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ANTISEISMIC PNEUMATIC SUSPENSION FOR BUILDINGS

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SUMMARY

This invention uses the mechanic proprieties of the pressurized air –as vehicles do- to give horizontal and vertical seismic isolation to the buildings.

INTRODUCTION

Using one or more BASE PRESSURIZED AIR ROOMS, we can provide to tall or large buildings with a very safe, simple and economical system, to protect them from horizontal and vertical seismic displacements and accelerations.

RESULTS

The design of a 69-story building using a base pneumatic suspension, establishing the system elements and the forces, efforts, materials, security factors, construction processes, horizontal and vertical seismic isolation parameters, hurricane performance, operation, maintenance, and cost of this base pneumatic suspension system.

DISCUSSION

A. THE BUILDING (FIGURES 1-2-3)
It is a 69-Story hotel located in the Port of Acapulco, Mexico. The building has four parking basements with 524 parking spaces and 65 floors over street level with lobbies, restaurants, stairs, elevators, offices, other facilities and 1089 rooms.
The total building area is 109 762 m^2
The dead loads (structure, walls, facades and equipment) are 70 138 000 kg.
The live loads (furniture, automobiles and people) are 27 400 000 kg.
The maximum capacity of guests and employees is 3450 people.
The building rests on four BASE PRESSURIZED ROOMS (BPR) located in its base. Each one is 34.800 m by 34.800 m, therefore, the maximum pneumatic pressure is:

$$\text{BASE PRESSURE} = \frac{\text{DEAD LOAD} + \text{LIVE LOAD}}{\text{BASE AREA}} \qquad [1]$$

$$\text{BASE PRESSURE} = \frac{70\,138\,000\text{ kg} + 27\,400\,000\text{ kg}}{4\text{ rooms} \times 3480\text{ cm} \times 3480\text{ cm}} = 2.014\ {}^{\text{kg}}\!/_{\text{cm}^2} \qquad [1]$$

The detachments, between the 4 sides of the four parking basements, and the peripheral concrete retaining wall is 240 mm wide. These separations between the soil and the structure allow the free ground movement up to 240 mm in every direction during a seism.

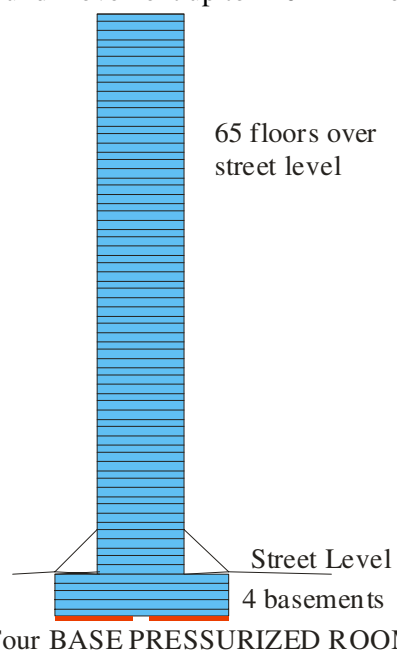

FIGURE 1. 69-STORY BUILDING WITH BASE PNEUMATIC SUSPENSION. SCHEMATIC ELEVATION

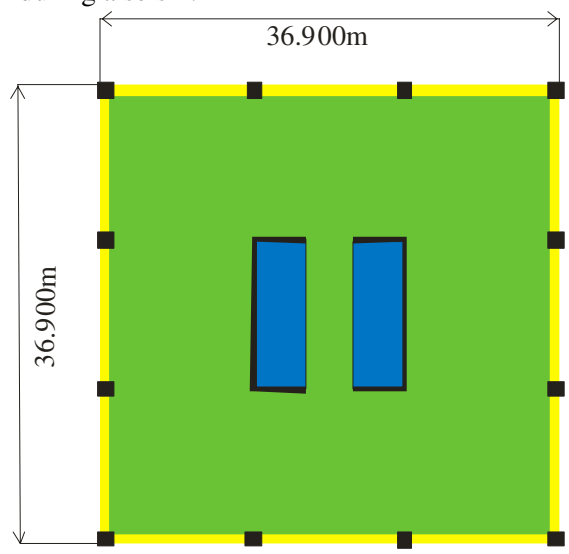

FIGURE 2. 65- TYPICAL FLOORS OVER STREET LEVEL. SCHEMATIC PLANT

B. 4-BASE PRESSURIZED ROOMS (BPR) (FIGURES 4-5-6)

The four BASE PRESSURIZED ROOMS constructed over a horizontal, impermeable concrete flat slab, over the traditional foundation, are 34.800 m by 34.800 m each. Each of this four BASE PRESSURIZED ROOMS has a STEEL SUPPORTING FRAME embedded in its perimeter, to receive the 600 mm width NYLON-RUBBER BAND (NRB). Over the four impermeable concrete slabs, there will be plastic channels, in the shape of a "U", located all along the place of the concrete beams of the foundation caisson.

Below each plastic channel there will be expanded polystyrene plates of 20 mm thick, leaving the plates separated some centimetres between them, to allow the passage of the compressed air at the pressurization time.

Between the beams, there will be square pieces of corrugated and galvanized steel foil, 170 mm over the impermeable concrete slab. To support the steel foils and the concrete slab, which is going to be cast, there will be pieces of expanded polystyrene of 170 mm thick with the necessary size and separation, leaving the expanded polystyrene pieces separated some centimetres to allow the pass of the compressed air in the time of pressurization.

Over the steel foils will be placed the reinforced steel bars, the concrete of the beams and the plates of the foundation caisson.

Around each one of the upper concrete plates of the four BASE PRESSURIZED ROOMS, another STEEL SUPPORTING FRAME has been embedded, separated 300 mm from the first one.

During the construction of the building, the peripheral NYLON-RUBBER BANDS (NRB) could be placed and the four BASE PRESSURIZED ROOMS pressurized with the appropriate pressure to separate the two concrete plates at a maximum of 300 mm

The detachments, between the 4 sides of the four parking basements , and the peripheral concrete retaining wall is 240 mm wide. These separations between the soil and the structure allow the free ground movement up to 240 mm in every direction during a seism.

