Total Engineering Solution in Wind Engineering & Vibration Control

TESolution. Co.,Ltd.

www.tesolution.com

TE Solution

Total Engineering Solution
in Wind Engineering and Vibration Control

TESolution Specialties

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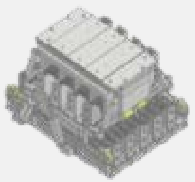
Total Engineering Solution in Wind Engineering & Vibration Control



Vibration Control Devices

▶ Passive, Active & Semi-Active Control

-Tuned Mass Damper
-Active Mass Damper
-Hybrid Mass Damper
-Stockbridge Damper for Cables

Wind Tunnel Test for Buildings

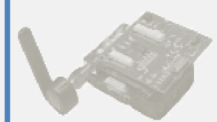
▶ Wind Tunnel Testing & Analysis

-High Frequency Force Balance Test
-Cladding Pressure Test
-Aeroelastic Model Test
-Pedestrian Level Wind Environment Test
-Topography Model Test

Wind Tunnel Test for Bridges

▶ Wind Tunnel Testing & Analysis

-Section Model Test
-Full Bridge Model Test
-Pylon Model Test
-Buffeting Analysis
-Flutter Analysis
-Cable Model Test & Analysis

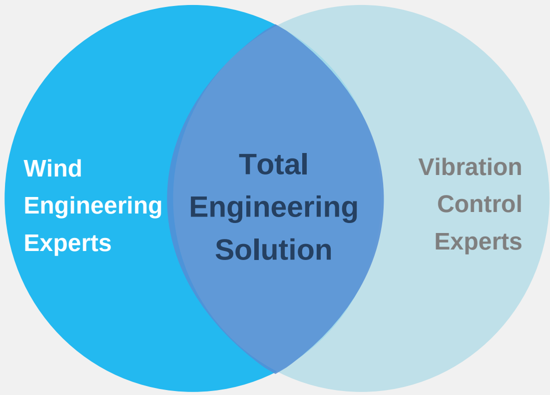


Analytics of Wind & Vibration

▶ Analytics of Wind & Vibration

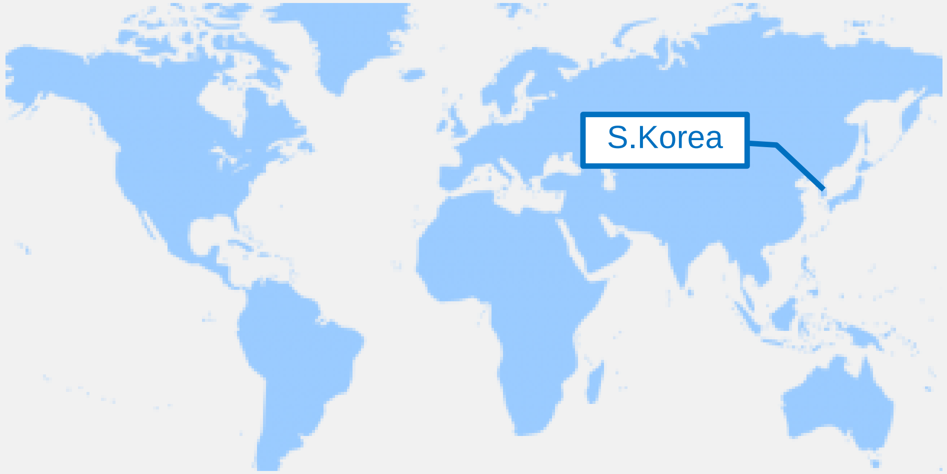
-Wind Climate Analysis
-Computational Wind Engineering
-Vibration Test of the Structure
-System Identification of Structure
-Wireless Smart Sensors
-Structural Health Monitoring

[People]



"We strive to provide
Total Engineering Solution in Wind Engineering & Vibration Control."

