A vision towards a performance-based design approach for tall structures merging wind and seismic effects.

Amaya Ballate Delgado[1,2], Ashraf El Damatty[1,3], Patricia Martín Rodríguez[2]

[1] Department of Civil and Environmental Engineering,
The University of Western Ontario, London, Ontario, Canada

[2] Department of Structures, Faculty of Civil Engineering.
Technological University of Havana ¨Jose Antonio Echeverría¨, CUJAE, La Habana, Cuba.

[3] WindEEE Research Institute,
The University of Western Ontario, London, Ontario, Canada

About me

BASc: Civil Engineering

Technological University of Havana ¨Jose Antonio Echeverría¨, CUJAE, La Habana, Cuba. (2017)

MSc: Civil Engineering

Technological University of Havana ¨Jose Antonio Echeverría¨, CUJAE, La Habana, Cuba. (2021)

PhD. student

Dual Degree PhD Program CUJAE - Western University

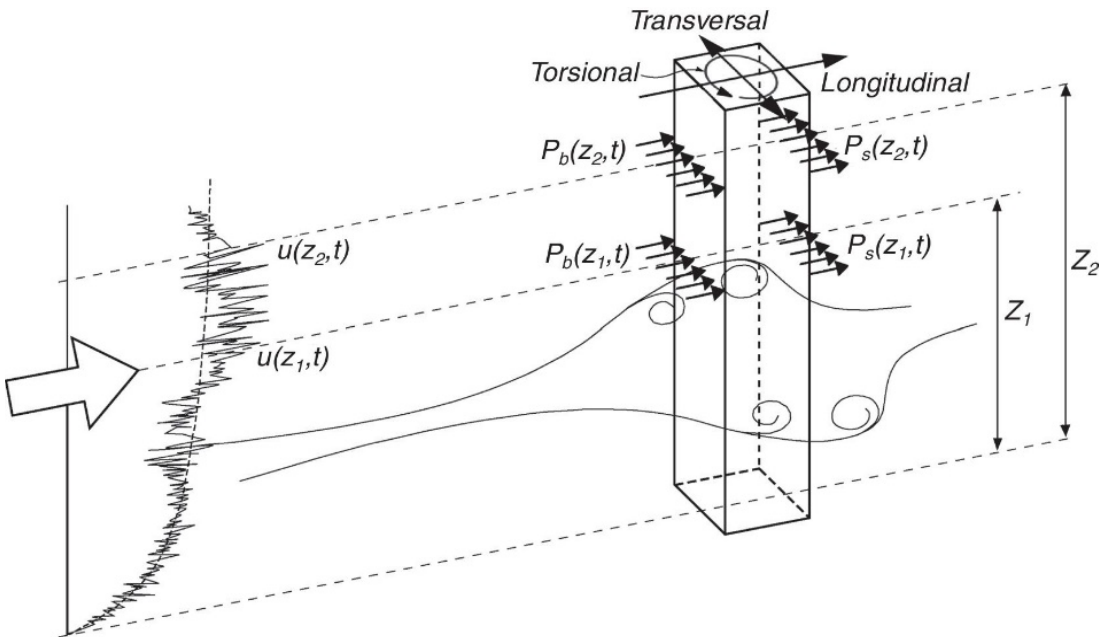
Canadian Queen Elizabeth II Diamond Jubilee Scholarship (QES).

Agenda

- Background
- Framework for the ductility based approach for wind design. Results and Discussions.
- Future research and Objective.

Background

Limitations of the current design of tall buildings under wind loads



The **plastic capacity** of the structural systems is ignored. Tall uneconomical buildings with an excessive margin of safety.

The implied margin of **safety against damage and collapse due to very severe windstorms** exceeding factored design wind loads is not exactly known.

Additional uncertainties due to the **dynamic characteristics** of contemporary tall buildings are not taken into account.

PERFORMANCE BASED WIND DESIGN (PBWD)

Background

Seismic design

Ductility based approach

↓

Allows inelastic actions to take place in the structure under extreme seismic events.

Elastic force → Reduced by a load reduction factor

Ductility capacity needs to be achieved by the structure.

Wind design

Application of a similar concept in wind engineering

- the structure always possesses a certain level of ductility that the wind design does not benefit from.
- trend in the design codes to increase the return period used in wind design

Reduction factor is applied to the resonant component of the wind response.