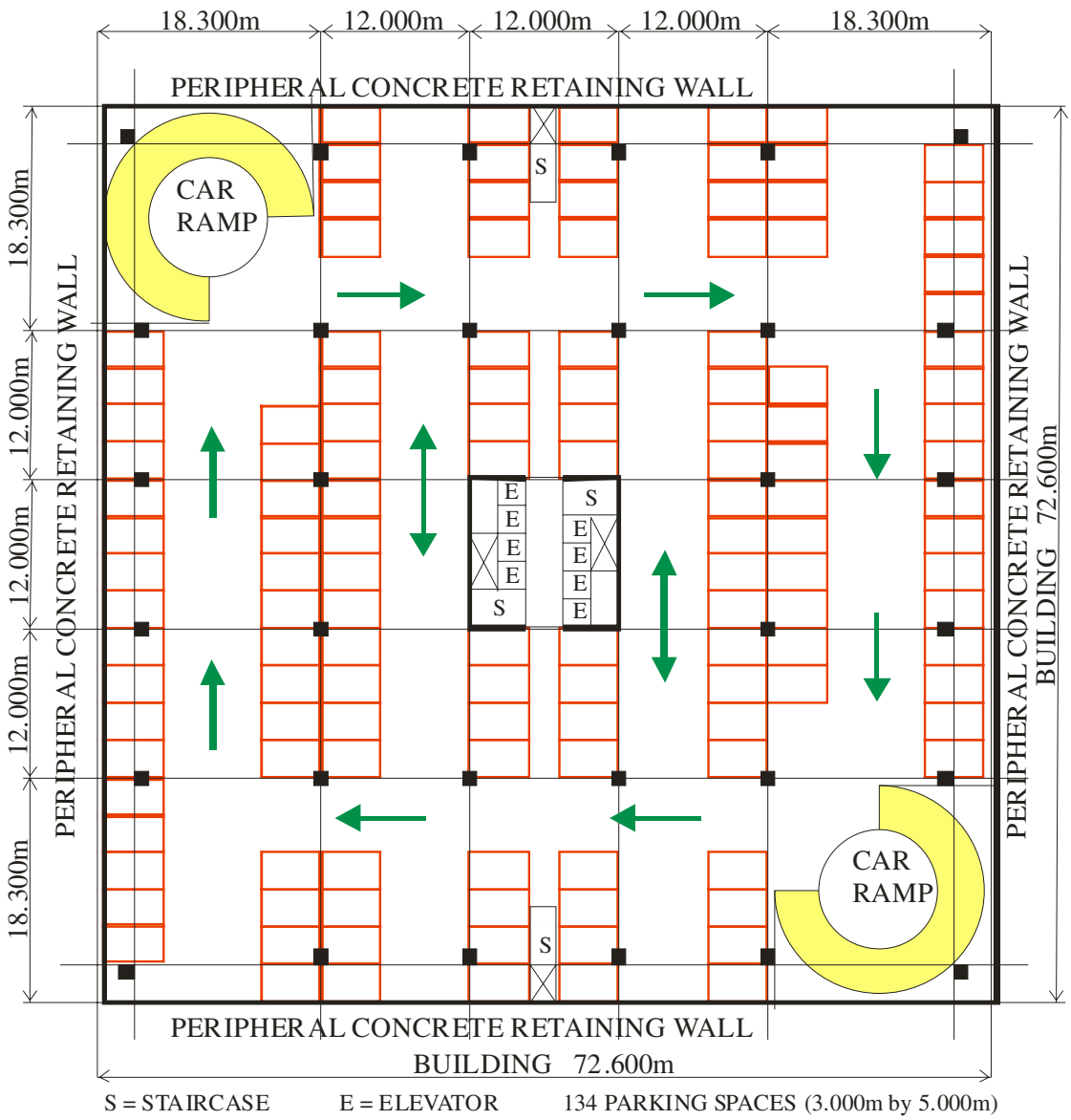

FIGURE 3. FIRST, SECOND, THIRD AND FOURTH PARKING BASEMENTS. PLANT SCALE 1: 600

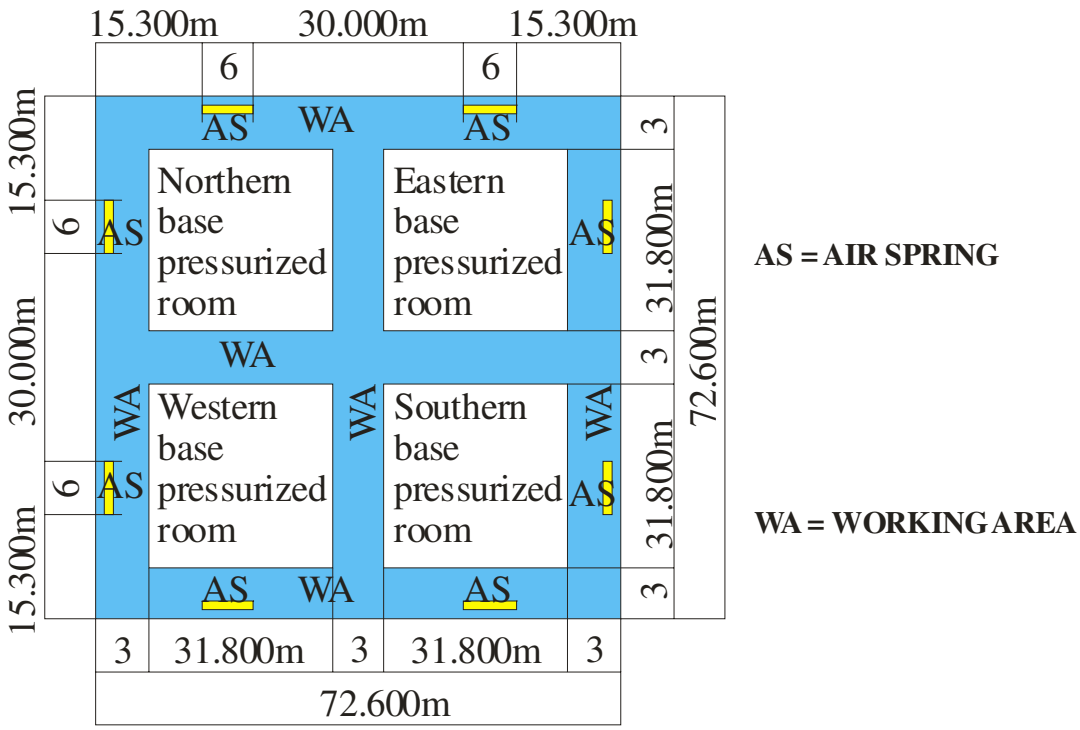

FIGURE 4. FOUR BASE PRESSURIZED ROOMS. EIGHT CONCRETE AIR SPRINGS (AS) CENTRAL AND PERIPHERAL WORKING AREA (WA). SCHEMATIC PLANT