[Location]



142 Seungjin-gil, Gongdo-eup, Anseong-si, Gyeonggi-do, 17563 Korea

TESolution Company History

2001 Foundation of TESolution

2003 Installation of Korea's first TMD on bridge during construction (2nd Jindo Bridge)

2004 Installation of Korea's first TMD on residential building (Centum City, Busan)

2005 Moved HQ to Anseong with new office building and wind tunnel facilities

2007 Installation of the first AMD in Korea (Lotte-Hotel Ulsan)

2010 Installation of the biggest TMD in Korea (160t. Posco E&C HQ)

2011 Completion of Test Tower Development

2012 Marked 150 Wind Tunnel Tests for Bridges

Built Korea's first HMD at Techno Mart

2014 Marked 200 Wind Tunnel Test for Buildings

Certified with ISO9001:2008, ISO140001:2009, OHSAS18001:2007

2015 Dubai Ferris Wheel TMD Project

Taipei Treasure Garden Res. Building TMD Project

2016 New York Ferris Wheel TMD Project

R&D of Stockbridge Damper

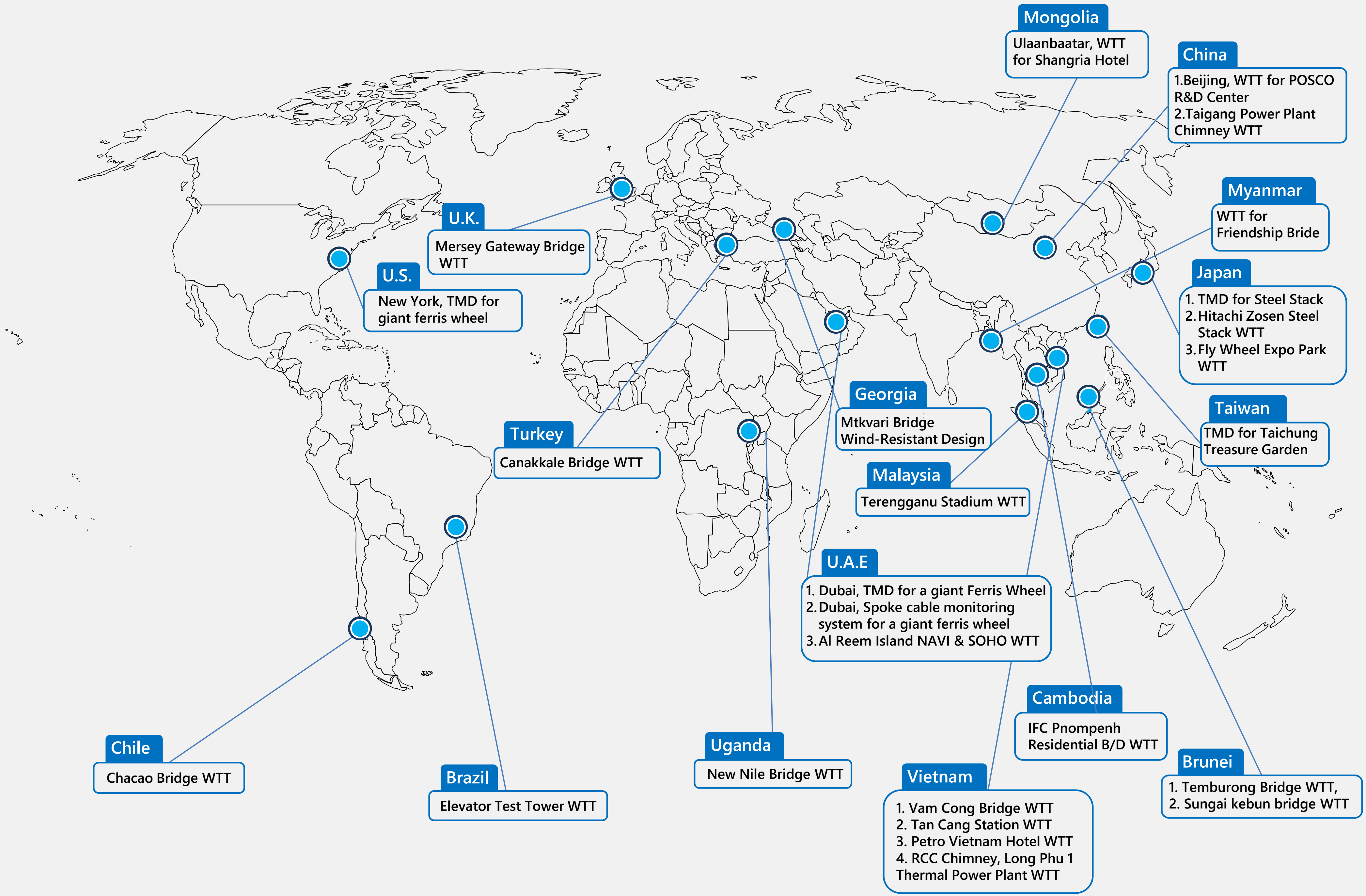
Dr. Yun-Seok, Kim – CEO, TESolution

Our company was established in February 2001, with the goal to provide better life to our clients through our accurate evaluation of safety and serviceability of various structures and our solutions to improve them, based on our differentiated technical expertise and accumulated experience in the field of Wind Engineering & Vibration Control.

