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Wind Action Effects on Mixed Reinforced Concrete Structures in Non Seismic Zones

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Abstract:

The effects of wind loads on reinforced concrete structure are considerable when the structure is exposed frequently from the wind actions. The wind exercises dynamic effects on the constructions that depends on the altitude of the site and frequency of the exercise. The non-regularity of the building shapes and the external surface of them increase the sensibility from the wind loads of the high-raise buildings. The interaction between structural response and aerodynamic actions can effect negatively on the security of a ductile reinforced concrete frames. In high-rise structures due to the asymmetric action of the wind pressure, the structure could have important shear stress, bending moment and torsional stress. Building structures with a columns- shear walls type of structure will decrease the fatigue of structural elements from wind loads. In these conditions the reinforced concrete structure should be designed considering even the resonance of the natural period of the structure and the wind fluctuations effects from each directions. The results of this paper are provided using the auxiliary finite element software 'Midas Gen'. Analyzing and assessing the results we identify which type of structure is suitable to decrease the materials stress in the structure under horizontal wind loads.

Key words: Wind action, shear force, mixed reinforced concrete structure, shear walls, finite elements.

1. INTRODUCTION

High-rise building should be design not only considering seismic action but also considering even the wind action. Base on aeroelasticity theory the wind action induced on the reinforced concrete structures aerodynamic forces. The wind pressure induces to the structure significant shear stresses and moment in the base. While calculating wind action on the structure is very essential to consider: The site where is going to be build, the structural type, exterior shape of the building and the height of the building.

In high-rise building an opaque shape increase the wind action in proportion with the structure height.

It is necessary to carry out experimental tests and numerical calculation with auxiliary software to define with reliable accuracy: the characteristics of the wind in terms of speed and direction, taking into account also the non-correlation of turbulent fluctuations and the characteristics of the aerodynamics action.

In this paper we have studied a 14 stories reinforced concrete building [6] located in historic district of the Milan Fair in Milan, Italy. The area is not a seismic zone with a peak ground acceleration from (0.050g $\leq$ PGA $\leq$ 0.075g). Wind reference speed is a middle range speed comparing with the other part of Italy near the Mediterranean Coasts. It is very important to evaluate all the wind proprieties related to the site according to Italian Construction Regulations (NTC 2008) [3] and Eurocodes [4].

2. METHODOLOGY USED

The methodology used to complete this paper is: "desk research" and "field research". Desk research consists in reviewing the available literature which addresses issues of wind effect on the buildings. Field research consists in inspection of construction site and addressing a list of question to the architects and structural designers who have design these kind of buildings. Also using an auxiliary finite element software called 'Midas Gen' was indispensable.

3. THEORETICAL PART. WIND PROPERTIES.

The structures can be design with a semi-static equivalent method but also the structural safety and serviceability need to be designed taking in account the dynamic nature of the wind and the possible interaction.

The asses of wind load on the buildings starts with the identification of wind reference speed [v_{ref}].

Wind reference speed is defined as the maximum value of the average speed over a time interval of 10 minutes for the wind, measured 10 meters from the ground. This speed corresponds to a return period T_r = 50 years, or to a probability of being exceeded in a year equal to 2%. The site with an altitude under 1500 meter from sea level, the wind speed should not be taken less than the value given by the following expression [1]:

$$v_{ref} = v_{ref,0} \qquad a_s \leq a_o \quad (1)$$

$$v_{ref} = v_{ref,0} + k_a (a_s - a_o) \quad a_s > a_o \quad (2)$$

where:

a_s - is the altitude (m) of the site from the sea level.

$v_{ref,0}$, a_o, k_a- are parameters related to the region that includes city of Milan that is part of zone 1[3].

Area	**Description**	$v_{ref,0}$ (m/s)	a_o(m)	$k_a\ (\frac{1}{s})$
1	Valle d'Aosta, Piemonte, Lombardia, TrentinoAlto Adige, Veneto, Friuli Venezia Giulia.	25	1000	0.010

Table 1.