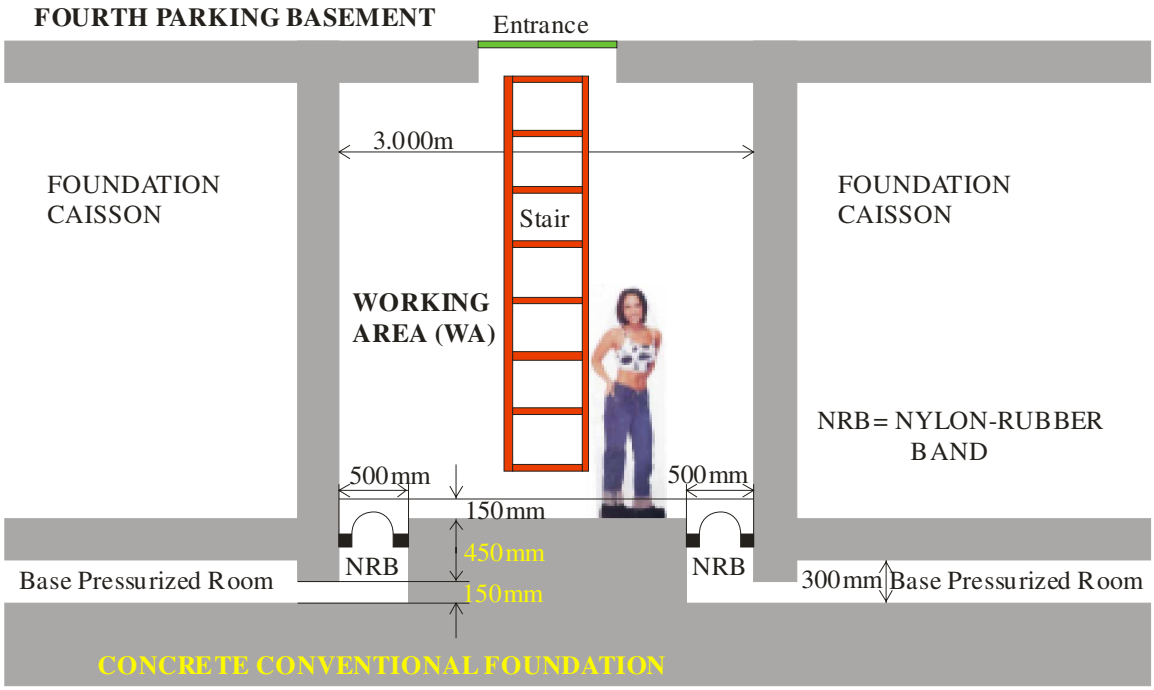

FIGURE 5. CENTRAL WORKING AREA (WA) AND BASE PRESSURIZED ROOMS. SECTION SCALE 1: 50

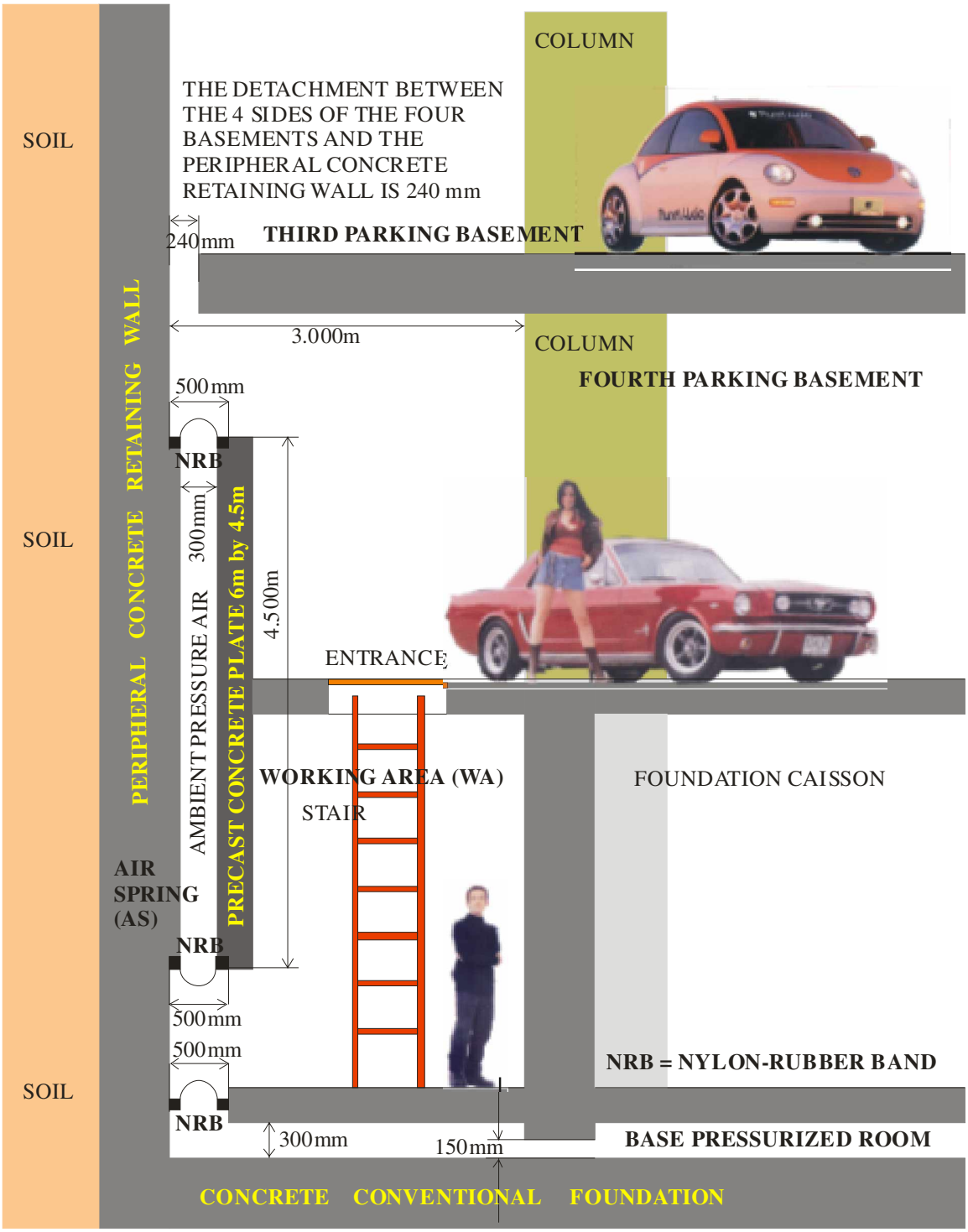

FIGURE 6. BASE PRESSURIZED ROOM, PERIPHERAL WORKING AREA (WA) AND 6.000m by 4.500m CONCRETE AIR SPRING (AS). DETAIL SECTION SCALE 1: 50

C. NYLON-RUBBER BAND (NRB) (FIGURES 7-8-10)

A 600 mm width NYLON-RUBBER BAND CALCULATION: This peripheral band works with a normal separation of 300 mm –in static conditions- but in a seismic period, could close or open 240 mm; therefore, the minimum separation between the STEEL SUPPORTING FRAMES will be 60 mm, and the maximum separation will be 540 mm. The maximum effort in the peripheral NYLON-RUBBER BAND will be at its maximum separation and at its maximum air pressure.