As to the field of Wind Engineering, TESolution provides solutions for safer and better life with evaluation on aerodynamic stability, serviceability against wind-induced vibration and pedestrian-level wind environment of buildings and bridges based on our highest level of expertise and technically advanced facilities.

As to the field of Vibration Control, TESolution provides solutions to improve the quality of residential environment through our vibration control devices that reduce or suppress the vibration induced by wind, earthquake, pedestrians or road traffic.

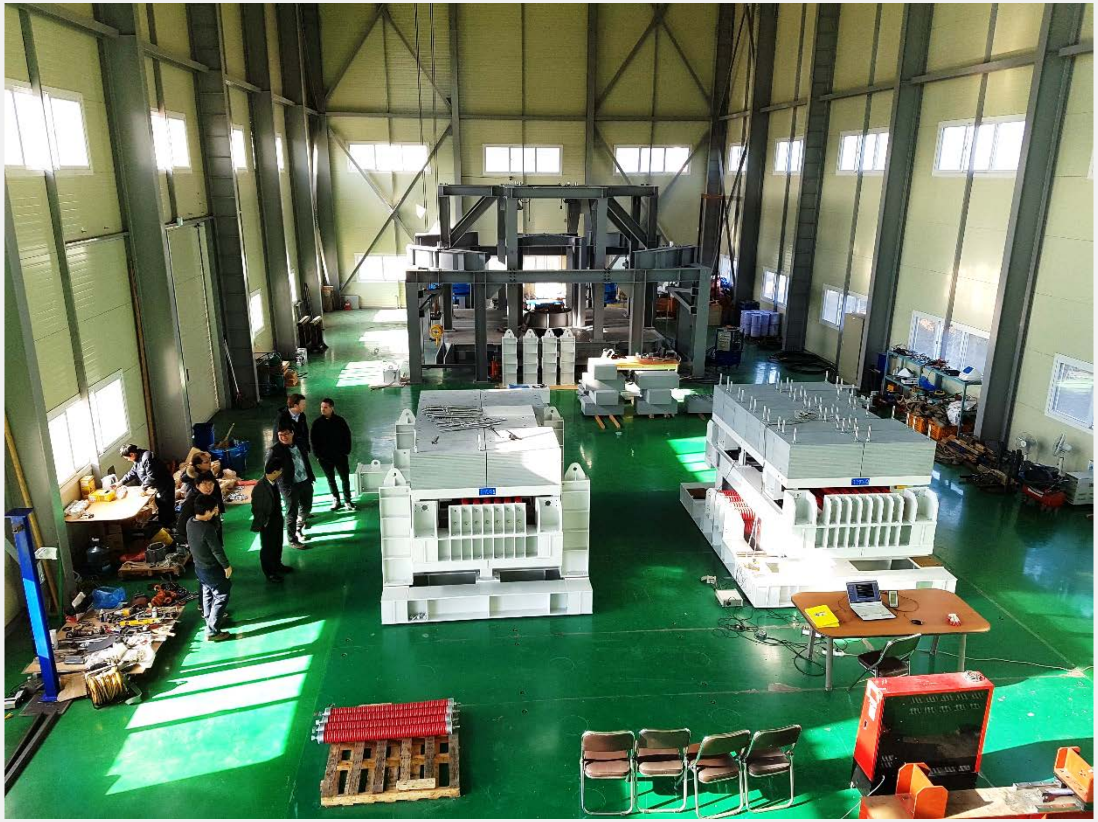
TESolution's Global Presence



Structural Laboratory

Two structural laboratories at TESolution are well-equipped for performance testing of full–scale vibration control devices, such as Tuned Mass Damper(TMD) and Active Mass Damper(AMD). Fabrication procedures of vibration control devices are carefully checked in order to prevent unexpected problems at construction site. The 1st structural laboratory has test reaction floor with 300-tons bearing capacity, OH crane with 5-ton capacity, and 200KW electric power supplier.