Framework

Elezaby, F., & Damatty, A. E. (2020)

Step I: Conduct wind tunnel pressure test - Evaluate $C_p(t)$, $F_x(t)$ & $F_Y(t)$

Step II: Develop 3-D Finite element model – Evaluate natural frequencies and mode shapes.

Step III: Evaluate Total, Mean, Background and resonant component ($V_T(t)$, V_{mean} ,$V_{BG}(t)$, $V_R(t)$)

- Dynamic time history analysis – Evaluate
- Quasi-static analysis – Evaluate $V_{mean} + V_{BG}(t)$
- Evaluate $V_R = V_T(t) - [V_{mean} + V_{BG}(t)]$

Step IV: Ductility design approach- $V_{T\text{-}I}(t) = V_{mean} + V_B(t) + V_R(t)/\mathbf{R}$

- Reduced Wind resonant component
- Redesign shear wall on reduced load

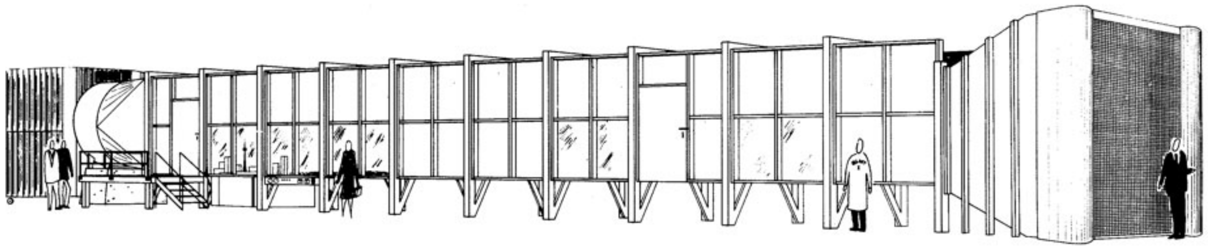
Step V: Check the dynamic characteristics of the building with the new design

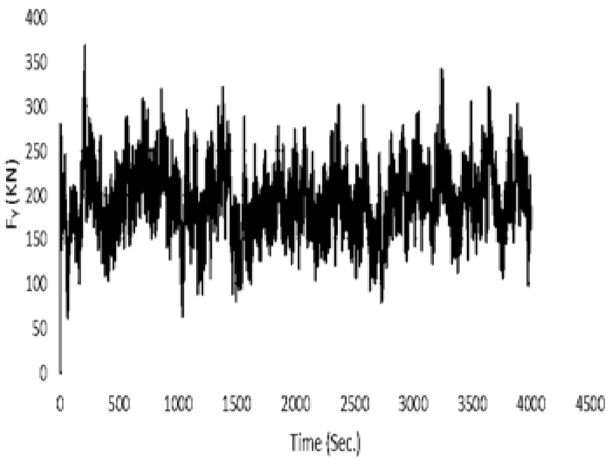
Step VI: Check if the structure possesses enough ductility to justify the reduction of load - Assess the inelastic actions

Case of study: 65 story (232 m) reinforced concrete building.

Processing of wind functions (Step I)

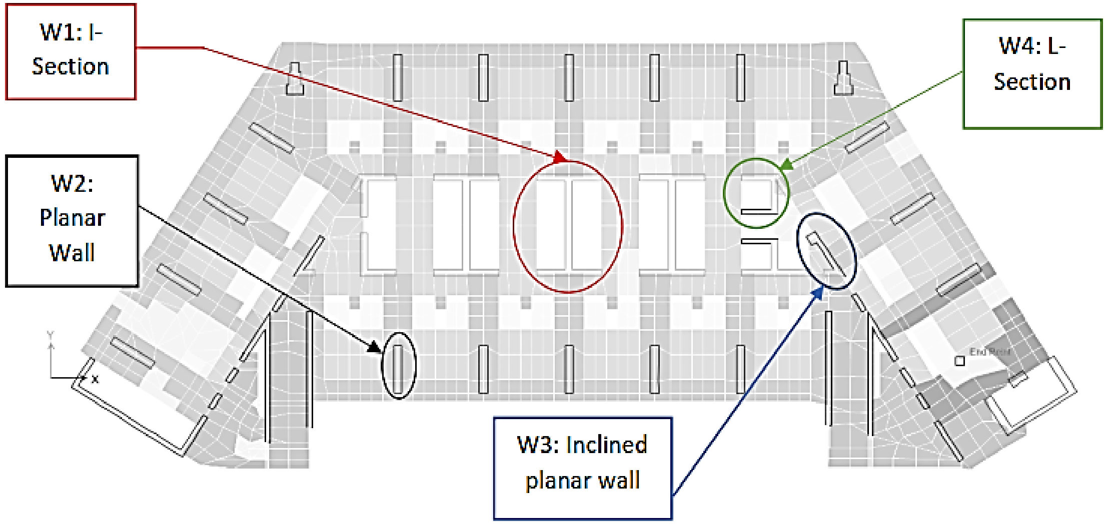
Experimental wind tunnel data- University of Western Ontario