Using the tables of the "CIRCULAR ARCS CALCULATION", MONTERREY MANUAL [1]
FORMULAS:

$$ARCH(a) = (\pi \times \text{RADIUS} \times \text{ANGLE}) \div 180^{O} \qquad [2]$$

$$ANGLE(A^{O}) = (180^{O} \times \text{ARCH}) \div (\pi \times \text{RADIUS}) \qquad [3]$$

$$RADIUS(r) = [(4 \times \text{HEIGHT}^2) + \text{CHORD}^2] \div [8 \times \text{HEIGHT}] \qquad [4]$$

$$HEIGHT(h) = \text{r} - \left(0.5 \times \sqrt{4\text{r}^2 - \text{CHORD}^2}\right) \qquad [5]$$

$$CHORD(c) = 2\sqrt{2hr - h^2} \qquad [6]$$

$$\text{BAND EFFORT PER METER} = \frac{PRESSURE \times c \times 100cm}{2 \times SIN(A^{O}/2)} \qquad [7]$$

$$\text{BAND EFFORT PER METER} = PRESSURE \times r \times 100cm \qquad [8]$$

$$\text{PNEUMATIC COMPRESSION} = PRESSURE \times HEIGHT \times 100cm \qquad [9]$$

LATERAL PRESSURE = BAND EFFORT – PNEUMATIC COMPRESSION [10]

MAXIMUM BAND EFFORT: ARCH (a) = 600 mm, CHORD(c) = 540 mm, r = 381.8mm

$$ANGLE(A^{O}) = (180^{O} \times 600\text{mm}) \div (\pi \times 381.8\text{mm}) = 90^{o} \qquad [3]$$

$$\text{Maximum band effort} = \frac{2.014\ \text{kg.f.}/\text{cm}^2 \times 54\ \text{cm} \times 100\ \text{cm}}{2 \times \text{SIN}(90^{O}/2)} = 7690\ {}^{kg.f.}/_{m} \qquad [7]$$

TABLE 1. BAND CHORDS, ARCHES, ANGLES, RADIUS, HEIGHTS, EFFORTS AND TOTALS LATERAL PRESSURES

600 mm WIDTH NYLON-RUBBER BAND. PRESSURE $2.014\,\text{kg.f.}/\text{cm}^2$								
Distance Between supports CHORD (c) mm	Seismic movement mm	BAND ARCH (a) mm	BAND ANGLE (A) Degrees	BAND RADIUS (r.) mm	BAND HEIGHT (h) mm	BAND EFFORT tension Kg. f Per meter (-)	AIR Pressure Kg. f Per meter (+)	TOTAL Lateral Pressure Kg. f Per meter
60	(-) 240	479.4	319.4	86.0	226.9	1732	4570	(+) 2838
120	(-) 180	479.4	283.4	96.9	233.3	1952	4699	(+) 2747
180	(-) 120	479.4	250.2	109.8	233.0	2211	4693	(+) 2482
240	(-) 60	479.4	213.9	128.4	234.4	2586	4721	(+) 2135
300	ZERO	479.4	183.1	150.2	214.4	3021	4318	(+) 1297
360	(+) 60	565.6	180.0	180.0	197.2	3625	3972	(+) 347
420	(+) 120	600.0	161.5	213.0	178.8	4285	3601	(-) 684
480	(+) 180	600.0	129.6	265.0	152.2	5342	3065	(-) 2277
540	(+) 240	600.0	90.0	381.8	111.8	7690	2252	(-) 5438

(+) Means OPENING TENDENCY (-) Means CLOSING TENDENCY

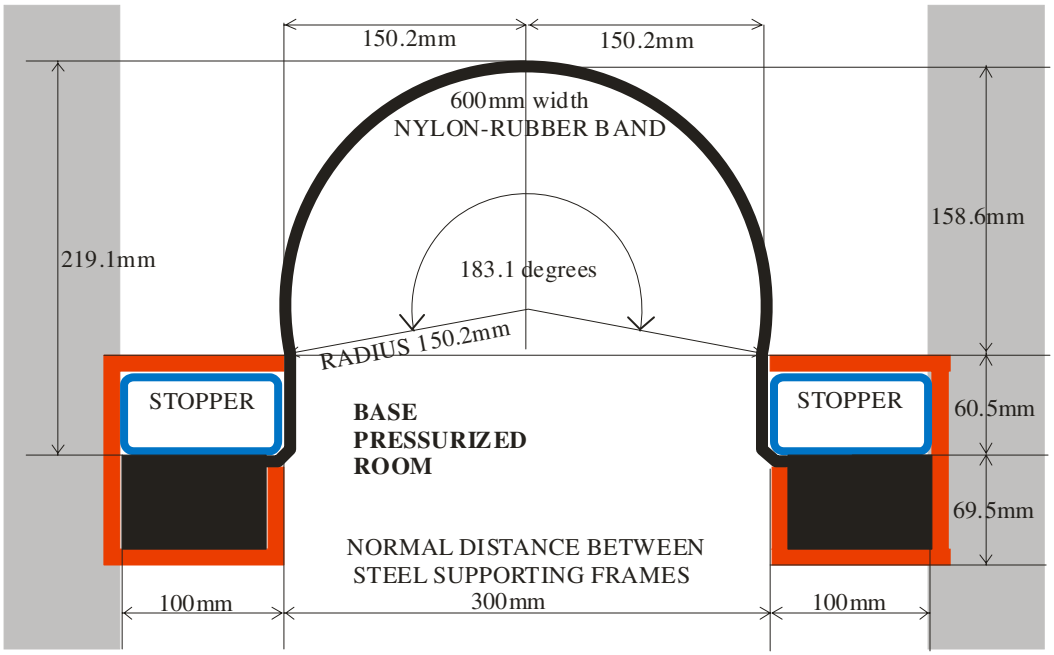

FIGURE 7. 600mm width NYLON-RUBBER BAND (NRB) in normal distance between STEEL SUPPORTING FRAMES by 300mm SECTION SCALE 1: 4