Return period

Wind reference speed of the $v_{R(TR)}$ refers to a generic return period T_R, is given by the expression [1]:

$$v_{R(TR)} = \alpha_R\,(T_R)\,v_{ref} \qquad (3)$$

where:

α_R - is a coefficient, which depends on the probability of the annual overflow of the wind speed$(1/TR)$.

where:

T_R = 500 years , $\alpha_R =$ 1,122;

T_R = 1000 years, α_R = 1,156;

v_{ref} - is wind reference speed for a return period of 50 years.

Wind peak velocity and Exposure coefficient

To determine the values of wind speed is essential to take in account the site where the building is located and its height from the ground.

For a ground elevation not exceeding 200 m is defined the following peak wind speed [1]:

$$v_P(z) = c_{ev}\ v_{R(TR)} \qquad (4)$$

where:

c_{ev} - is the exposure coefficient according to Italian Construction Regulation (NTC 2008) and EN 13241 – EN 12444.

Wind pressure

The wind pressure is calculated in $^{N}/_{m2}$ according to the given expression [1]:

$$p = q_{ref}\, c_{ev}\, c_p\, c_d \qquad (5)$$

Where :

q_{ref} – is the reference wind pressure calculated with the following expression:

$$q_{ref} = \frac{{v_{ref}}^2}{1.6} \qquad (6)$$

c_p - is form coefficient which depends from the geometric shape and the breadth of the structure according to the wind directions.

c_d - is the dynamic coefficient related with the non-contemporaneity of maximum wind pressure and structural vibration.

Peak kinetic pressure

Peak kinetic pressure is associated with peak wind speed [1]:

$$q\,(z) = \frac{1}{2}\,\rho\, c_{ev}\,(z)[v_{R(TR)}]^2 \qquad (7)$$

Where: ρ is the air density equal to 1.25kg/m^3

Internal and external pressure coefficient

Wind action on a single element consists in defining the critical combination of internal and external pressure.

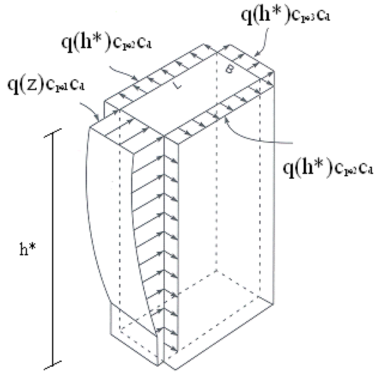
External and internal pressures are defined according to these expressions:

$$w_{ex} = q\ c_{pe}\, c_d \qquad (8)$$

$$w_{in} = q\ c_{pi}\, c_d \qquad (9)$$

c_{pe} , c_{pi} - are the external and internal pressure coefficient obtain from experimental test depending of structure form and height.

In the picture below is shown the pressure distribution on the vertical parts of the building related to story elevation. [2]



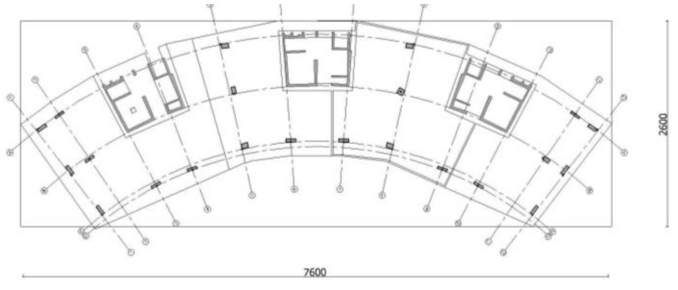
Picture 1. Pressure distribution

Due to asymmetric wind loads, torsion stresses need to be considered for buildings taller than 20 meters.