High-frequency pressure integration (HFPI) technique

3D Finite element model (Step II)

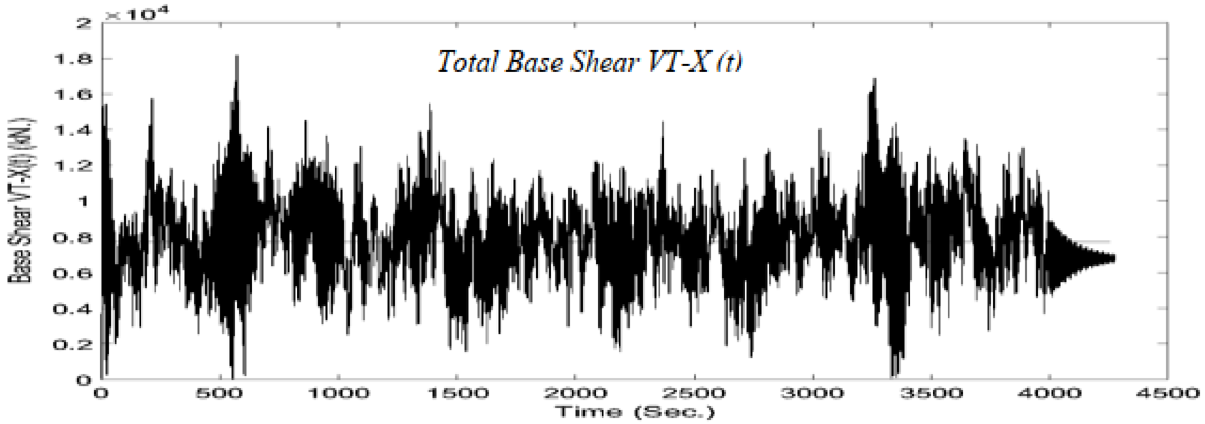


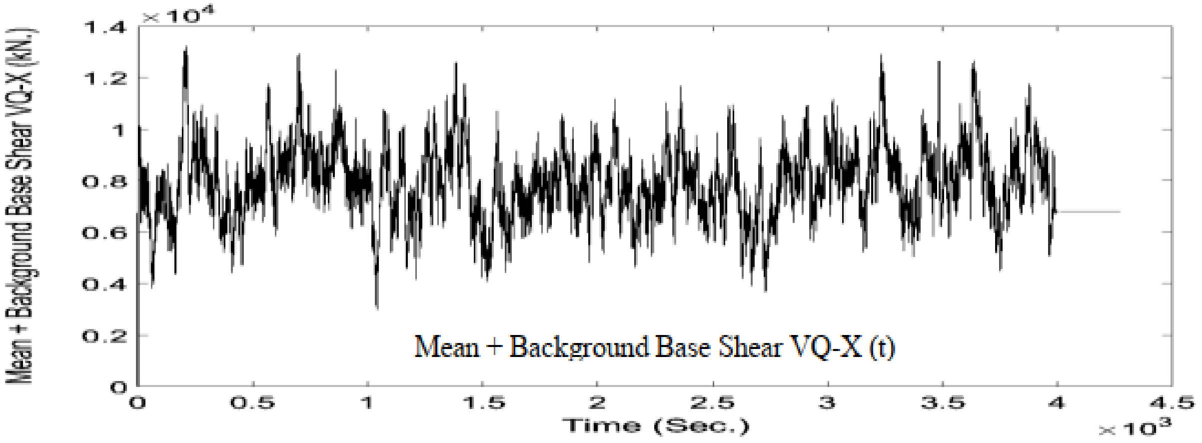
The wind tunnel measurements are used to estimate the **mean**, time-varying **background** component and the time varying **resonant** component