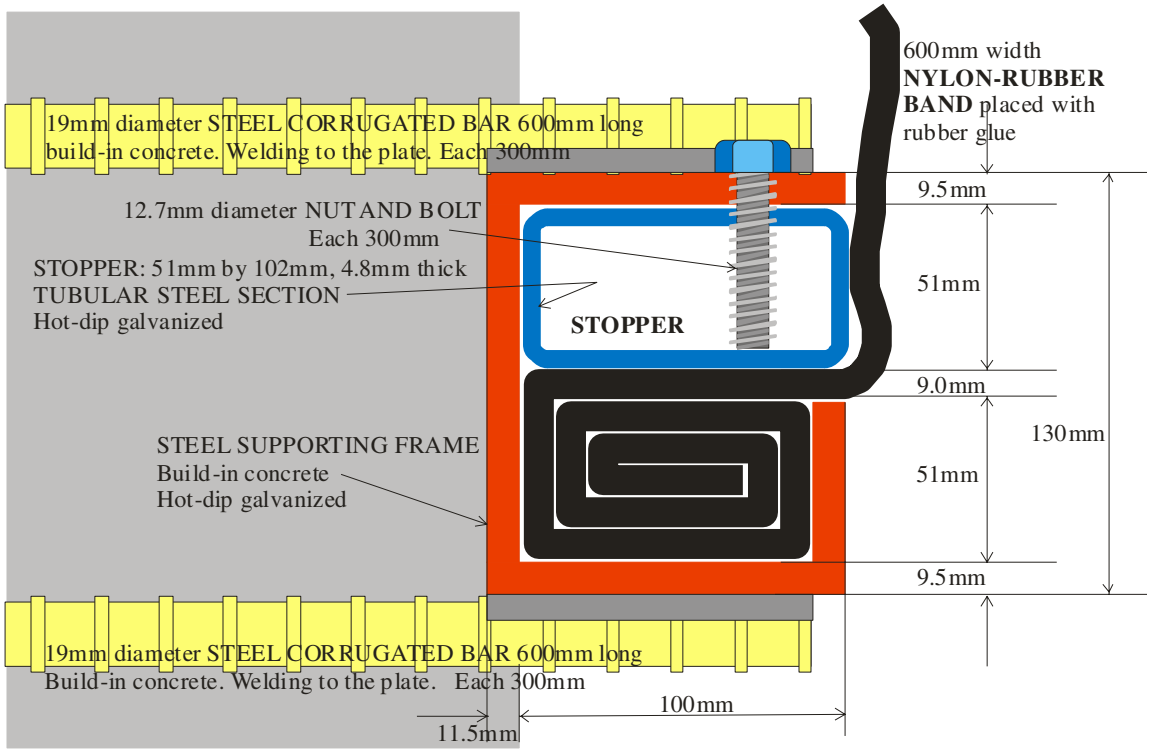

FIGURE 8. STEEL SUPPORTING FRAME TO THE NYLON-RUBBER BAND. SECTION SCALA 1: 2

Taking the tension of the peripheral band we used Nylon-6 wire, a common material used in the tire industry.

TABLE 2. NYLON-6 WIRE

WEAVED, PRIMED AND HOT STRETCHED NYLON-6 WIRE (caprolactam or 6-amino-caproic acid)	
Rupture stress per wire = 32.2 kg.	Denier 1890 / 2-24
8.20 wires per centimetre	Medium thick = 0.81 mm ± 0.02 mm
Rupture stress per meter = 26 404 kg	Weight = 0.446 kg/m^2

SECURITY FACTOR = $[\text{rupture stress per meter}] \div [\text{maximum band effort}]$ [11]

Dynamic Security Factor = $[26\ 404\text{kg.f./m}] \div [7690\text{kg.f./m}] = 3.433$ (satisfactory) [11]

Static Security Factor = $[26\ 404\text{kg.f./m}] \div [3021\text{kg.f./m}] = 8.740$ (satisfactory) [11]

D. WORKING AREA (WA) (FIGURES 4-5-6)

To install the 600 mm width NYLON-RUBBER BANDS (NRB) on the four peripheral STEEL SUPPORTING FRAMES, around the 4-BASE PRESSURIZED ROOMS, we need a 3.000m width WORKING AREA. This area will be used to give maintenance and eventually replace the NYLON-RUBBER BAND.

E. EIGHT CONCRETE AIR SPRINGS (AS) (FIGURES 4-6)

The eight 6.000m-width by 4.500m-height air springs (8AS), placed in the periphery of the fourth basement and the foundation caisson (two on each side), transmit some of the soil movement to the building during a seism and transmit part of the wind effort to the soil. (figures 9-10-11)

Each one of the eight air springs is a parallel pair of 6.000m by 4.500m concrete plates. One of the plates is part of the periphery concrete retaining wall, and the other one is a precast concrete plate. The distance between the two concrete plates is 300 mm and has on its four sides 600 mm-width NYLON-RUBBER BANDS (NRB)-the same to the one used in the 4-BASE PRESSURIZED ROOMS (figures 5 and 6), shaping a hermetic space.

The interior air pressure is the ambient pressure, but if the wind forces move the building or the seism forces move the soil, the distance between the two concrete plates could increase, reducing the air pressure, or could reduce, increasing the air pressure. In both cases the air springs try to return to its 300 mm initial distance.

The atmospheric pressure at 200m over the sea level is 0.976 kg/cm2. KONRAD DIEM [2]

The air pressure variation depends on the distance of the two concrete plates, and is:

$$\text{FORCED PRESSURE} = \left[\frac{\text{original separation}}{\text{forced separation}} - 1\right] \times \text{atmospheric pressure} \qquad [12]$$

The maximum pressure in an AIR SPRING is when the distance between the two concrete plates is 60 mm:

$$\text{MAXIMUM PRESSURE} = \left[\frac{300mm}{60mm} - 1\right] \times 0.976 \, {}^{kg.f.}\!/_{cm^2} = 3.904 \, {}^{kg.f.}\!/_{cm^2} \qquad [12]$$

The minimum pressure in the AIR SPRING is when the distance between the two concrete plates is 540 mm:

$$\text{MINIMUM PRESSURE} = \left[\frac{300mm}{540mm} - 1\right] \times 0.976 \, {}^{kg}\!/_{cm^2} = (-)0.434 \, {}^{\text{kg.f.}}\!/_{\text{cm}^2} \qquad [12]$$

TABLE 3. AIR SPRINGS PRESSURES AND FORCES

EIGHT 6.000m wide by 4.500m high AIR SPRINGS. DIFFERENT DISPLACEMENTS			
Displacement between concrete plates (mm)	Forced separations in opposite air springs (mm)	Unit pressures in two opposite air springs (kg.f / cm2)	Forces in four 6.000m by 4.500m air springs (kg.f)
0	300 + 300 = 600	0 + 0 = 0	0
60	360 + 240 = 600	0.163 + 0.244 = 0.407	219 780
120	420 + 180 = 600	0.279 + 0.651 = 0.930	502 200
180	480 + 120 = 600	0.366 + 1.464 = 1.830	988 200
240	540 + 60 = 600	0.434 + 3.904 = 4.338	2 342 520

F. HURRICANE EFFECTS (FIGURE 9)

Normally the effects of the wind pressure over the building are imperceptible. But we can eliminate, partially or totally, the displacements and leaning of the building with a pressure control in the four BASE PRESSURIZED ROOMS, and in the eight concrete AIR SPRINGS (AS). (FIGURES 4-5-6).