4. STRUCTURE ANALYSIS UNDER THE WIND LOADS

Structure description

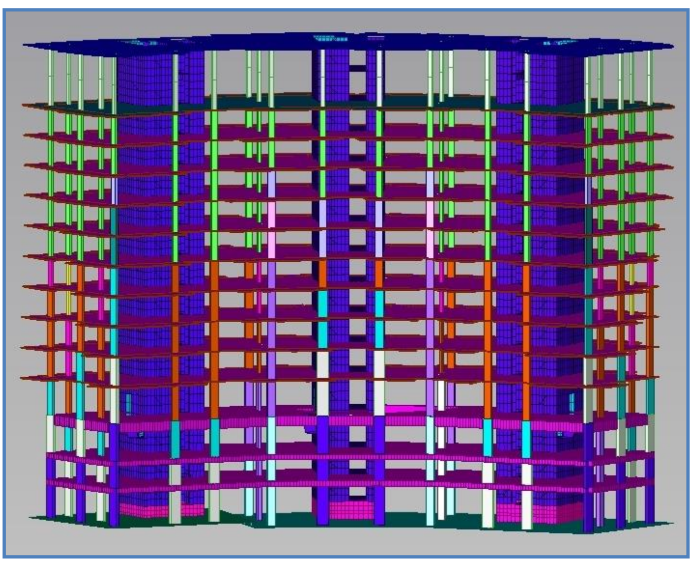
The building is a 14-storey structure with 3 underground storey and it is part of a residence located in Milan, Italy. [6] The the building plans has an opaque form and they have different shapes in height. The building has a mix reinforced concrete structure with 27 columns and 3 shear wall (cores). The horizontal elements are designed with bidirectional slabs and raft foundations where the slabs are considered infinitely rigid. [4]



Picture 2. Structure plan

Structural analysis, finite element analysis

The structural analysis under dead loads, live loads and wind loads is performed with auxiliary software MidasGen®. The modeling type is composed by 'plate' and 'beam' elements included in software library. The model of the buiding is shown in the picture belove, where all the elements has their dimensions and material caracteristics.



Picture 3. Building finite element model

The structure is calculated in Midas according to the Italian Construction Regulation NTC 2008 and Eurcodes 1 and 8. [3], [4], [5]

The ultimate limit state can be checked throught finite elements models by applying on the structure model the following load combinations [3] :

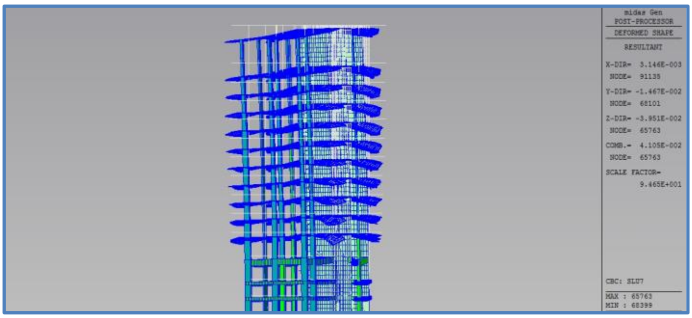
$$\Upsilon_{G1}\, G_1 + \Upsilon_{G2}\, G_2 + \Upsilon_{Q1}\, Q_{k1} + \Upsilon_{Q2}\, \psi_{02}\, Q_{k2} + \Upsilon_{Q3}\, \psi_{03}\, Q_{k3} + \ldots\ldots \quad (10)$$