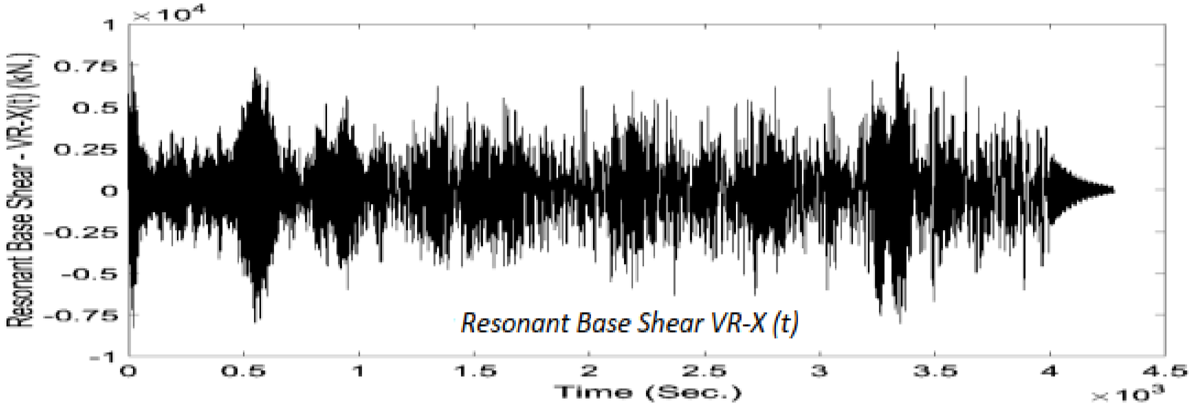
Building layout (ETABS)

(Step III)

Resonant component → Load reduction factor (R=2) → **New set of reduced straining actions**







(Step IV, V)

Redesign of the building

Smaller structural elements

Increase of the building flexibility

	Elastic				Inelastic 1		Inelastic 2	
	M_m	M_B	M_{R-e}	M_{T-e}	M_{R-ine1}	M_{T-ine1}	M_{R-ine2}	M_{T-ine2}
Moment Planar section (W1) (1)	7046	5316	8918	21280	4459	16821	4305	16148
Moment I-Section (W2) (2)	168338	90643	189644	448626	94822	353804	91976	343189

(1) Elastic Thickness: 500 mm; Inelastic Thickness: 350 mm.

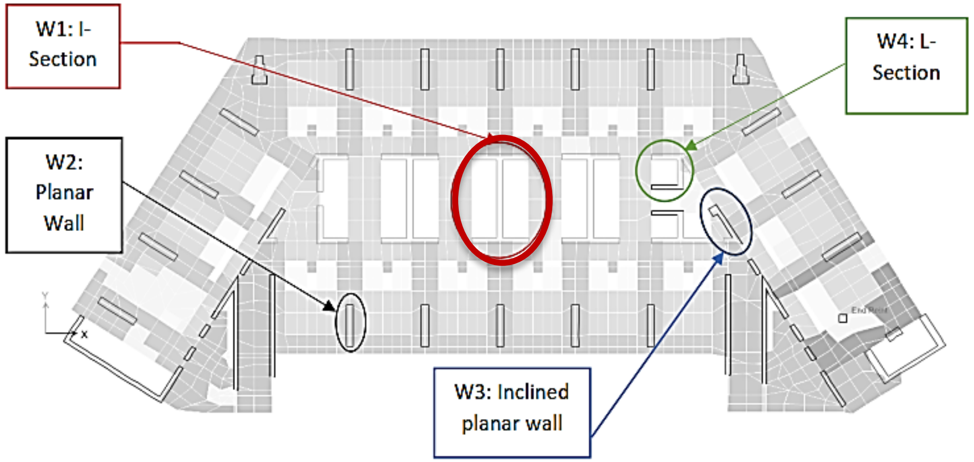
(2) Elastic Thickness: 350 mm; Inelastic Thickness: 280 mm.