The 2nd structural laboratory (15m width×40m length×20m height) was built in May, 2013 to accommodate bigger TMDs and AMDs for performance testing prior to shipping to work site and has two test reaction floors with 400-tons bearing capacity, OH crane with 5-ton capacity, and 500KW electric power supplier.



TESolution 1st Structural Lab

TESolution 2nd Structural Lab

Test Tower

The test tower is a 5 story (20m height) tall steel structure that is a unique test facility for various vibration control devices. This tower is mainly used to conduct performance test of newly developed vibration control devices such as AMD. In the excitation room, a vibration exciter simulates the vibration of the tower. In the control room, the control device stationed inside detects the vibration and counteracts in order to reduce the vibration of the tower.

Control Room

Composition	Control Room
Heights	Level 5 (20m Height)
Description	Performance testing for active type vibration control devices under development.

Excitation Room

Composition	Excitation Room
Heights	Level 4 (16m Height)
Description	vibration exciter that can excite the test tower in various ways is installed inside.

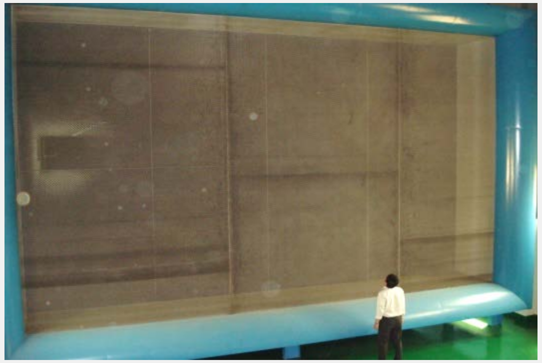
Boundary Layer Wind Tunnel

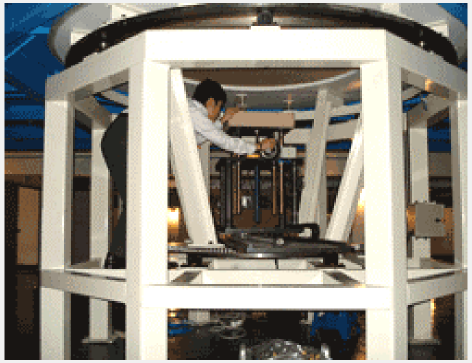
The boundary layer wind tunnel is a facility designed to simulate the air flow around structures for variety of aerodynamics studies with ground roughness and height into consideration.

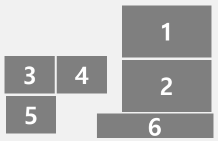
This wind tunnel is well suited for model studies of air flow over various structures, full model of long-span bridges, stand-alone pylon, and cable structures, as well as topographic feature.

Specification

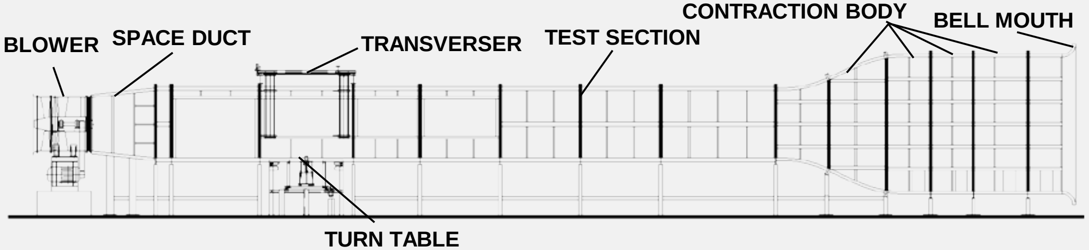
Category	Boundary Layer Wind Tunnel
Type	Open-circuit(Suction)
Dimension	8.0m(width) x 2.5m(height) x 23.2m(length)
Wind Speed	0.3 ~ 11.0m/s
Uniformity	Turbulence Intensity of 0.5%, Wind Velocity ±1.0% (for smooth flow)
Blower	3 x 132KW