Combination	Loads
SLU6	Self Weight (1.300) +Dead Load (1.300) +Parapets (1.300) +Claddings (1.300) + Gk su trave piano T (1.300) + Gk su trave piano -1(1.300)+ Wind dir. + X(1.500)
SLU7	Self Weight(1.300) +Dead Load(1.300) +Parapets(1.300) +Claddings(1.300) + Gk su trave piano T(1.300) + Gk su trave piano -1(1.300)+ Wind dir. +Y(1.500)
SLU8	Self Weight(1.300) + Dead Load(1.300) +Live Load(1.500) + Parapets(1.300) +Claddings(1.300) + Roof Load(1.500) + Gk su trave piano T(1.300) + Qk su trave piano T(1.500) + Gk su trave piano -1(1.300) + Qk su trave piano -1(1.500) + Wind dir. + X(1.050)
SLU9	Self Weight(1.300) + Dead Load(1.300) +Live Load(1.500)+ Parapets(1.300) +Claddings(1.300) + Roof Load(1.500) + Gk su trave piano T(1.300) + Qk su trave piano T(1.500) + Gk su trave piano -1(1.300) + Qk su trave piano -1(1.500) + Wind dir. +Y(1.050)
SLU10	Self Weight(1.300) +Dead Load(1.300) +Live Load(1.050) + Parapets(1.300) + Claddings(1.300) +Roof Load(1.050) + Gk su trave piano T(1.300) + Qk su trave piano T(1.050) + Gk su trave piano -1(1.300) + Qk su trave piano -1(1.050) + Wind dir. + X(1.500)
SLU11	Self Weight(1.300) +Dead Load(1.300) +Live Load(1.050) + Parapets(1.300) + Claddings(1.300) +Roof Load(1.050)+ Gk su trave piano T(1.300) + Qk su trave piano T(1.050) + Gk su trave piano -1(1.300) + Qk su trave piano -1(1.050) + Wind dir. +Y(1.500)
SLU11	Self Weight (1.000) +Dead Load(1.000) +Parapets (1.000)+Claddings(1.000) + Gk su trave piano T(1.000) + Gk su trave piano -1(1.000)+Wind dir. + X(1.500)
SLU12	Self Weight(1.000) +Dead Load(1.000) +Parapets (1.000)+Claddings(1.000) + Gk su trave piano T(1.000) + Gk su trave piano -1(1.000)+Wind dir. +Y(1.500)

Table 2. Load combinations

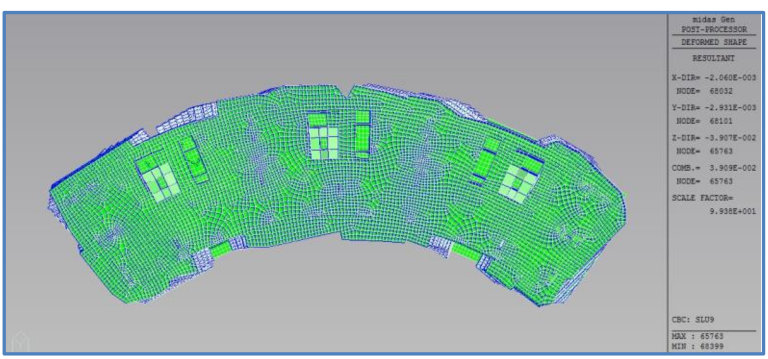
The seismic load is not included in the above combination. After the combination is applied we obtain the results and the deformed shapes of the model. According to the calculation of wind speed, dynamic wind action and building shape, the wind loads in Direction +X and Direction +Y are more effective than the other direction. Therefore we have choose to study only the load combination containing the wind loads in direction +X and +Y.

The deformed shapes and the displacements δ of the structure are shown in the following pictures:



Picture 3. Deformed shape and displacements according to SLU7 combination

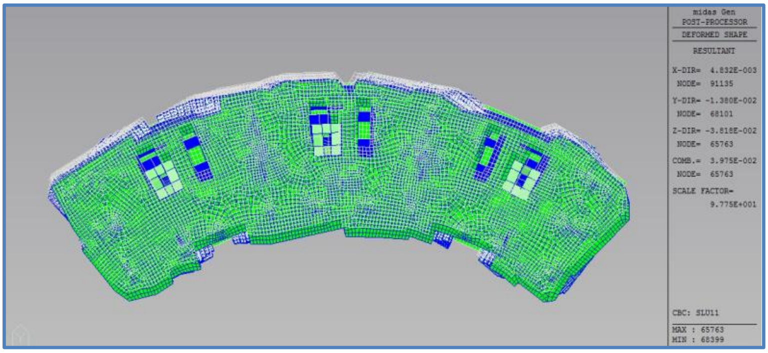
The displacement δ according to SLU2 combination in direction is: $X = 3.14 \ \cdot 10^{-3}\, m$, $Y = -1.46 \ \cdot 10^{-2}\, m$
$Z = -3.95 \ \cdot 10^{-2}\, m$, $Comb = 4.1 \ \cdot 10^{-2}\, m$



