar Estimation

Every single span of bar will equal 1200 mm., just like if they were two brackets of 600 mm each. Considering the point of bending change (center) as the extreme of the bracket, and applying the corresponding loads *(Figures 5, 6, and 7).*

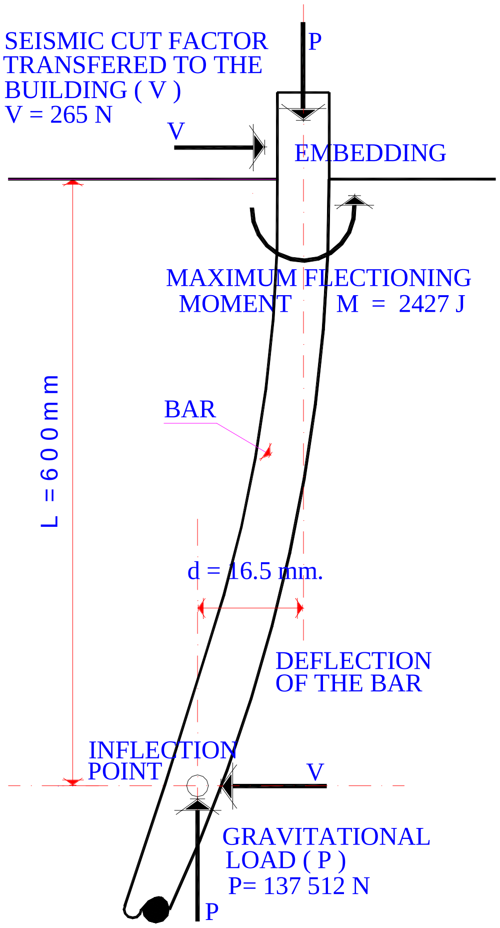

FIGURE 5. FREE-BODY DIAGRAM
of a Half Bar and the Forces which Act Over it

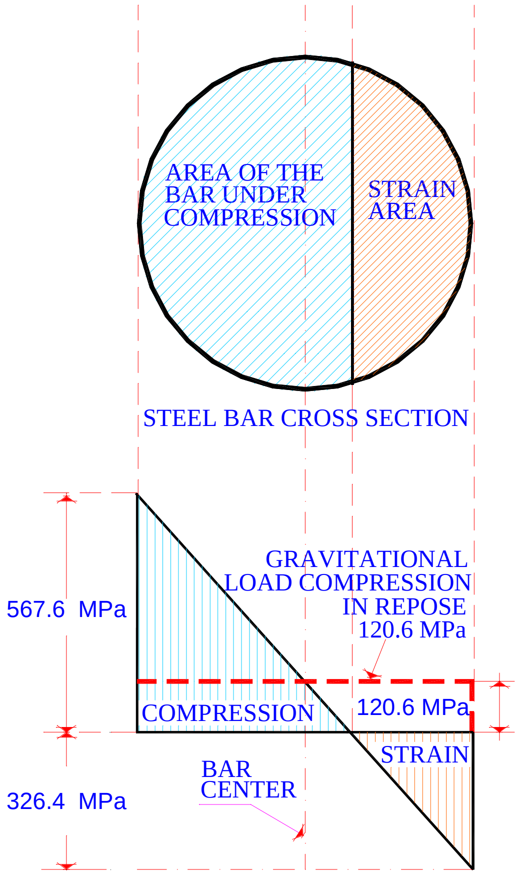

FIGURE 6. CROSS SECTION OF A 38.1 MM
Steel Bar and Diagram of Maximum Shear Acting Upon Such a Bar

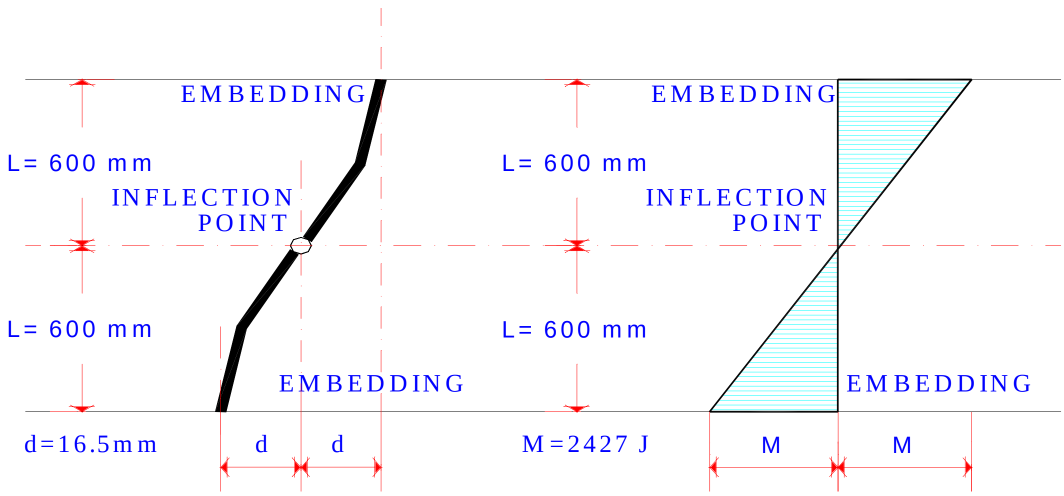

Figure 7. Diagram of Deflection and Stress Within a 1200 mm Bar

General Formulas:

$$K = \sqrt{\frac{P}{E\ I}} \tag{9}$$

$$d = \frac{V\ L^3}{E\ I\ (K\ L)^2}\left(\frac{tan\ (K\ L)}{K\ L} - 1\right) \tag{10}$$

$$MAXIMUM\ MOMENT = V\ L\,\frac{tan\ (K\ L)}{(K\ L)} \tag{11}$$

where K = CONSTANT d = DEFLECTION OF THE BAR

P = GRAVITATIONAL LOAD E = MODULUS OF ELASTICITY

I = BAR MOMENT OF INERTIA

V = SEISMIC CUT FACTOR TRANSFERRED TO THE BUILDING BY THE BAR

L = TOTAL LENGTH / 2 = 1200 mm / 2 = 600 mm (bracket) [Volmir, 1986]

$$K = \sqrt{\frac{137\,512\ N}{(205\,000\ MPa)(103\,434\ mm^4)}} = 0.0025466\ \ 1/mm \tag{9}$$

$$KL = (.0025466\,1/mm)(600\ mm) = 1.528$$

$$d = \frac{(265\ N)(600\ mm)^3}{(205\,000\ MPa)(103\,434\ mm^4)(1.528)^2}\left(\frac{23.33}{1.528} - 1\right) = 16.5\ mm \tag{10}$$

THE RESULTING DEFLECTION CORRESPONDING TO BOTH BASEMENTS:

(16.5 mm) (2 brackets) (2 spans) (2 basements) = 132 mm

$$MAXIMUM\ MOMENT = (265\ N)\left(0.6\ m\,\frac{23.33}{1.528}\right) = 2427\ J \tag{11}$$

$$SUM\ OF\ MOMENTS = Pd + VL \tag{12}$$

Bar Maximum Moment

$$SUM\ OF\ MOMENTS = [(137\,512\ N)(0.0165\ m)] + [(265\ N)(0.6\ m)] = 2427\ J \tag{12}$$

Bar Maximum Stress

$$STRESS\ PER\ MOMENT = MOMENT/SECTION\ MODULUS = M\ /\ S_X \tag{13}$$

$$STRESS\ PER\ MOMENT = (2\,427\,663\ N-mm)/(5429.6\ mm^3) = 447\ MPa \tag{13}$$

$$STRESS\ PER\ LOAD = GRAVITATIONAL\ LOAD/AREA = P\ /\ A \tag{14}$$

$$STRESS\ PER\ LOAD = 137\,512\ N/1140\ mm^2 = 120.6\ MPa \tag{14}$$

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$$MAXIMUM\ COMPRESSION = STRESS\ PER\ MOMENT + STRESS\ PER\ LOAD \tag{15}$$

$$MAXIMUM\ COMPRESSION = 447.0\ MPa + 120.6\ MPa = 567.6\ MPa \tag{15}$$

Dynamic Safety Factor:

$$SAFETY\ FACTOR = \frac{ELASTIC\ LIMIT\ TO\ STRAIN}{MAXIMUM\ TOTAL\ COMPRESION} \quad (16)$$

$$SAFETY\ FACTOR = (965\ MPa)/(567.6\ MPa) = 1.70 \quad (16)$$

The safety global factor from [2] is 1.70…SATISFACTORY

Bar Height Reduction during Deflection

When the maximum deflection occurs, equivalent stress of compression and strain will not alter the bar length on its axis. However, the bending will cause a temporary height reduction of the bar as follows:

$$DEFLECTION\ HEIGHT = \sqrt[2]{L^2 - [(4/3)(d)]^2} \quad (17)$$

$$DEFLECTION\ HEIGHT = \sqrt[2]{[(600)]^2 - [(4/3)(16.5)^2]} = 599.5956\ mm \quad (17)$$

HEIGHT REDUCTION = 600 mm—599.5956 mm = 0.4034 mm

The reduction of height in each basement: 0.4034mm X 2 brackets X 2 spans = 1.6140 mm.

The increase of gravitational load —as a result of momentary height reduction:

$$LOAD\ INCREASE = (GRAVITATIONAL\ LOAD)(REDUCTION) \quad (18)$$

$$LOAD\ INCREASE = (137\ 512\ N)(0.0004034) = 55.5\ N \quad (18)$$

Being the increase of gravitational load similar to 0.0004 P, it is considered to be negligible for this deflection and our practical purpose.

Multicolumns Design of a Gravitational Load Equivalent to 6 534 000 kg.

For the central columns of the 60-storey building, the following steel bars of 38.1 mm:

$$(LOAD - kg)(9.81) = LOAD - Newton \quad (19)$$

$$(6\ 534\ 000\ kg)(9.81) = 64\ 098\ 540\ N \quad (19)$$

$$TOTAL\ LOAD / BAR\ LOAD = NUMBER\ OF\ BARS \quad (20)$$

$$(64\ 098\ 540\ N)/(137\ 512\ N/bar) = 466\ bars \quad (20)$$

We will use 25 packs with 19 bars (each with a diameter of 38.1 mm) = 475 bars

REFERENCES

Aguirre, E. G. [1990] *Design of Machine Elements,* pages 354 and 838

Volmir, A. [1986] *Strength of Materials Problems,* pages 160, 350, and 449