The pressure control will be done with a computer program. In the hurricane case, predictable with some days in advance, it is possible to prepare the computer program control, but, if we don't control the pressures, the hurricane effects are the next:

The structure efforts with a 160 km/hour (100 mile/hour) hurricane are the following:
The basic wind pressure with 160 km/hour is 192 kg.f/m2. FRANK E. KIDDER [3]
The windward side factor is 0.8 and the leeward side factor is 0.5 CONSTRUCTION REGULATIONS OF MEXICO CITY [4] therefore, the wind force over the building is:

WIND FORCE = BASIC PRESSURE x (windward factor + leeward factor) x area [13]

$$192 kg/m^2 \times [0.8 + 0.5] \times 36.9m \times [65 - STORY \times 3.6m] = 2\ 155\ 196 \text{ kg} \quad [13]$$

And the torque to the centre of the concrete AIR SPRINGS (AS) in the fourth basement is:

WIND TORQUE = WIND FORCE x DISTANCE [14]

WIND TORQUE = 2 155 196 kg.f x 131.400 m = 283 192 754 kg.f.m [14]

The equilibrium forces in the base pressurized rooms are:

$$\text{EQUILIBRIUM FORCES} = \frac{\text{WIND TORQUE}}{\text{distance between base pressurized rooms}} \quad [15]$$

$$\text{EQUILIBRIUM FORCES} = \frac{283\,192\,754 \text{ kg.f.m}}{37.300 \text{ m}} = \pm\ 7\ 592\ 299 \text{ kg.f} \quad [15]$$

The pressures in the rooms are:

$$\text{PRESSURE} = \frac{[\text{DEAD LOAD} \div 2] \pm \text{EQUILIBRIUM FORCES}}{2 \times \text{BASE PRESSURIZED ROOM AREA}} \quad [16]$$

$$\text{The highest pressure} = \frac{[70\,138\,000 \text{ kg.f.} \div 2] + 7\ 592\ 299 \text{ kg.f.}}{2 \times 3480\text{cm} \times 3480\text{cm}} = 1.761 \text{ kg.f.}/\text{cm}^2 \quad [16]$$

$$\text{The lower pressure} = \frac{[70\,138\,000 \text{ kg.f.} \div 2] - 7\ 592\ 299 \text{ kg.f.}}{2 \times 3480\text{cm} \times 3480\text{cm}} = 1.134 \text{ kg.f.}/\text{cm}^2 \quad [16]$$

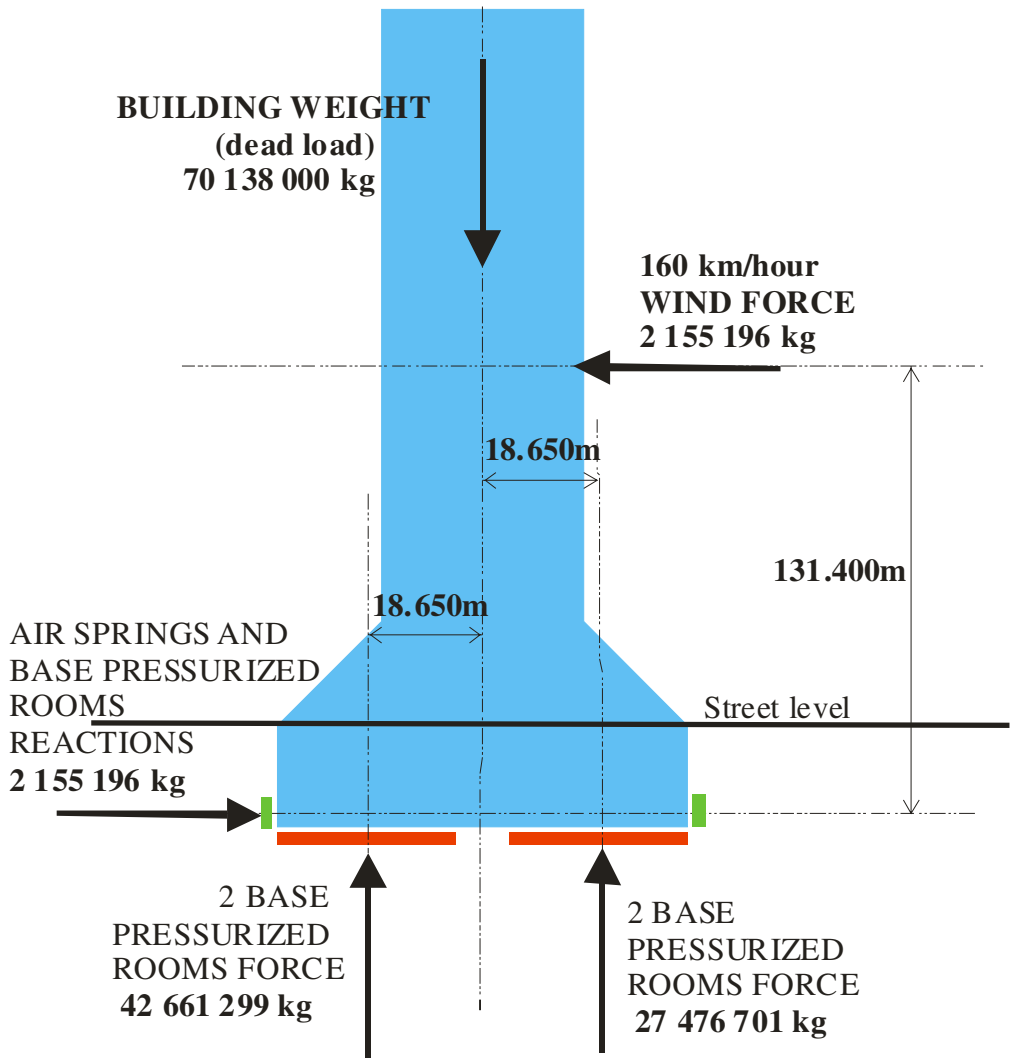

FIGURE 9. 69-STORY BUILDING DURING A 160 km/hour HURRICANE. EQUILIBRIUM FORCES DIAGRAM

HURRICANE EFFORTS: The wind force is 2 155 196 kg, and produces a 200 mm displacement between building and its foundation.

