Challenges in Wind Engineering in Shenzhen Pingan International Financial Center

深圳平安国际金融中心项目中风工程的挑战

Jon Galsworthy, Ph.D., P.Eng., General Manager, Principal at RWDI

Xiangdong Du, Ph.D., P.Eng., Principal at RWDI
杜向东，博士，注册工程师，RWDI董事，技术总监
Ping An Financial Center, Shenzhen

Design Architect: Kohn Pederson Fox   Structural Engineer: Thornton Tomasetti
Wind Storms in the Pearl River Region

Typhoon Utor, 2013

Typhoon Vicente, 2012

Tornado, 2002

All images from Hong Kong Observatory, http://www.hko.gov.hk
Shenzhen Pingan International Financial Center (PIFC) is the highest world’s tallest building in strong typhoon areas, wind impact and safety are critical challenges to achieve a viable design of buildings. At design stage, detailed studies about architectural shape and structural properties are discussed by RWDI, architect KPF and structural engineer TT in order to achieve a safe, feasible and economical design.

深圳平安金融中心是世界上在强台风影响区最高的建筑，抗风是得到经济合理的建筑设计的一个十分关键的因素。在设计阶段，RWDI与建筑设计师、结构工程师TT紧密合作，对建筑外形、结构特性进行了详细研究，得到了安全、合理和经济的设计。
Summary of Wind Engineering Studies:

A number of state of the art of technologies were conducted, including:

1. A combination of meteorological analysis and typhoon simulation applied in wind climate.
2. Optimized wind-resistance shape by architects and wind engineering consultants.
3. Comprehensive modern and advanced wind tunnel test methods (including HFFB, Aeroelastic model, cladding pressure, PLW, etc.) were conducted.
4. The state-of-the-art method of statistical analysis techniques and upcrossing method was combined with test results.

世界上最先进的技术均的到了合理的实施, 包括:

1. 风气候中应用了气象分析与台风模拟相结合；
2. 在建筑设计阶段，建筑师与风工程专家讨论了建筑体型，利用了优化的抗风体型；
3. 最为重要的是风洞试验中，多种现代先进的试验方法（包括高频天平、空气弹性响应模型模拟、幕墙风压测量、人行风环境测量等）得到的应用；
4. 先进的统计分析方法跨越概率法与试验结果想结合，得到了优化的最终结果，在设计中得到应用。
**Wind Climate 风气候**

RWDI investigated data from Shenzhen weather station, observed that the data have certain flaws.

1. Shenzhen weather station was founded in 1953, its meteorological equipment and measuring methods both satisfy criteria, but it was built on a small hill.

2. The fast development of Shenzhen City in recent 20 years.

3. RWDI对深圳气象台的数据进行了调研，发现气象台的数据有一定的缺陷。

4. 深圳城市的高速发展。
Wind Climate 风气候

RWDI processed comprehensive detailed analysis by using local meteorological data and modern advanced typhoon simulation techniques, the most reasonable data of local wind speed and wind direction data were obtained for different return periods.

在对深圳平安国际金融中心的设计阶段，RWDI 利用当地的气象数据与现代先进的台风模拟技术，进行了综合详尽分析，得到了最为合理的当地的不同重现期的风速风向数据。
**Wind Climate 风气候**

RWDI adopted the most advanced research methods in the world, the typhoon simulation results from ARA (American Research Association), combined typhoon simulation results and meteorological data, scientific and reasonable wind speed and wind direction results can be obtained.

RWDI采用了世界上最先进的研究方法，美国研究所ARA的台风模拟结果，将台风模拟的结果与气象资料相结合，得到了科学合理的风速风向结果。
Shape Optimization for Winds:

In the concept phase of structural design, KPF and RWDI had discussed relevant contents, plan about structural aerodynamic optimization had been discussed, and the architectural appearance finally chosen achieved effect of reducing wind-induced response.

外形抗风：

在建筑设计的概念阶段，KPF与RWDI进行了相关的讨论，关于体型空气动力优化的方案，最终选择的建筑外形（包括建筑体型向上收进和角部退台等），最终达到了降低风致响应的效果。
Vortex Shedding in Nature

Alternating Side Force

Wind Direction
Across Wind Effects 横风响应

The influence caused by wind on super high-rise buildings is significant, mainly because of across wind effect by vortex shedding formed when wind cross through buildings, results in a strong excited force moves from side to side on super high-rise building, causes lateral dynamic response on structure.

即当风流过建筑时，会形成较强的涡旋脱落，在建筑侧面形成周期性的压力变化，从而导致超高层建筑受到强烈的左右摆动的激振力，导致结构产生横向的动力响应。
Shape Optimization for Winds: 外形抗风： Shanghai Center

Tapered Box

100° Configuration

110° Configuration

120° Configuration

180° Configuration

Final Configuration
Shape Optimization for Winds: 外形抗风:

Taipei 101

Architect: C Y Lee & Partners
Engineer: Thornton Tomasetti / Evergreen
Shape Optimization for Winds: 外形抗风:

1. Cross-section changes with height.
2. Stepped corners

外形抗风：

首先深圳平安国际金融中心大厦沿高度向上收进，其次，在建筑角部采用了退台的设计，
**Wind Tunnel Test:** 风洞试验:

RWDI's boundary layer wind tunnel facility simulates the mean speed profile and turbulence of the natural wind approaching the modeled area by having a long working section with a roughened floor and specially designed turbulence generators, or spires, at the upwind end. Floor roughness and spires have been selected to simulate four basic terrain conditions, ranging from open terrain, or water, to built-up urban terrain.