(Step VI)

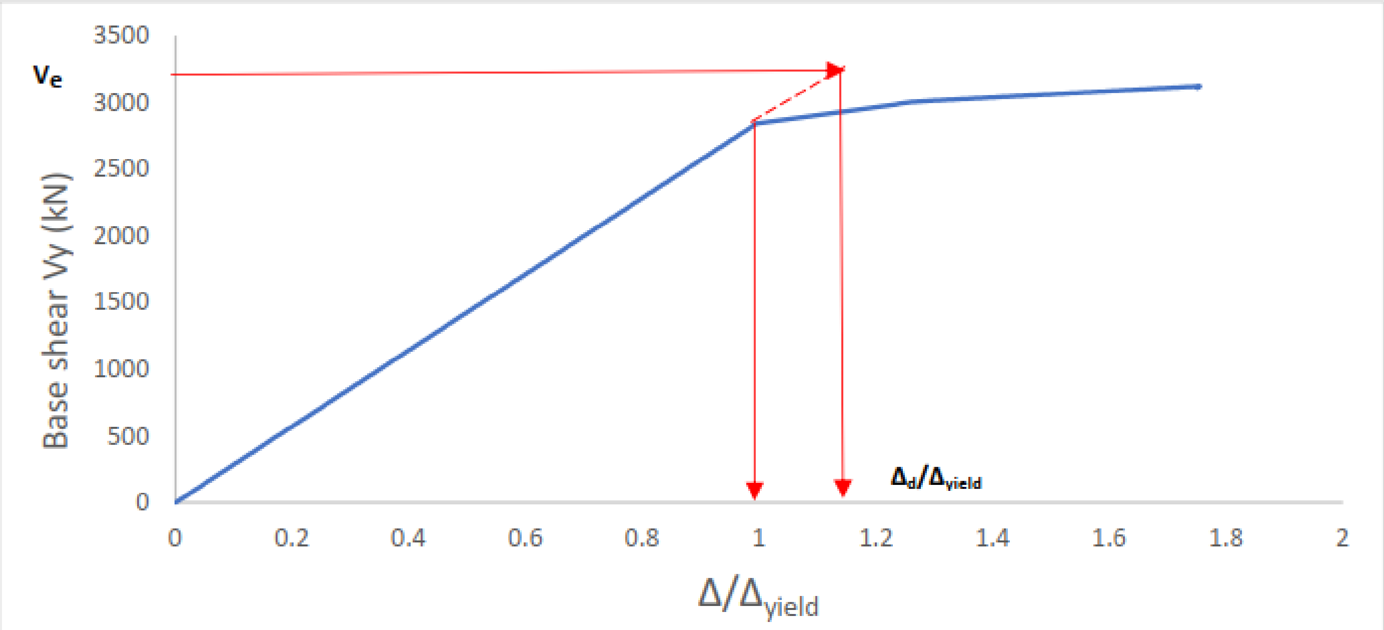
Assessment of Ductility Demand of Individual Walls and Achieved Performance Level.

Assessment of the ductility demand (Step VI)

The element is simulated using two-dimensional finite element modeling.

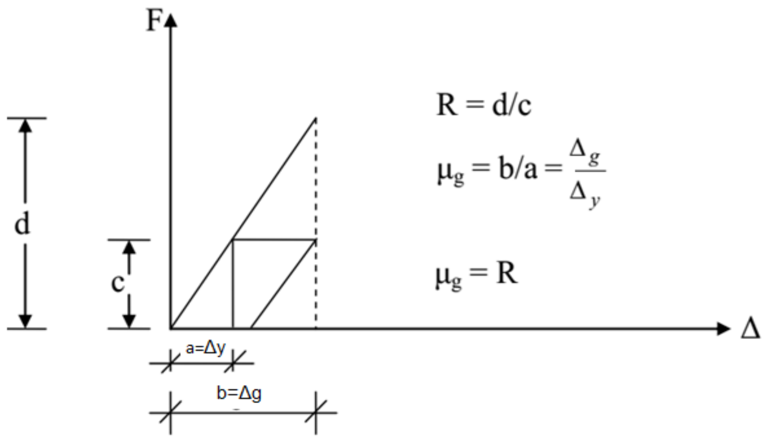


Nonlinear static pushover analysis is conducted separately for each shear wall with reduced cross sections.