1.TEST SECTION
2.SUCTION TYPE MULTI-FAN
3.INLET OF SETTLING CHAMBER
4.TURNTABLE SYSTEM
5.TRAVERSE SYSTEM
6.OUTLINE OF WIND TUNNEL



Wind Tunnel for Section Model

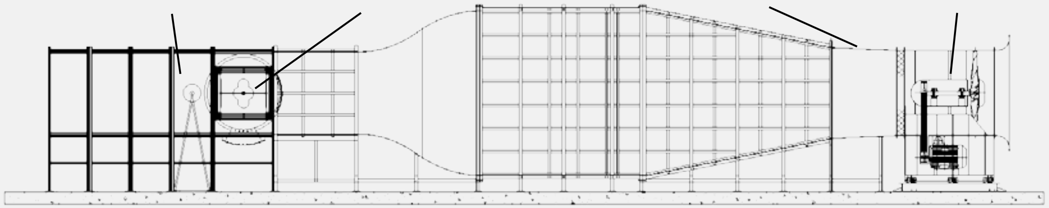
Bridge cross-section model test is conducted to investigate the aerodynamic response characteristics of the bridge section.

TESoluotion currently operates two different sizes of 2D wind tunnel that are primarily used to check the aerodynamic stability of long-span bridge, such as vortex-induced vibration, flutter, and galloping phenomena with bridge section model.

Testing rig for 2D wind tunnel consists of various equipment such as spring-support system, active turbulence generator, and forced oscillator.

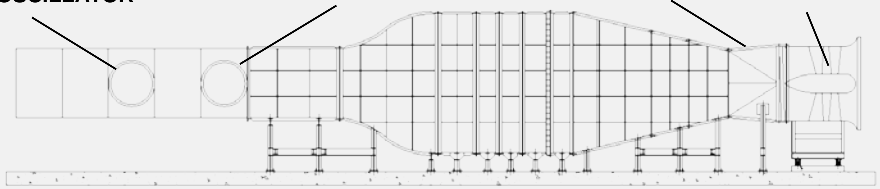
MID-SIZE 2D WIND TUNNEL

Type	Test Section Dimension	Wind Speed
Eiffel-type	1.5 m (W) x 2.0 m (H) x 7.5 m (L)	0.3m/s ~ 25.0 m/s



SMALL-SIZE 2D WIND TUNNEL

Type	Test Section Dimension	Wind Speed
Eiffel-type	1 m (W) x 1.5 m (H) x 6 m (L)	0.3m/s ~ 21.0m/s



TESolution Mid-size 2d Wind Tunnel

TESolution Small-size 2d Wind Tunnel

Vibration Control Devices

With accumulated R&D effort on top of the highest expertise in the field, TESolution has been providing tailored solutions of vibration control to various types of structures, including skyscrapers, long-span bridges, footbridges, cable cars, air traffic control towers, etc.

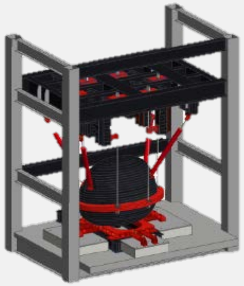
Especially as the structures are becoming taller, lighter, and longer with the advancement of the construction technology, they are also becoming more vulnerable to vibrations induced by dynamic loads such as wind and traffic.

For the serviceability of skyscrapers, structural safety of bridges, or pedestrian comfort of footbridges, TESolution's vibration control device such as Tuned Mass Damper(TMD), Active Mass Damper(AMD), and Hybrid Mass Damper(HMD) can be the solution to vibration control .