边界层风洞是通过具有粗糙地板的较长工作段和上风口特殊设计的紊流尖劈来模拟自然风场的平均风速剖面和紊乱度。特殊设计的四种粗糙地板和紊流尖劈组合可模拟四种基本的地貌，包括开阔地貌（或水面）到已充分开发的市区地貌。
Wind Tunnel Test
风洞试验
**HFFB Study**

下图给出总风荷载随风向的变化。由于较好的几何外形，平安国际金融中心塔楼的风荷载小于一般的长方形柱体结构。特别是楼角外形、大楼上部收缩并改变切角、以及使大楼表面粗糙的竖直构件等都使得横风向荷载降低。

The figure below shows the overall wind-induced loads for each wind direction are presented. The corner geometry over the extent of the building, the tapering and change to a chamfer detail near the top of the building, and the vertical surface elements which roughen the tower surface all have the effect of reducing the across-wind loading.
Aeroelastic Model Test
气动弹性模型研究

The aeroelastic model, being elastic, moves in a similar way to the real building, and this allows motion-dependent aerodynamic forces to be included in scale model simulation.

气动弹性模型在风场中的振动情况与实际结构相似，由此能模拟由结构振动引起的气动力部分。
Cladding Wind Pressure
幕墙风压试验:
Shenzhen Pingan IFC Building is located at Shenzhen city center, which means its surrounding environment is very complicated. When a strong wind is blowing, it will be influenced by surrounding buildings and will lead to the production of complex turbulence in flow and flow acceleration. Wind tunnel test can simulate surrounding buildings, then achieve accurate wind pressure distribution information.

深圳平安金融中心大厦在深圳市区，周边环境十分复杂，当强风吹来是，会受到周边建筑的影响，会产生复杂的湍流扰流和流动加速，风洞试验可以模拟周边的建筑，从而准确获得风压分布的信息。

© Council on Tall Buildings and Urban Habitat
Strong upper level winds are directed to grade level by tall buildings. Winds can be channelled between tall buildings.

Wind conditions for Pedestrians and Patrons
结果及讨论Results and Discussion:

Pedestrian comfort, in terms of wind speed and direction at street level, tower entrances, and so on, are simulated and the comfort level of the wind environment in these areas are assessed.

高层建筑引起的风环境问题越来越受到设计师和业主的重视，高层建筑高度和周边建筑的影响，建筑的周边风速有时会很高，这主要是由于几个原因（图11）：

a) 高层建筑在上面对风起到阻挡，导致风的下洗加速的现象；b) 建筑之间的空间产生峡谷流加速。
此项研究对该建筑项目屋面和周围的人行区域的风速和风向进行模拟，从而对风舒适性与风安全性分别做出评估。
Modelling of 60m Spire
Conclusions
During the study process leading up to the design of the nearly 600-meter Shenzhen Pingan International Financial Center, architects, structural engineers and wind engineering consulting engineers cooperated very closely. Safe, feasible structural and cladding wind environment design parameters were achieved by comprehensive, systematic and well-established wind engineering studies, including:

• Applications of advanced climatic simulation analysis techniques, including typhoon simulation and extreme value statistical analysis. This produced accurate wind climate data, which is the key point of wind engineering studies.

• The optimization and selection of architecture shapes, which were applied on Shenzhen Pingan IFC to overcome the influence of crosswind response effectively, reduce wind load and provide design basics for constructing a 600-meter super high-rise building in typhoon zone.

• Overall wind tunnel testing, which provided the basics of structure and cladding design, including the simulation of surrounding buildings to avoid the uncertainties produced by the nearby environment.

• A pedestrian wind study, which verified whether the wind environment near the building would satisfy requirements.

Conclusion
在对近600米的深圳平安国际金融中心超高层大厦的研究中，风工程顾问工程师与建筑师和结构工程师紧密配合，通过综合的、系统的和完善的风工程的研究得到了安全、合理的结构、幕墙风环境的设计参数，其中包括：

1. 运用世界上先进的气候模拟分析技术，包括台风模拟、极值统计分析，得到合理的风气候数据，这是风工程研究的关键基础。

2. 对建筑的体型的选择和优化在深圳平安国际金融中心的到了应用，有效地克服了高层建筑中常见的横风响应的影响，降低了风荷载，为在台风影响区内建成600米的超高层建筑提供了设计基础。

3. 全面的风洞试验为设计提供了结构和幕墙的设计依据，对周边建筑的模拟避免了周边影响所带来的不确定因素。

4. 人行风环境的研究证实建筑周边的风环境还是满足各项要求的。