A study of wind behavior on the Olympic Facilities used in Mexico City in 1968

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Abstract–**In 1963, the Government of Mexico City asked the International Olympic Committee to hold the XIX Olympic Games of 1968. In order to realize this event it was necessary to build the Mexican Olympic Buildings. For the structural design were necessary to do tests in the wind tunnel of the Engineering Institute of the UNAM in order to determine the effect of the wind on the roof deck of the Olympic swimming pool and the gymnasium, and the Sports Palace. Currently, an increase in the frequency of maintenance of the Olympic swimming pool deck has been observed, which may be due to an increase of the wind loads. This paper shows the results of the comparison of the equivalent wind forces using the pressure coefficients obtained of the wind tunnel tests of the Sports Palace, the Olympic swimming pool and the gymnasium. These experimental wind forces are compared with those obtained by the pressure coefficients suggested in some current international codes based on the wind speed of design suggested by Mexican standards.**

1. INTRODUCTION

In 1963, the Government of Mexico asked the International Olympic Committee to hold the XIX Olympic Games of 1968. After making an inventory of the existing sports facilities, it was decided to build the Mexican Olympic Sports Center, the Olympic Village, the swimming pool, the velodrome, the Sports Palace, among others. In this way the necessary engineering studies for the design and construction of these important works began. Two structures with special architectural features for their time stood out and represented major technical problems of design: (1) The Sports Palace and (2) The Olympic swimming pool and the Gymnasium.

The architectural design was carried out by the architects Félix Candela, Enrique Castañeda and Antonio Peyri. The roof deck of this structure would serve to cover several Olympic events and many shows after the Olympic Games.

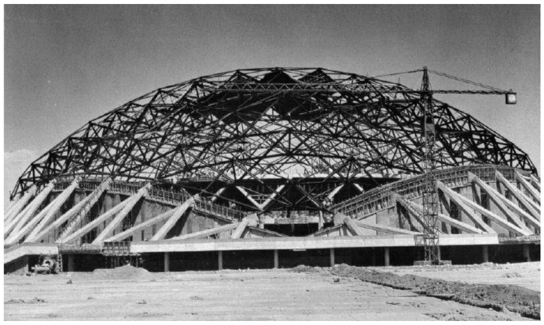

Fig. 1: General view of the Sports Palace [1]

The roof deck of the sports palace was spherical in shape (Fig.1) with light metal structure formed of laminated structures of aluminum and wood. The supporting structure consists of an almost orthogonal grid of steel truss with a height of 5 m, arranged according to maximum circles of a sphere and angularly separated by 8 degrees. The spherical roof deck is limited by four maximum circles and divided into 121 squares whose sides vary from 13 to 10 m. The trusses are formed by triangulated diamonds with radial straps. Each frame is covered by four hyperbolic paraboloid surfaces with two layers of marine triplay on an aluminum grid.

The architectural project of the Olympic swimming pool and the Gymnasium was carried out by the architects Gutiérrez Bringas, Recamier Montes, Rosen Morrinson and Valverde Garcés. The shape of the roof deck of the Olympic swimming pool is formed by two hanging roof mantles supported on three parallel columns, with an outer shape approximately of a paraboloid of anticlastic translation, with a maximum longitudinal deflection of 7.5 m and 5 m in the swimming pool and in the gymnasium, respectively.

Fig. 2: General view of the Olympic swimming pool and gymnasium [2]

The sports palace and the Olympic swimming pool and gymnasium are sensitive to the effects of wind loads due to their special architectural features and due to their light weight.

In this paper, the original design pressure coefficients were reviewed and compared with those proposed in the current international wind design codes. On the other hand, the wind design loads were calculated according to the design wind velocities currently proposed in The Complementary Technical Norms for wind design of Mexico City [3], and these were compared with the wind loads estimated during the years of its construction. An increase in wind loads was observed, which is why the deck roof of the Olympic swimming pool currently exhibits visible oscillations, which should shorten the time for the tensioning of the cables forming the deck roof (Fig. 3).