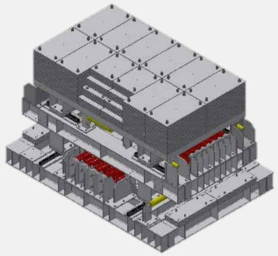
- **Basic/Detail design : Determination of dimension, types, and specifications of vibration control devices, drawing works**
- **Fabrication/ Performance test at TESolution : Friction/vibration tests**
- **Vibration Measurement: Measurement of structural frequency, damping ratio, and estimation of mode shape.**
- **Installation supervision/ Performance test at construction site : Frequency tuning and verification of required control performance**
- **Maintenance : Periodically check the TMD’s control performance and durability of the key components**

Vibration Control

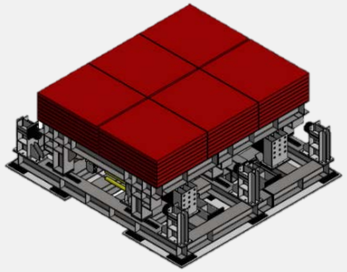
Pendulum-type Tuned Mass Damper



Sliding-type Tuned Mass Damper



Active Mass Damper



Vibration Control Devices – Applications for Buildings

Wind-induced vibrations on high-rise residential and office buildings have highly negative impact on habitability and service-ability.

International organization for standardization (ISO) and building codes in many countries (such as AIJ2004, ISO 10134) recommend that structures meet specific criteria of vibration control classified by natural period of the building and human perception level of building acceleration.

The objective of vibration control device is to improve damping efficiency and habitability of building by reducing the building acceleration with the installation of vibration control device such as tuned mass damper (TMD) and active mass damper(AMD) on the structures.

Haeundae Centum Park, Busan, Korea 2004

▶ 3 x 100 ton Sliding type TMD

Lotte Hotel, Ulsan, Korea, 2007

▶ 2 x 20 ton AMD

Songdo POSCO E&C Headquarter, Incheon, Korea, 2010

▶ Tower A – 80 ton Sliding type TMD
▶ Tower B - 160 ton Sliding type TMD

TechnoMart, Seoul, Korea, 2013

▶ Hybrid Mass Damper
40 ton TMD for vertical vibration control
50 ton AMD for horizontal vibration control

Taichung Treasure Garden, Taichung, Taiwan, 2016

▶ 150 ton Pendulum type TMD

Vibration Control Devices – Applications for Bridges

Long-span bridges, such as suspension or cable-stayed bridges are structurally highly vulnerable to wind load due to relatively low bending / torsional stiffness and damping ratio. Wind-induced vibration on long-span bridges can not only occur on girder, but also on various components such as pylon, stay cables and hanger cables. Girder and pylon during the construction stage are especially more prone to wind load. In case of footbridge, vibration serviceability may not be satisfied even if the structural safety is satisfied due to excessive vertical vibration from pedestrian movement can cause them to experience unpleasant sensation of dizziness when crossing the bridge.

Furthermore, repeated occurrence of vibrations can intensify structural damages on bridges due to fatigue.

Vibration control devices are installed on bridges not only to increase the wind resistant performance during construction and in-service stages but also to improve serviceability of bridges during in-service stage.


Geoga Bridge during the construction


TMD for 2nd Jindo Bridge


Yoido Setgang Foot-Bridge


Ulleung Foot-Bridge


2nd Jindo Bridge

Vibration Control Devices – Applications for Special Structures

Flexible structures, such as chimney, steel tower, and cable cars are highly vulnerable to wind load because of their long period and low damping characteristics. It can be dangerous if they are exposed to wind-induced vibration for long period of time as it can hurt structural safety due to fatigue or serviceability as inhabitants suffer from fear of potential collapse. With advanced technology and numerous past experiences, TESolution Vibration control devices can be designed in various shapes and sizes to fit in the tightest installation location to significantly reduce wind-induced vibration and maintain habitable environment.

Also, for airport air traffic control tower(ATC) where air traffic control staff reside 24 hours and slightest wind-induced vibration can significantly affect their work performance, active type mass dampers(AMD) of much smaller size can be installed to fit inside tight installation space, while maintaining the same level of damping performance as much bigger passive type TMDs.