Picture 4. Displacements according to SLU9 combination, Wind Dir +Y

The displacement δ according to SLU4 combination in direction is: $X = 2.06 \ \cdot 10^{-3}\, m$, $Y = -2.93 \ \cdot 10^{-2}\, m$

$Z = -3.90 \cdot 10^{-2}\ m$, $Comb = 3.9 \cdot 10^{-2}\ m$



Picture 5. Displacements according to SLU11 combination, Wind Dir +Y

The displacement δ according to SLU11 combination in direction is: $X = 4.83 \cdot 10^{-3}\ m$, $Y = -1.38 \cdot 10^{-2}\ m$
$Z = -3.81 \cdot 10^{-2}\ m$, $Comb = 3.97 \cdot 10^{-2}\ m$

The combination SLU7, SLU9 and SLU 11 are the most unfavorable combination, with a maximum displacement in a range of 4.1 cm. This displacement occurs when the wind acts in Y+ direction perpendicular with curved part of the building. As shown above despite the wind characteristic even the structure shape is very essential, a curved shape from the inside part is more exposed from the wind pressure than another kind of structure shape.

Shear forces due to wind actions

It is very important detect the response of the structural elements from the wind loads in order to define favorite structure type. Our type of structure is a mix structure with columns and shear walls. Applying the load combination indicated in the table above we have receive results how the shear force act at the base of the building due to the wind action. So the results gained from MidasGen are:

Shear force in columns from wind action in Direction +X

Node	Load	FX (kN)	FY (kN)
68421	Wind dir. + X	-0.846658	0.51069
68449	Wind dir. + X	-1.579307	0.480815
68513	Wind dir. + X	-2.550082	1.25344
68551	Wind dir. + X	-2.991933	2.783342
68577	Wind dir. + X	-2.978638	1.797422
68625	Wind dir. + X	-6.637478	-2.86718
68697	Wind dir. + X	-5.633559	-1.896513
70769	Wind dir. + X	-4.084956	0.256067
70782	Wind dir. + X	-4.006024	0.972928
70926	Wind dir. + X	-1.175941	-0.335996
70940	Wind dir. + X	-1.549706	-1.465329
70954	Wind dir. + X	-0.669131	0.066229
70969	Wind dir. + X	-1.597311	-0.691187
70975	Wind dir. + X	-2.85756	1.17284
71012	Wind dir. + X	-0.262222	0.04051
106561	Wind dir. + X	-4.412907	-0.007497
106562	Wind dir. + X	-3.845276	0.212319
106563	Wind dir. + X	-3.08133	0.52792
106564	Wind dir. + X	-0.392292	-0.048392
106565	Wind dir. + X	-2.118005	0.415492
106566	Wind dir. + X	-3.19862	1.148174
106613	Wind dir. + X	-6.4394	-1.449748
	Load	FX (kN)	FY (kN)
$\sum Columns$	Wind dir. + X	-62.9083	2.876346

Table 3. Wind loads Dir +X in the columns

Shear force in shear-walls (cores) from wind action in Direction +X

Node	Load	FX (kN)	FY (kN)
68399	Wind dir. + X	-6.642206	4.037496
68400	Wind dir. + X	-6.520156	3.841845
68403	Wind dir. + X	-5.920017	3.470722
68405	Wind dir. + X	-6.101898	3.71619
68407	Wind dir. + X	-5.686608	3.450649
68409	Wind dir. + X	-5.331568	2.812928
68411	Wind dir. + X	-6.620217	3.544216
68413	Wind dir. + X	-5.031939	1.547634
68415	Wind dir. + X	-14.53173	3.525861
68417	Wind dir. + X	-5.02373	-1.940968
68419	Wind dir. + X	-7.834387	4.675398
68447	Wind dir. + X	-6.577331	3.368042
68479	Wind dir. + X	-7.095701	2.51394