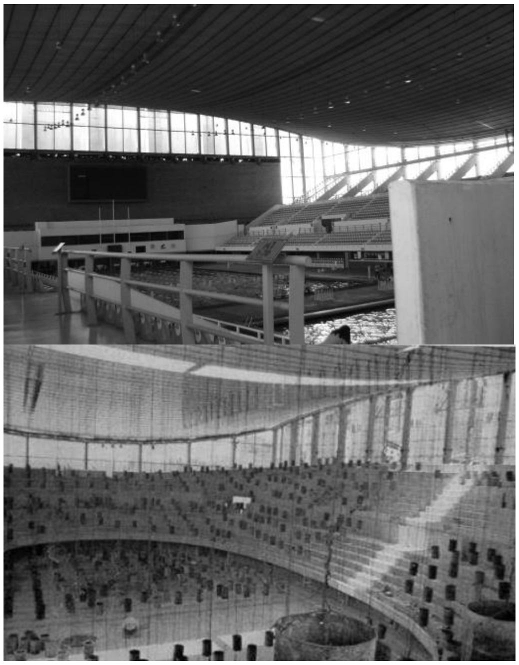

Fig. 3: Corrective maintenance of the roof deck of the Olympic swimming pool

2. HISTORICAL COMPARISON OF THE WIND VELOCITY IN THE VALLEY OF MEXICO

The Latin American Tower was designed in 1958 in Mexico City, however, at that time direct measurements of wind velocity and wind pressures coefficients were not yet done for the purposes of designing civil works; therefore, the design recommendations were based on empirical values [4]. The wind design of the Latin American Tower was made with a pressure of 70 *kgf/m*^{2} corresponding to a wind velocity, V_o, of 96.6 km/h. This wind pressure was applied from the floor 44 to 13, while it changed from 70 to 0 *kgf/m*^{2} on the lower floors. The experiments carried out at that time to determine the pressure of the wind on areas of 25 to 100 *ft*^{2} resulted in the experimental formula:

$$p = 0.0075 V_0^2 \qquad (1)$$

Where the wind velocity, V_o, is in *km/h* and the wind pressure, p, is in *kgf/m*^{2}.

In 1964 [5] was reported a wind velocity between 110 and 120 *km/h* for the zone of the Valley of Mexico and for a return period of 50 years. In the wind design code proposed in 1976 for Mexico City [6], the design velocity was taken proportional to the cube root of the height above ground. The minimum wind velocity at 10 *m* and for structures of group B was 80 *km / h*, although the suggested wind velocity was 110 *km / h*. On the other hand, the wind velocity was increased by 15% for Group A structures with respect to those mentioned above, therefore the minimum wind speed for the structures of group A was 92 *km/h*; both were independent of the terrain roughness. It was considered a turbulence factor of 1.3 for the case of structures susceptible to the dynamic wind effects (vibration period greater than 2 *s*). This document was not clear, but it is understood that the averaging time was referred to 15 *s* for a return period of 100 years.

The Civil Works Design Manual of the CFE reported for the Valley of Mexico a wind velocity of 100 *km / h*, for a period of return of 100 years and averaged every 15 *s* [7].

In 1983, Dr. Rascón [8] presented one of the best documented works on the calculation of wind design velocity in Mexico City for different periods of return.

Its main hypothesis was that the wind design velocity recorded in the 1983 wind code was too conservative. As a result, he proposed not to change the design guidelines until other studies were done, however, he proposed wind design velocities averaged over 3 *s* and for return periods of 25, 50, 100 and 200 years. The values proposed for each return period were 85 *km / h*, 90 *km / h*, 95 *km / h* and 100 *km / h*, respectively.

The wind design code [9] widely used nationally in 1987, specifies that wind pressure (kgf/m^2) be calculated with:

$$p = 0.00555 C_p V_0^2 \tag{2}$$

Where the wind velocity is in *km/h*. The wind design velocity of equation (2) must be proportional to the fifth root of the height on the ground, taking the velocity at 10 *m* and not less than 78 *km / h*. The minimum wind velocity values shown in Table 1 can be taken as an alternative for the use of equation (2).

Table. 1: Minimum wind velocity for equation (2)

Height above ground	V_o
0 - 15 *m*	85 *km/h*
12 - 25 *m*	94 *km/h*
25 - 50 *m*	108 *km/h*
50 - 100 *m*	118 *km/h*

Where, a wind velocity of less than 110 *km / h* will not be assumed for high-rise buildings in prominent places.

In the reference document [10], a basic velocity of 80 *km / h* was established for group B structures and for a return period of more than 50 years based on a statistical analysis of the measurements made in the Observatory of Tacubaya for more than 40 years; while a value of 86 *km/h* was established for structures of group A and for a return period greater than 100 years.