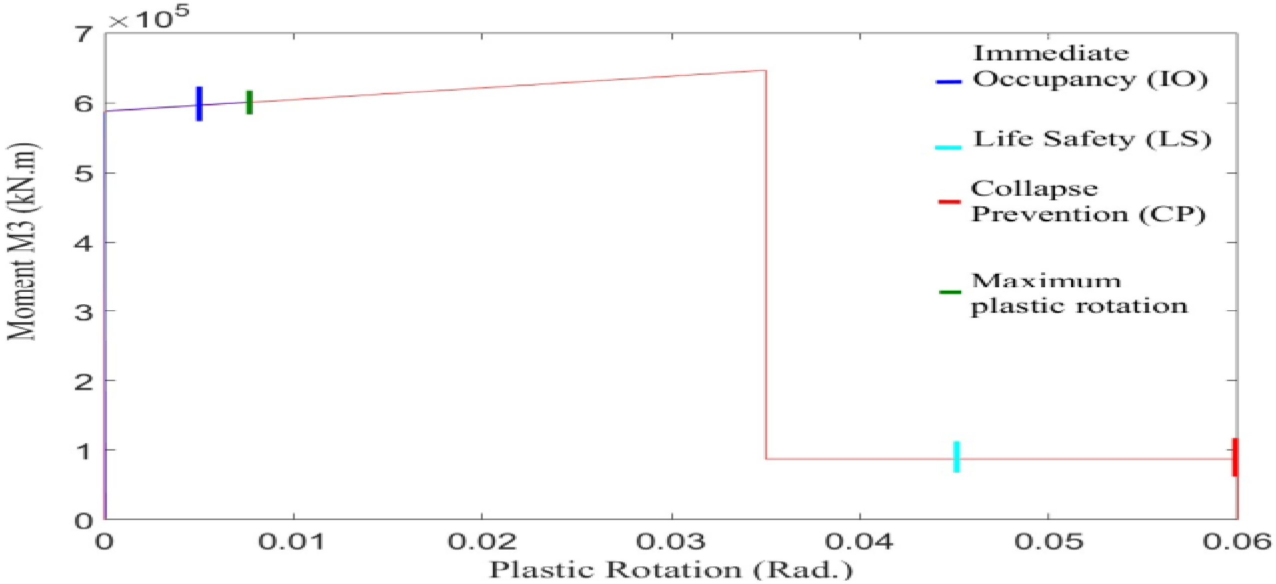


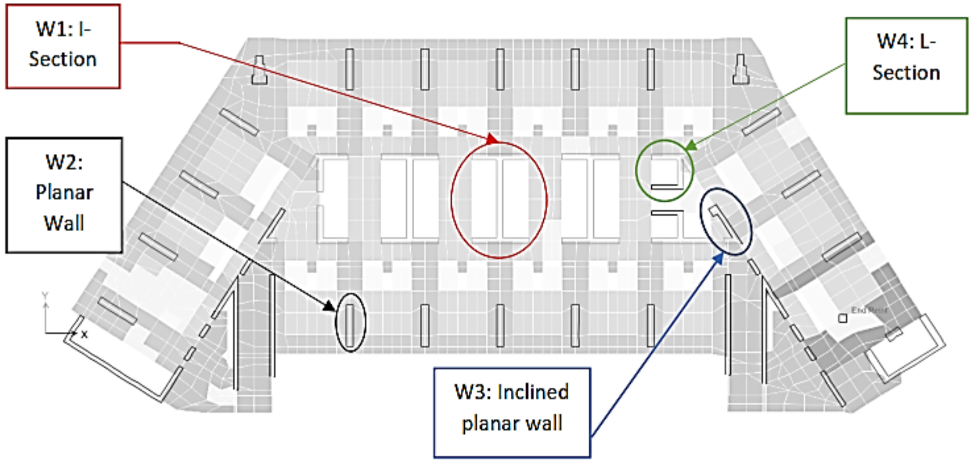
Pushover Load-Displacement Curve for I-Section Shear Wall

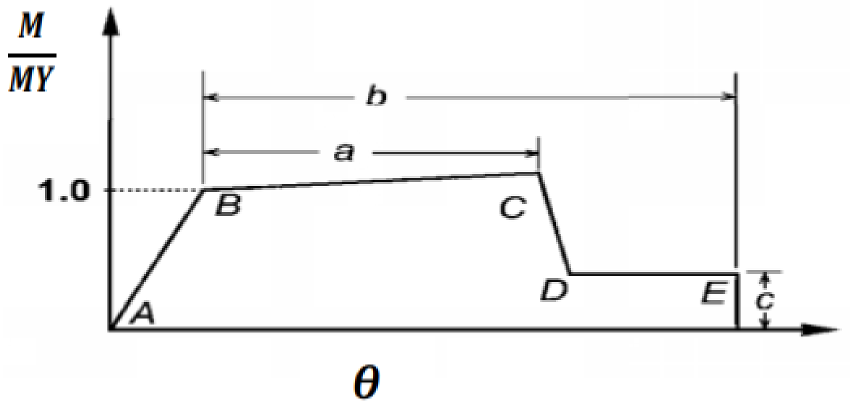
Adopting the concept of equal displacements.