68481	Wind dir. + X	-15.188341	2.195556
………..	Wind dir. + X	……….	…………
132411	Wind dir. + X	0.421531	-1.859873
132413	Wind dir. + X	-1.856025	2.303245
132416	Wind dir. + X	0.494551	-1.942501
132418	Wind dir. + X	-1.346341	0.860285
132421	Wind dir. + X	0.471393	-1.796449
132424	Wind dir. + X	0.194359	-0.378337
132473	Wind dir. + X	-7.653122	-1.620024
132474	Wind dir. + X	-8.482214	0.492299
132476	Wind dir. + X	-3.562012	-1.270593
	Load	FX (kN)	FY(kN)
$\sum Core$	Wind dir. + X	-1126.04	-2.876494

Table 4. Wind loads Dir +X in the cores

<u>The resultant shear force from wind action in Direction +X is :</u>

Load	FX (kN)	FY (kN)
Columns	-62.908336	2.876346
Shear-walls (Core)	-1126.04	-2.876494
$\sum$ Wind dir. + X	-1188.945355	-0.000149

The experimental results show that the shear-walls absorb 1126 KN, more than 95 % of the shear force from wind action in direction +X. The shear force in Y direction is insignificant.

<u>Shear force in columns from wind action in Direction +Y</u>

Node	**Load**	**FX (kN)**	**FY (kN)**
68421	Wind dir. + Y	-0.365871	-0.725145
68449	Wind dir. + Y	-0.196831	-1.126682
68513	Wind dir. + Y	1.660326	-5.391662
68551	Wind dir. + Y	5.025805	-9.104953
68577	Wind dir. + Y	2.268065	-5.817403
68625	Wind dir. + Y	-6.028016	-4.72704
68697	Wind dir. + Y	-4.093424	-4.913439
70769	Wind dir. + Y	-0.328776	-3.00545
70782	Wind dir. + Y	-2.8533	-1.412392
70926	Wind dir. + Y	-0.262655	-2.391232
70940	Wind dir. + Y	-2.919813	-5.340115
70954	Wind dir. + Y	1.066095	0.499621
70969	Wind dir. + Y	-0.803495	-2.582798

70975	Wind dir. + Y	2.078905	-1.850555
71012	Wind dir. + Y	0.662991	0.064199
106561	Wind dir. + Y	-0.262485	-0.990305
106562	Wind dir. + Y	0.31383	-1.138636
106563	Wind dir. + Y	1.056246	-1.57011
106564	Wind dir. + Y	0.144743	0.481158
106565	Wind dir. + Y	1.135618	-0.260303
106566	Wind dir. + Y	2.21522	-1.839671
106613	Wind dir. + Y	-13.82262	-3.292384
	Load	FX (kN)	FY(kN)
∑ Columns	Wind dir. + Y	-14.309442	-56.435297

Table 5. Wind loads Dir +Y in the columns

Shear force in shear-walls (core) from wind action in Direction +Y

Node	**Load**	**FX (kN)**	**FY (kN)**
68399	Wind dir. + Y	-3.710087	-5.116103
68400	Wind dir. + Y	-2.792985	-6.734333
68403	Wind dir. + Y	-1.688796	-7.671727
68405	Wind dir. + Y	-4.129657	-4.372974
68407	Wind dir. + Y	-0.550493	-8.38428
68409	Wind dir. + Y	-3.504336	-8.35904
68411	Wind dir. + Y	0.71826	-9.539092
68413	Wind dir. + Y	-5.595751	-18.597555
68415	Wind dir. + Y	3.153021	-13.905521
68417	Wind dir. + Y	-14.674947	-49.30217
68419	Wind dir. + Y	1.502684	-10.820265
68447	Wind dir. + Y	1.072996	-10.502819
68479	Wind dir. + Y	3.378817	-10.407089
………	……………..	…………	………….
132402	Wind dir. + Y	4.132314	2.73843
132403	Wind dir. + Y	0.355559	0.303504
132404	Wind dir. + Y	-2.183286	-2.223224
132405	Wind dir. + Y	-7.090192	-8.610901
132410	Wind dir. + Y	3.951148	-12.443944
132411	Wind dir. + Y	0.033619	-2.762322
132413	Wind dir. + Y	3.622716	-3.017302
132416	Wind dir. + Y	-2.171302	2.061599
132418	Wind dir. + Y	4.413392	-0.336379
132421	Wind dir. + Y	-3.997563	3.915308
132424	Wind dir. + Y	8.764438	-22.529369
132473	Wind dir. + Y	17.14272	3.26905
132474	Wind dir. + Y	18.596837	-3.411718
132476	Wind dir. + Y	8.980452	3.604369
	Load	FX	FY