AMD for Airport ATC Tower

Namsan Cable Car

Pyeong-Chang Ski Jump Tower

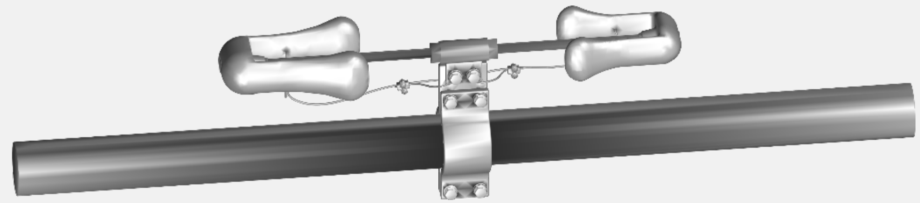
Incheon International Airport ATC Tower

Stockbridge Damper for Bridge Cables

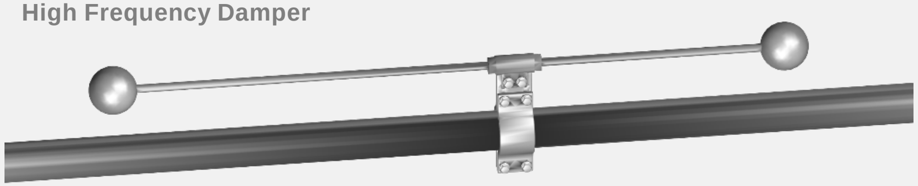
Hanger ropes of suspension bridges and stay-cables of cable-stayed bridges, even though very effective in carrying tensional loads of the bridge, are susceptible to various kinds of wind-induced vibration due to their low damping ratio:

- **Aeolian vibration (vortex-induced vibration)**
- **Galloping**
- **Wake galloping**
- **Rain-Wind induced vibration**
- **Parametric excitation**
- **Buffeting**

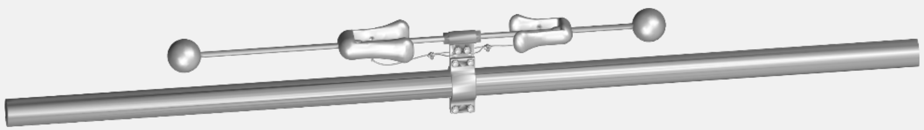
Stockbridge damper, currently most commonly used vibration damper for power line, can be designed to dissipate the input wind energy over a wide range of frequencies. Stockbridge damper is not only much more cost efficient way of controlling cable vibration compared to traditional viscous dampers, but also is much easier to install and its installation location can be easily adjusted to attain the maximum damping. TESolution has developed three different types of Stockbridge dampers that are ideal for reducing wind induced vibration on the bridge cables: High frequency, Low frequency, and combined type damper.



High Frequency Damper



Low Frequency Damper



Combined type Damper(High & Low Frequency)

Stockbridge Damper, Ulsan Bridge(suspension bridge), 2015

Stockbridge Damper, Palyung Bridge(suspension bridge), 2016

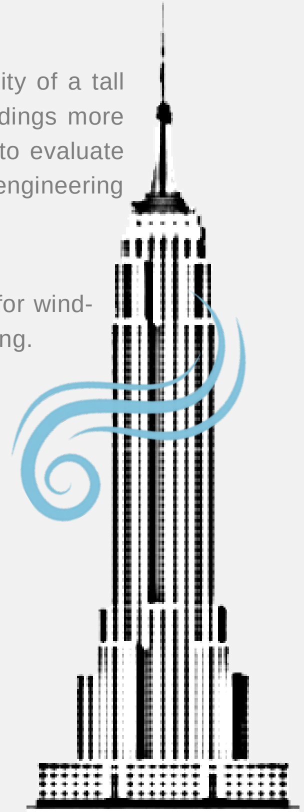
Stockbridge Damper, Pyeongtaek Bridge(cable stayed),2016

Wind Tunnel Tests for Buildings

WTT for Bldgs

As buildings become taller and more lightweight, they become more sensitive to wind-induced vibration. Especially, structural safety and serviceability of a tall building are determined more by across-wind vibration than along-wind vibration and in order to evaluate the effect of across-wind vibration on buildings more thoroughly, wind tunnel testing must be conducted. Also, densification with buildings with more asymmetric shape and figure makes it more difficult to evaluate cladding pressure and can additionally require evaluation of pedestrian level wind environment. In the end, wind tunnel testing conducted by wind engineering specialist is a must in order to satisfy standards for structural safety, occupant comfort, safety of cladding and pedestrian level wind environment.