The Complementary Technical Norms of 1987 then adopted a design pressure of:

$$p = C_p \left(\frac{z}{10} \right)^{2/a} K \ p_o \tag{3}$$

Where K is the corrective factor of exposure conditions; C_p is the wind pressure coefficient; and p_o is the wind pressure at 10 *m*, which is equal to 30 kgf/m^2 for structures of group *B* and corresponding to a wind velocity of 80 *km / h*. On the other hand, the value of p_o is equal to 35 kgf/m^2 for structures of group A and corresponding to a wind velocity of 86 *km / h*.

In 2000, the new wind design norms were drafted, which were formalized in 2004 [3], in which a design wind velocity at 10 *m* is averaged every 3 *s* for different zones of Mexico City. The most unfavorable wind velocity for Group A structures (return period of 200 years) was 140.4 *km/h*; 129.6 *km/h*, for Group B structures (return period of 50 years); and 111.6 *km/h*, for temporary structures (return period of 10 years).

From the historical description described in the previous paragraphs, it can be seen that the wind design velocities for civil structures in Mexico City have been conservatively proposed from 1958 to 2004, without making clear the averaging times and the return periods, even assuming that for 40 years were not modified.

Interestingly, as will be seen later, the wind design velocity for the roof deck of the Olympic swimming pool and the Sports Palace in 1963 was 120 *km/h*, which would correspond to the recommended one for a return period of 50 years in the current norm (2017). Which can only imply any of the following two precepts: (1) the wind design velocities were too conservative, or (2) the Valley of Mexico has not undergone changes in the wind design speed in the last 54 years.

3. EOLIC DESIGN OF THE SPORTS PALACE

The Sports Palace has an area of 27,000 m^2, of which 5,000 m^2 belong to the track and 22,000 m^2 belong to the grandstands. The roof deck covers a surface in plant of 13,700 m^2 with a distance of 135 *m* between supports (Fig. 4).

The gravitational load plus lateral wind load proved to be the most unfavorable load combination for the structural design of the roof deck. On the other hand, the gravitational load plus sinks proved to be the most unfavorable load combination for the structural design of the foundation.

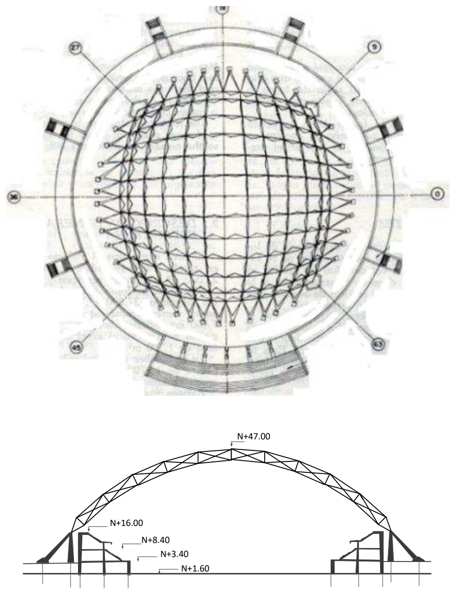

Fig. 4: General view of the Olympic Palace [1]

The wind design was based on the results of the tests performed on a rigid model of the Sports Palace in the wind tunnel of the Engineering Institute of the UNAM [1], mainly considering suctions with an average value of 70 kgf / m^2. The wind tunnel in which the model was tested had a prismatic test section of $0.80 \cdot 1.15 \cdot 1.73$ m in length (Fig. 5), and allowed to model a uniform wind velocity distribution with speeds up to 220 km / h.

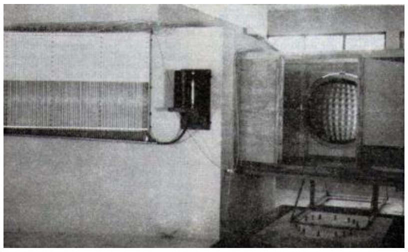

Fig. 5: General view of the wind tunnel model of the Sports Palace [1]

As a result of the wind tunnel tests, the pressure coefficients shown in Figure 6 were obtained for the case of the roof deck valleys.