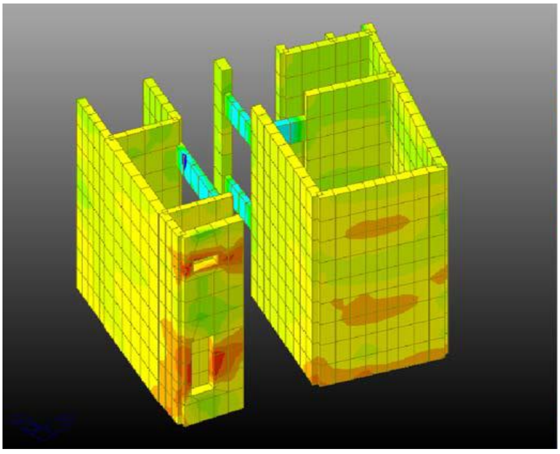
		(kN)	(kN)
∑ Core	Wind dir. + Y	14.309048	-3471.124325

Table 6. Wind loads Dir +Y in the cores

<u>The resultant shear force from wind action in Direction +Y is :</u>

Load (Wind)	FX (kN)	FY(kN)
Columns	-14.309442	-56.435297
Shear-walls (Core)	14.309048	-3471.124325
∑ Wind dir. + Y	-0.000395	-3527.559624

Also the evaluation of the above data extracted from Midas Gen , shows that the shear-walls absorb 3471 kN, the equivalent of 98 % of the shear force. Comparing with the shear force induced from the wind in Direction +X, the shear force induced from the wind in Direction +Y is more effective with a difference of 2399 kN. Wind action in direction +Y generate more shear strength, so for the designing of the shear-walls more attention is needed from the designer.



Picture 6. Shear-wall stress effect from wind loads in Y direction

During design of cores in Midas Gen we have accepted some simplifying assumptions in order to increase the security level of the calculation by:

-Neglecting the axial force, because the axial force increase the shear strength of the shear walls.
-Neglecting some secondary structural membrane.

So the wind horizontal action into the shear-wall is more persistent than the other loads and induce to the building cores severe additional stress. The shear stress especially are localized on the base of the cores and in the part were the exterior shape of the building is not regular and with curved surface. Aslo as seen in the picture on the last floor (Penthouse) the shear-stress are apparent.

5. CONCLUSION

Wind load is very essential to be evaluated during the design of a building in non-seismic zones. Before starting to design a high-rise reinforced concrete structure it very important to know the wind characteristics of the area. Conducing a good study to determinate the wind dynamic actions (wind reference speed, wind peak velocity and related coefficient) can bring to the designer important information in order to design a secure structure not only from the seismic action. Evaluating the structural response of the buildings from aerodynamic forces is essential to determinate the serviceability and performance capabilities of them. The forms and the height of the building can increase the vulnerability of it from the wind loads. Designing an aerodynamic structure decreases the wind effectiveness and the fatigue of the structural elements in static conditions. Structure with curved plans is not advisable to be built in zones with a high intensity of wind action, especially when the curved part is perpendicular with the direction of the maximum wind load. Shear force on the base of the building especially exercises its strength in the shear-walls, so special attention is needed during the calculation and setting the positions of the shear–walls inside the structure plan. The cores reduce significantly the displacement of the building due to the wind loads. Columns element play an insignificant role in absorbing the shear force from the wind action.. The auxiliary finite element software conduced to accurate results to assess the wind actions in every structural elements. Also the software help to make the right correction of the structural elements dimensions and positions in order to save material and to make a secure structure.

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