TABLE 4. HURRICANE RESISTANCE TO A 200 mm DISPLACEMENT

ELEMENT AND NUMBER	FORCED SEPARATION mm	ELEMENT DIMENSION	TOTAL QUANTITY	UNIT RESISTANCE	TOTAL RESISTANCE Kg.f.
600 mm WIDTH NYLON-RUBBER BAND IN 4 BASE PRESSURIZED ROOMS					
4 BANDS	500 mm	34.800 m	139.200 m	3048 kg/m	424 282
4 BANDS	100 mm	34.800 m	139.200 m	2807 kg/m	390 734
8 BANDS	300 mm	34.800 m	278.400 m	180 kg/m	50 112
EIGHT CONCRETE AIR SPRINGS (AS) (6.000 m. by 4.500 m. each one)					
2 AS	500 mm	600 x 450 cm	540000 cm2	0.3904 kg/cm2	210 816
2 AS	100 mm	600 x 450 cm	540000 cm2	1.9520 kg/cm2	1 054 080
4 AS	300 mm	21.000 meter	84.000 m	180 kg/meter	15 120
TOTAL RESISTANCE					2 145 144

BUILDING SLOPE DURING A HURRICANE:

Height increase or decrease = $\frac{\text{Original Pressure} \times \text{Original Height}}{\text{FORCED PRESSURE}}$ [17]

Height increase = $\frac{1.448\text{kg.f.}/\text{cm}^2 \times 300\text{mm}}{1.134\text{kg.f.}/\text{cm}^2}$ = 383.1 mm [17]

Height decrease = $\frac{1.448\text{kg.f.}/\text{cm}^2 \times 300\text{mm}}{1.761\text{kg.f.}/\text{cm}^2}$ = 246.7 mm [17]

Height difference = 383.1 mm – 246.7 mm = 136.4 mm

BUILDING SLOPE = $\frac{\text{HEIGHT DIFFERENCE}}{\text{Rooms Centres Distance}} = \frac{0.1364\text{m}}{37.300\text{m}}$ = 0.00365 [18]

G. AIR COMPRESSOR.

We will use the next equipment: 2 ROTARY SCREW AIR COMPRESSORS with a 40 H. P. electric motor. Style ES-40. Air delivery with a working pressure of 7.030 kg/cm^2 (6.9 bar): 5.23 m^3/min, therefore:

COMPLETE PRESSURIZATION TIME = (C. P. TIME)

C. P. TIME = $\frac{\text{VOLUME} \times \text{PRESSURE}}{\text{Air Delivery} \times \text{Working Pressure}}$ [19]

C. P. TIME = $\frac{4\text{rooms} \times 35.300\text{m} \times 35.300\text{m} \times 0.300\text{m} \times 2.014\text{kg}/\text{cm}^2}{2\text{ compressors} \times 5.22\text{m}^3/\text{min} \times 7.030\text{kg}/\text{cm}^2}$ = 41.03 min [19]

H. CONTROL EQUIPMENT, OPERATION AND MAINTENANCE:

The air pressure and/or the interior height on the 4 BASE PRESSURIZED ROOMS change with the environmental temperature, the wind pressure, and the LIVE LOADS variations.

As an example, we take the effects of all the people and all the cars entering the building:

Weight = $[persons \times average] + [cars \times average]$ [20]

Weight = $[3450\,persons \times 70\,kg/person] + [524\,cars \times 1140\,kg/car]$ = 838 860 kg. [20]

NEW LIVE LOADS = 27 400 000 kg – 838 860 kg = 26 561 140 kg

NEW INTERIOR HEIGHT IN THE PRESSURIZED ROOMS = NEW HEIGHT

NEW HEIGHT = $\frac{\text{New Loads} \times \text{Original Height}}{\text{ORIGINAL LOADS}}$ [21]

NEW HEIGHT = $\frac{(70\,138\,000\text{kg} + 26\,561\,140\text{kg}) \times 300\text{mm}}{(70\,138\,000\text{kg} + 27\,400\,000\text{kg})}$ = 297.420 mm [21]

Variation = 300 mm – 297.420 mm = 2.580 mm

To return to their original height the 4 BASE PRESSURIZED ROOMS, we need pressurize during this time: PRESSURIZED TIME (P. TIME)

P. TIME = $\frac{4rooms \times 35.300m \times 35.300m \times 0.00258m \times 2.014\,kg/cm^2}{5.22\,m^3/\text{min} \times 7.030\,kg/cm^2}$ = 0.706 min [19]

0.706 minutes = 42 seconds

Therefore, it is very easy to control the 300 mm height of the 4 BASE PRESSURIZED ROOMS by having the rotary screw compressors work for a few seconds or releasing some of the compressed air.

This pressure control can be done with the appropriate sensors, valves and electric equipment controlled by a computer program.

I. HORIZONTAL SEISMIC ISOLATION

The horizontal isolation margins depend on the displacements between soil and structure and are the following:

TABLE 5. BASE HORIZONTAL ISOLATION

4 BASE PRESSURIZED ROOMS and its 600 mm width NYLON-RUBBER BANDS					
Displacement Between soil and structure (mm)	Forced separations in opposite sides (mm)	Unit forces in opposite sides TABLE 2	Total forces in Opposite sides 4 rooms of 34.800m each	Total forces in Parallel sides 4 rooms of 2 x 4.800m each	TOTAL FORCES IN 4 SIDES OF 4 ROOMS
0	300+300=600	0	0	0	0
60	360+240=600	-347+2135	248 890	15 034	263 924
120	420+180=600	684+2482	440 707	30 067	470 774
180	480+120=600	2277+2747	699 341	45 101	744 442
240	540+ 60=600	5438+2838	1 152 019	60 134	1 212 153

TABLE 6. TOTAL HORIZONTAL ISOLATION

Displacement Between soil And structure (mm)	Forced Separation in Opposite sides (mm)	FORCES IN 4 BASE Pressurized Rooms (kg)	FORCES IN 8 AIR SPRINGS TABLE 4 (kg)	TOTAL FORCES IN BASE + AIR SPRINGS (kg)	TOTAL FORCES BY BUILDING WEIGHT * (ratio)
0	300+300=600	0	0	0	
60	360+240=600	263 924	219 780	483 704	0.005
120	420+180=600	470 774	502 200	972 974	0.010
180	480+120=600	744 442	988 200	1 732 642	0.018
240	540+ 60=600	1 212 153	2 342 520	3 554 673	0.036
* BUILDING WEIGHT = 70 138 000 kg + 27 400 000 kg = 97 538 000 kg					

J. VERTICAL SEISMIC ISOLATION (FIGURE 10)

The analysis of the vertical isolation will be done considering in all cases with a horizontal 180mm displacement too. This is 300 mm + 180 mm = 480 mm.

STRAIGHT SEPARATION BETWEEN BAND SUPPORTS = STRAIGHT SEP.

$$\text{STRAIGHT SEP.} = \sqrt{(\text{HORIZONTAL SEP.})^2 + (\text{VERTICAL SEP.})^2} \qquad [22]$$

To the maximum effort:

$$\text{STRAIGHT SEP.} = \sqrt{(480mm)^2 + (150mm)^2} = 502.9 \text{ mm} \qquad [22]$$

BAND ANGLE: Using the "MONTERREY MANUAL [1]", to ARCH = 600 mm

CHORD = 502.9 mm, BAND ANGLE = 115.78^{O}

$$\text{BAND RADIUS} = \frac{\text{ARCH} \times 360^{O}}{2\pi \times \text{ANGLE}} = \frac{600\text{mm} \times 360^{O}}{2\pi \times 115.78^{O}} = 296.9 \text{ mm} \qquad [23]$$

$$\text{FORCED PRESSURE} = \frac{\text{Original Height} \times \text{Original Pressure}}{\text{FORCED HEIGHT}} \qquad [24]$$

$$\text{FORCED PRESSURE} = \frac{300\text{mm} \times 2.014\,\text{kg}/\text{cm}^2}{150\text{mm}} = 4.028\,{}^{kg}/_{cm^2} \qquad [24]$$

$$\text{BAND EFFORT} = 4.028\,\text{kg.f.}/\text{cm}^2 \times 29.69 \times 100\text{cm} = 11\,959\,\text{kg.f.}/\text{meter} \qquad [8]$$