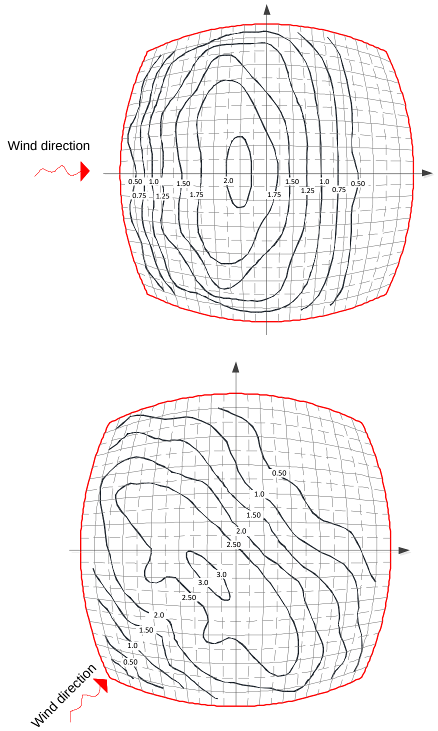

Fig. 6: Wind pressure coefficients on the roof deck valleys of the Sports Palace [1]

As a result of the wind tunnel tests, the pressure coefficients shown in Figure 7 were obtained for the case of the roof deck crests.

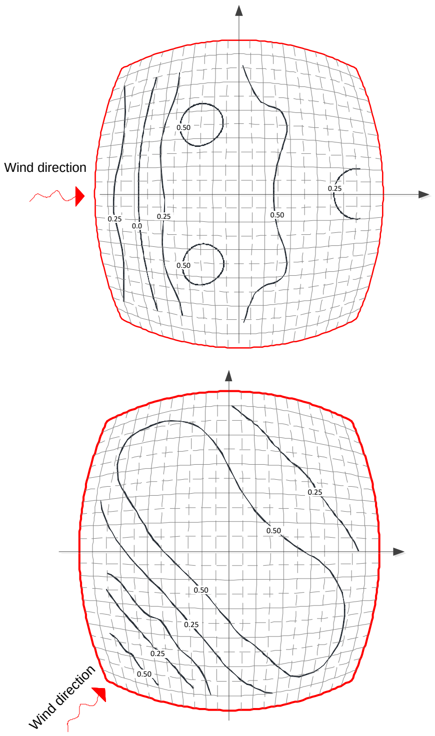

Fig. 7: Wind pressure coefficients on the roof deck crests of the Sports Palace [1]

4. EOLIC DESIGN OF THE OLYMPIC SWIMMING POOL AND GYMNASIUM

The Olympic swimming pool and Gymnasium project includes two suspension roofs. The roof deck of the swimming pool has a distance of 112 *m* between supports, and the roof deck of the Gymnasium has a distance of 79 *m* between supports. The roof decks are hanging in the North-South direction, with a deflection of 7.5 *m* in the pool and of 5 *m* in the gymnasium. In the East-West direction, the roof decks have reverse curvature with arrows of 5 *m* and 3 *m*, respectively.

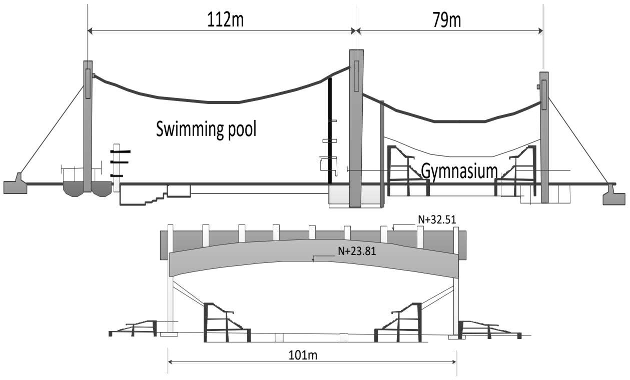

Fig. 8: General view of The Olympic Swimming pool and Gymnasium [2]

The most unfavorable condition during the structural design of the roof deck formed by cables was that produced by the wind. The design wind velocity was 120 *km / h*.

An experimental research program was performed to study wind effects on the deck roof of the Olympic swimming pool and Gymnasium. Firstly, the wind pressure distribution was investigated by means of wind tunnel tests on a rigid model. Secondly, flexible models, reproducing the stiffness of the deck roof on the prototype, were studied to define the effect of the vibration on the wind pressures, the deflections of the deck roof, and the dynamics effects of them.

It was found that pressures measured on the rigid model were not modified by the vibration. The order of the magnitude of the deflection for the design wind velocity was established. It was concluded that appreciable effects of dynamic amplification or resonance were probable.

Figure 9 shows a view of the roof deck model during tests in the wind tunnel.