Assessment of the ductility demand (Step VI)







Shear Wall Module	Ductility Demand (μ)	Plastic Rotation (Θ_p) (rad.)	Performance Levels		
			Ductile	Moderate Ductile	Limited Ductile
I – Section (W1)	1.17	0.008	Between IO and LS	Between IO and LS	Between IO and LS
Planar Wall (4200 mm long) (W2)	1.3	0.004	Smaller than IO	Smaller than IO	Between IO and LS

Conclusions of this study

The case study results shows that by reducing wind resonant component by a factor of “2” and redesigning the walls, their dimensions are reduced by 20-25% with no major change in the fundamental period.

The ductility demands for all individual walls resulting from the reduction of the cross sections were found to vary between 1.17 and 1.25.

The results revealed that even with limited ductility design, the reduction of the resonant loads by a factor of 2 was associated with a performance level for all walls lying between the Immediate Occupancy and the Life Safety limits.

Future research

Establish controlled inelasticity limit states for wind design of tall buildings through physical experiments, nonlinear aeroelastic wind tunnel tests and numerical studies.

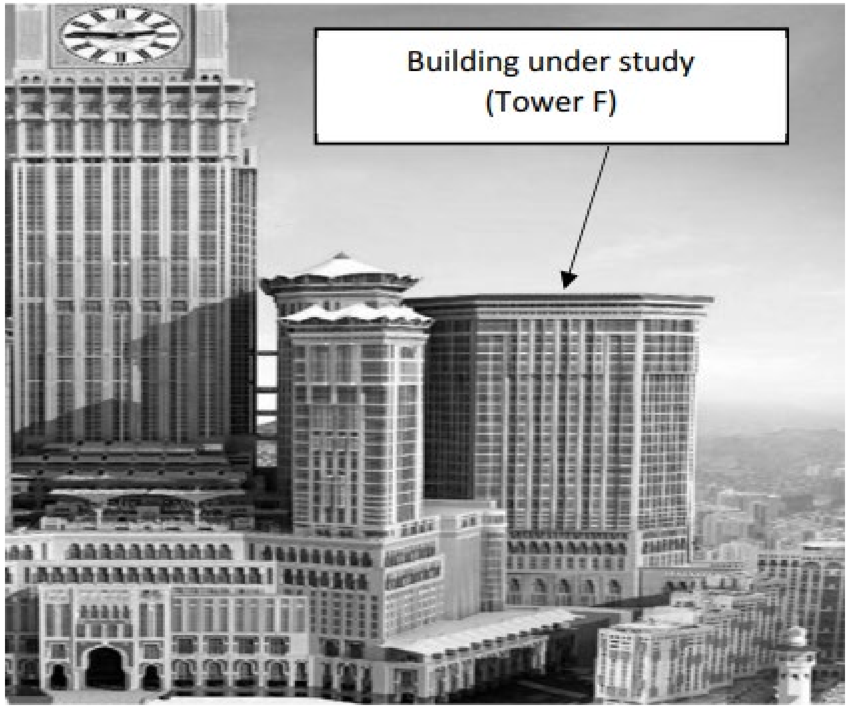
To study the influence of the inelastic response of single and multiple degree-of-freedom systems under wind loads of the following parameters:

- Fundamental period
- Damping
- Post-stiffness yield ratio
- Turbulence intensity
- **Mean wind velocity**