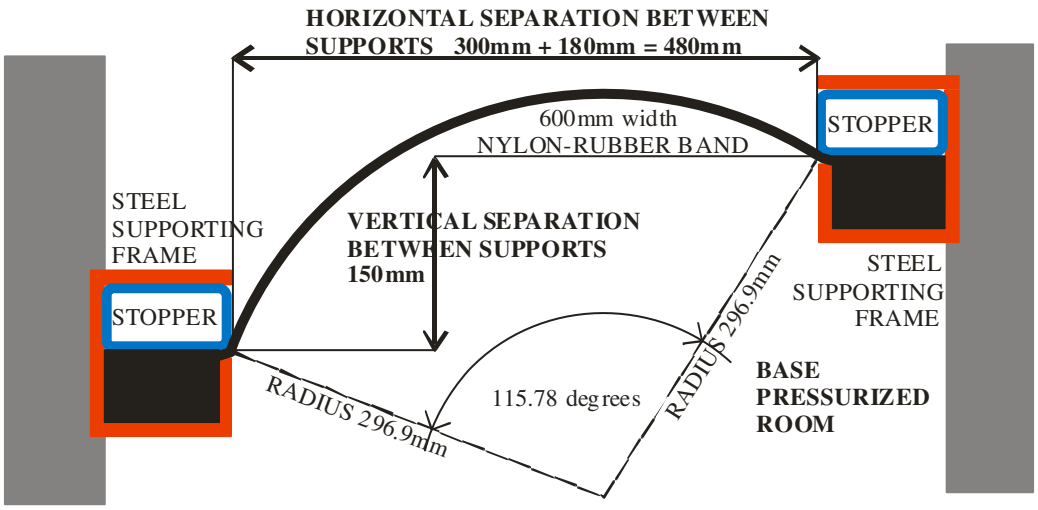

FIGURE 10. NYLON-RUBBER BAND IN THE MAXIMUM VERTICAL AND HORIZONTAL DISPLACEMENT BETWEEN SOIL AND STRUCTURE. DETAIL SECTION SCALE 1: 5

TABLE 7. VERTICAL SEISMIC ISOLATION

VERTICAL ISOLATION WITH A 180 mm HORIZONTAL FORCED DISPLACEMENT						
Separation Between 2 Concrete plates (mm)	Straight separation between supports (mm)	BAND ANGLE DEGREE	BAND RADIUS (mm)	Vertical acceleration GRAVITY	AIR PRESSURE kg/cm^2	NYLON-RUBBER BAND EFFORT Kg. f.
150	502.9	115.78	296.9	2.000	4.028	11,959
180	494.8	120.85	284.5	1.666	3.357	9550
210	488.4	124.69	275.7	1.428	2.877	7932
240	483.7	127.45	269.7	1.250	2.517	6790
270	480.9	129.10	266.3	1.111	2.238	5960
300	480.0	129.60	265.2	1.000	2.014	5341
330	480.9	129.10	266.3	0.909	1.831	4876
360	483.7	127.45	269.7	0.833	1.678	4526
390	488.4	124.69	275.7	0.769	1.549	4271
420	494.8	120.85	284.5	0.714	1.438	4091
450	502.9	115.78	296.9	0.666	1.343	3987
480	512.6	109.60	313.7	0.625	1.258	3949

$$\text{DYNAMIC SECURITY FACTOR} = \frac{26\,404\ \text{kg.f.}/\text{m}}{11\,959\ \text{kg.f.}/\text{m}} = 2.208 \ \text{(satisfactory)} \qquad [11]$$

K. SYSTEM COST IN U.S. DOLLARS

TABLE 8. VALUE----PNEUMATIC BASE SUSPENSION VALUE

JULY 2003 US DOLLARS

ELEMENT	QUANTITY	UNIT AMOUNT	TOTAL AMOUNT
4-BASE PRESSURIZED ROOMS 4-(BPR)			
Bottom concrete plate. Concrete f´c=250 kg/cm2 (72.900m X 72.900m X 0.150m)	797.16 m3.	133.20	106 182.00
Steel corrugated bars fy = 4200 kg/cm2	67 493 kg	0.47	31 722.00
Top concrete plates (4) Concrete f´c=300 kg/cm2 (4 X 34.450m X 34.450m X 0.300m)	1424.20 m3.	140.90	200 670.00
Steel galvanized foil	4747.21 m2.	7.40	35 129.00
Steel corrugated bars fy = 4200 kg/cm2	200 570 kg	0.47	94 268.00
Steel supporting frames to the NRB (34.450m + 35.450m) X 4 X 4	1118.40 m.	69.70	77 953.00
Nylon-rubber band (NRB) 34.950m X 4 X 4	559.20 m.	80.45	44 988.00
PERIPHERAL AND CENTRAL WORKING AREA (WA)			
Service entrance	21 pieces	325.45	6 835.00
Steel galvanized stairs	21 pieces	166.50	3 497.00
8- AIR SPRINGS 8-(AS)			
Precast concrete plates 4.50m X 6.00m	8 pieces	3292.00	26 336.00
Steel supporting frames to the NRB (4.500m + 6.000m) X 2 X 2 X 8 pieces	336.00 m.	69.70	23 419.00
Nylon-rubber band (NRB) (4.500m + 6.000m) X 2 X 8	168.00 m.	80.45	13 516.00
ROTARY SCREW AIR COMPRESSOR AND CONTROL EQUIPMENTS			
40 H.P. rotary screw air compressor	2 pieces	16 417.00	32 834.00
Control equipments and fitting	1 pieces	45 640.00	45 640.00
PNEUMATIC BASE SUSPENSION VALUE (JULY 2003- US DOLLARS) $ 742 989.00			

69-STORY BUILDING VALUE (JULY 2003 – US DOLLARS)

109 762 m^2 Building area $ 93’896,650.00

RELATION BETWEEN THE BASE PNEUMATIC SUSPENSION VALUE AND THE 69-STORY BUILDING VALUE:

RELATIVE VALUE = SYSTEM VALUE / BUILDING VALUE [25]

RELATIVE VALUE = $ 742 989.00 / $ 93’896 650.00 = 0.0079 [25]

(LESS THAN THE 1%)

CONCLUSIONS

This ANTISEISMIC PNEUMATIC SUSPENSION FOR BUILDINGS system, avoids more than the 99 per cent of the seismic movements.

The system cost is less than one per cent of the building value.

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