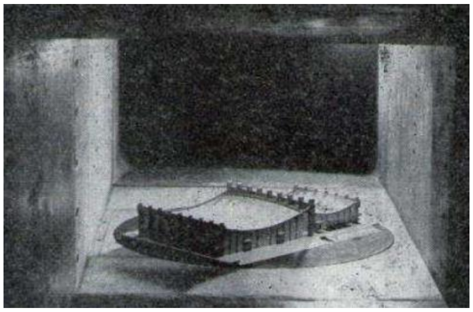

Fig. 9: General view of the wind tunnel model of The Olympic swimming pool and Gymnasium [2]

The wind pressure coefficients were calculated with a rigid roof deck model and the pressures were then calculated by the equation:

$$p = \frac{1}{2}\rho C_p V_0^2 \qquad (4)$$

Where the mean value of air density is:

$$\rho = 0.123\frac{kgf \cdot s^2}{m^4} \qquad (5)$$

Therefore, the wind pressure was calculated by the equation:

$$p = 0.0615 C_p V_0^2 \qquad (6)$$

Where the wind velocity, V_o , is in *m/s*. During the wind tunnel tests, it was observed that the roof deck pressures oscillated with a vibration period of about one second, which could be due to the vortex shedding at the edges of the roof decks, however, this could not be verified.

Figure 10 shows the wind pressure coefficients on the roof decks of the Olympic swimming pool.

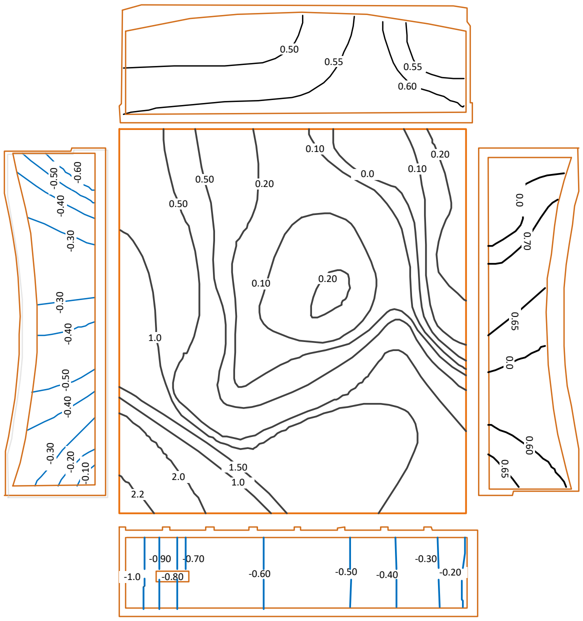

Fig. 10: Wind pressure coefficients on the roof deck of the Olympic swimming pool [2]

Figure 11 shows the wind pressure coefficients on the roof decks of the Gymnasium.

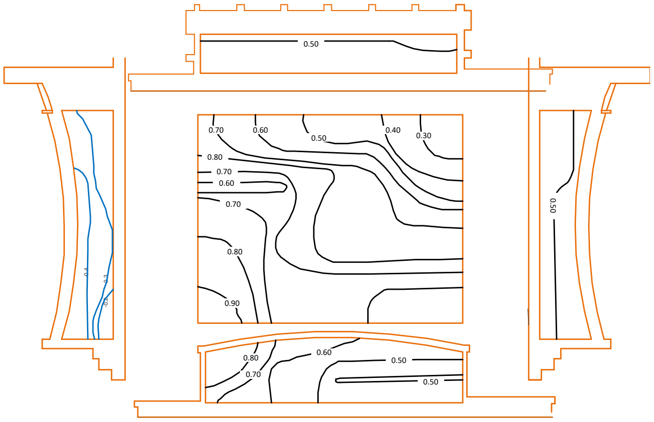

Fig. 11: Wind pressure coefficients on the roof deck of the Gymnasium [2]

5. CALCULATION OF WIND LOADS WITH DIFFERENT DESIGN CODES

The wind design loads on the roof decks of the Olympic structures studied in this paper during their design were based on the results of the wind tunnel tests for the determination of pressure coefficients. However, since 1965 different international wind design codes have emerged, which proposed wind pressure coefficients for the design of roof decks with a similar shape to those studied here. In addition, design wind velocities in the Valley of Mexico have increased in recent years. In order to determine the increase of the wind loads on the roof decks, the pressures and the design forces have been calculated by means of the recommendations of different international wind design codes assuming the design wind velocity referred in the current wind design code of Mexico City [3].

For the case of the roof deck of the Sports Palace, some international wind design codes consider roof decks with similar shape. The values of the pressures and the total forces obtained by these codes are shown in Table 2.