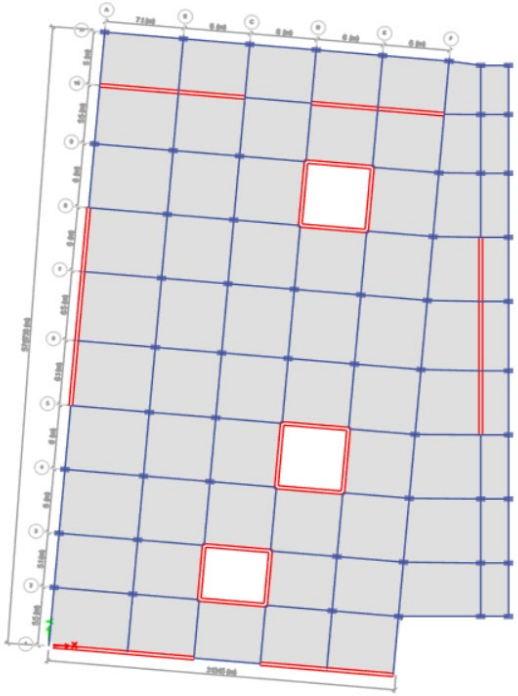
- Number of inelastic cycles
- Degradation of element strength and stiffness
- Generates the presence of large values of residual deformations

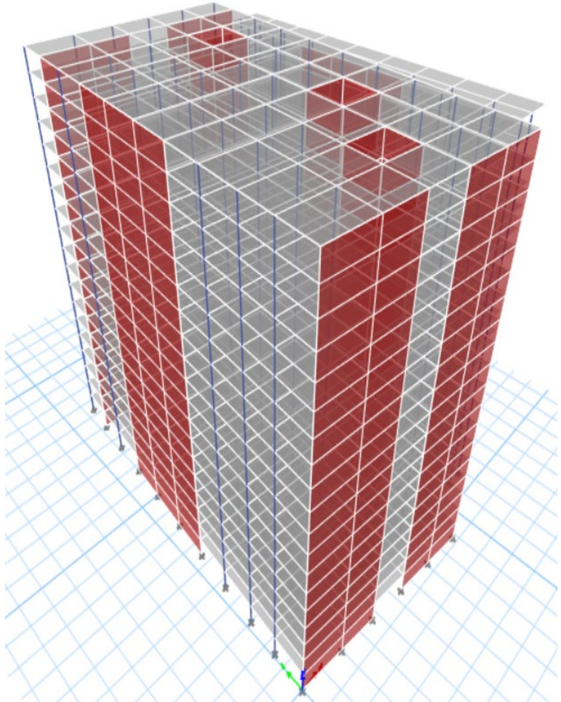
Overall objective

Determine the influence of the mean wind speed on the nonlinear behavior of tall reinforced concrete buildings when the PBWD methodology is applied.



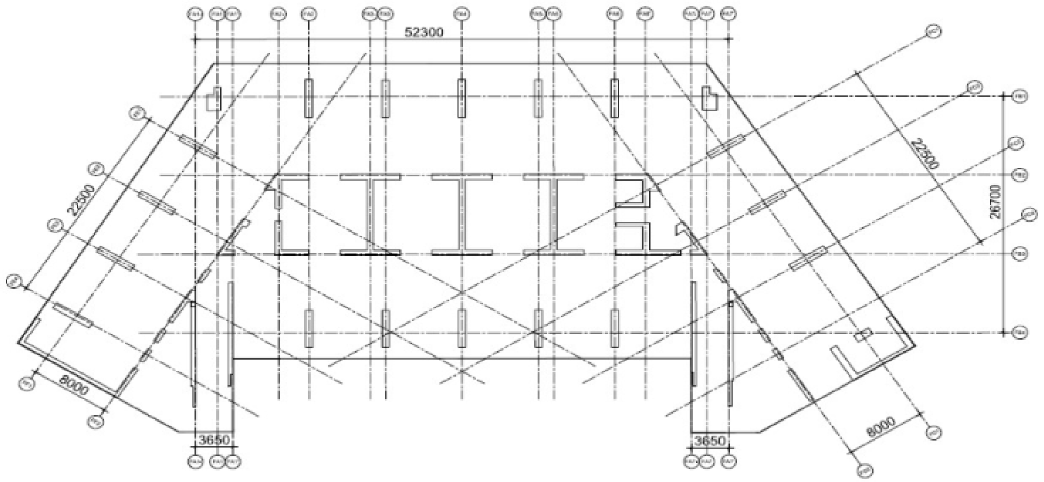
- 65 stories with a total height of 232 m





- Reinforced concrete building 57 m high (19 stories).

Future research



Extend the Elezaby, F., & El Damatty, A. investigation based on the same concept of equal displacements.

- Assessment of the change of the **wind speed** and **reduction factors.**

Full nonlinear dynamic analysis

- Assess inelastic behavior

Require the determination of the hysteresis behavior of the lateral loads resisting systems under simulated wind loads.

Thank you