Table. 2: Wind design pressures and maximum forces on leeward of the Sports Palace

Wind design code	Pressure (*Pa*)	Force (*kN*)
Wind Tunnel (1963)	535.34	1879.36
AIJ [11]	873.44	2618.98
BS EN 1991-4:2005 [12]	912.6	1748.66
ASCE7-2005 [13]	1006.72	1694.9

In Table 2, it can be observed that there is a small increase on the wind loads with respect to those obtained by the wind tunnel tests carried out in 1963; reason why the behavior of this roof deck can be considered adequate when it is subjected to wind loads.

For the case of the roof deck of the Olympic swimming pool, there is no recommendations for a roof deck with similar shape; therefore, it is not possible to make a comparison of the wind pressure. However, it is possible to calculate the wind pressures and forces with the current wind design code of Mexico City [3] and compare them with those obtained with the wind tunnel tests carried out in 1963. The wind pressures and forces on the roof deck of the Olympic swimming pool and Gymnasium are shown in Table 3.

Table. 3: Wind design pressures and maximum forces on leeward of the Olympic swimming pool and Gymnasium

Reference	Wind tunnel (1963)	NTC-RCDF-2004 [3]
Pressure (*Pa*)	434	537
Force on roof deck (*kN*)	1,500.0	1,515.36
Force on windward wall (*kN*)	650.0	690.28

In table 3, it can be observed that there is a small increase on the wind pressures and forces with respect to those obtained during the original design of the Olympic swimming pool and Gymnasium. This situation may be the consequence of significant oscillations in the cable-stayed roof deck, thus shortening its maintenance time and the pretensioning of the cables.

6. CONCLUSION

In this paper was analyzed the possible change on the wind design forces on the Sports Palace and the Olympic swimming pool and Gymnasium that were designed in 1968 for Mexico City.

A historical comparison was made of the wind design velocities in the Valley of Mexico from 1968 to the date. It was concluded that the wind design velocities were considerably overestimated at the design date of the Olympic installations (1968). This is why the original wind design velocities are similar to those obtained by the current wind design code of Mexico City [3].

Wind forces were compared on the roof deck of the Sports Palace through various wind design codes, with the result that the design forces have little variation from those obtained in the wind tunnel test carried out in 1963.

In the case of the roof deck of the Olympic swimming pool it was not possible to compare the design forces obtained with other design codes, since they do not contemplate structures with similar shapes.

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REFERENCES

[1] Sotelo G., Springall, R., “Palacio de los Deportes, Estudios del efecto del Viento sobre la Estructura”, Revista de Ingeniería, UNAM, Vol XXXVIII, No. 4, 1968

[2] Capella A., Springall R., “Alberca y Gimnasio olímpicos, Efectos del Viento sobre la Estructura”, Revista de Ingeniería, UNAM, Vol XXXVIII, No. 4, 1968.

[3] Department of the City of Mexico, “Normas Técnicas Complementarias para Diseño por Viento”, 2004, Mexico.

[4] Adolfo Zeevaert, Luis Cuevas, “La Torre Latinoamericana”, 1^{a} ed., 84 p., 1983, Mexico

[5] Cuevas R. N., “Aplicación de la estadística de extremos a la determinación de velocidades de viento para diseños estructurales”, Revista de Ingeniería, UNAM, , Vol XXIV, No. 4, 1964.

[6] II-UNAM, “Manual de Diseño por viento, según el Reglamento de Construcciones para el Distrito Federal; Parte 1, 2 ,3 y 4”, 1976.

[7] De Pablo G., “Apuntes del Diseño Estructural, Dimensionamiento de Cubiertas industriales”, Centro de Educación Continua UNAM, 1976.

[8] Rascón Ch., Brito R., “Velocidades básicas para el diseño eólico de estructuras en la Ciudad de México”, Revista de Ingeniería, UNAM, Vol. LIII, 77-87, 1983.

[9] AHMSA, “Compendio del Manual AHMSA para la construcción en acero”, AHMSA, 1987.

[10] II-UNAM, “Comentarios, ayudas de diseño y ejemplos de las normas técnicas complementarias para diseño por viento, DDF”, Series del Instituto de Ingeniería, N. ES-8, 1992.

[11] AIJ, Architectural Institute of Japan Recommendations for Load son Buildings, Chapter 6, Wind Loads, 2004.

[12] British Standard, “BS EN 1991-4:2005, Eurocode 1: Actions on structure, Part 1-4: General actions-Wind Actions”, 2005.

[13] ASCE/SE 7-2005, Minimum Design Loads for Buildings and the Others Structures, American Society of Civil Engineering.