TESolution is a group of experts in the field of wind engineering and vibration control who dedicated their career providing total engineering solutions for wind-induced vibration. TESolution has participated in many domestic / international projects and continues to play a leading role in the field of wind engineering.



High Frequency Force Balance Test

Topography Model Test

Cladding Pressure Test

Busan International Finance Center

Samsung Raemian Yongsan Residencial Complex

Al Reem Island Abudhabi, U.A.E

High Frequency Force Balance Test

The High Frequency Force Balance Test(HFFBT) is conducted to predict wind loads for structural design and wind-induced vibration. Light rigid model is used for this test, and the wind force and moments are measured with the HFFB. From time history of the measured wind force and moment coefficient, spectral modal analysis is conduced to analyze wind response. The major findings from the HFFBT can be summarized as follows.

- **Base shear, base moment**
- **Static equivalent floor-by-floor wind load for structural design**
- **Wind-induced acceleration, serviceability evaluation (AIJ, ISO6897, ISO10137, NBCC, etc.)**

3

1.BIFC 1 2

2.Lotte Castle

3.Busan Marine City Complex

Cladding Pressure Test

Cladding pressure test is conducted to evaluate the design wind loads on claddings and components of a building and stadium roof.

Pressures on the surface of a rigid model are measured by multi point pressure measurement system.

The pressure tabs are evenly distributed to ensure sufficient coverage to provide information on distribution of cladding pressure of the building. External pressure coefficients (mean, RMS and peak values) are used in predicting cladding design pressures.

- **Pressure for cladding design**
- **Wind load for design of roof structures**
- **Cladding pressure for structural member design of open-air structures such as parapet, canopy, free-standing wall, etc.**

1.Sarang Church, Seoul
2.National Ocean Science and Education Center
3.Munhak Stadium

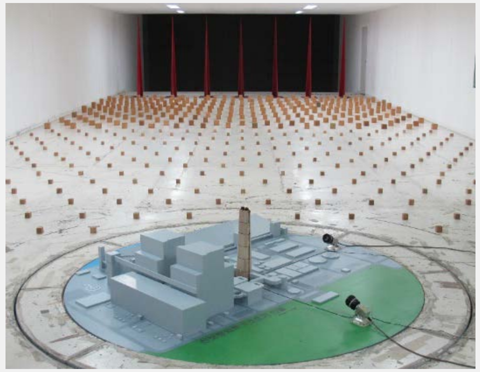
Aeroelastic Model Test

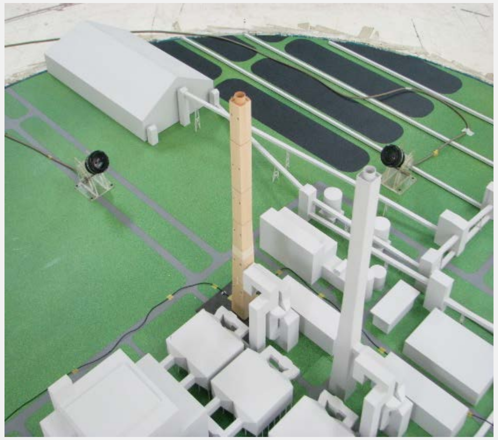
The Aeroelastic Model Test is conducted to evaluate wind load, and to examine the possibility of vortex-induced vibration or aero-dynamic instability. For the Aeroelastic Model Test, the model is designed with precisely scaled dynamic properties of the full-scale buildings (stiffness, mass, natural frequency, and damping properties of the structural system) and built with flexible material that vibrates like the prototype structure. The Aeroelastic Model Test can evaluate wind response, which takes the combination effect of vibration modes, the effect of additional aerodynamic force due to vibration, and the aerodynamic damping into account.

Major findings from the Aeroelastic Model Test can be summarized as follows.

- **Displacement and acceleration response**
- **Possibility of vortex-induced vibration or aerodynamic instability**
- **The same findings to that of HFFB Test**
- **Study of vibration mitigation**

1.Dangjin Power Plant #9,10 Stack
2.Gosung-Hi Power Plant #1,2 Stack
3.Shin-Boryung Power Plant #1,2 Stack



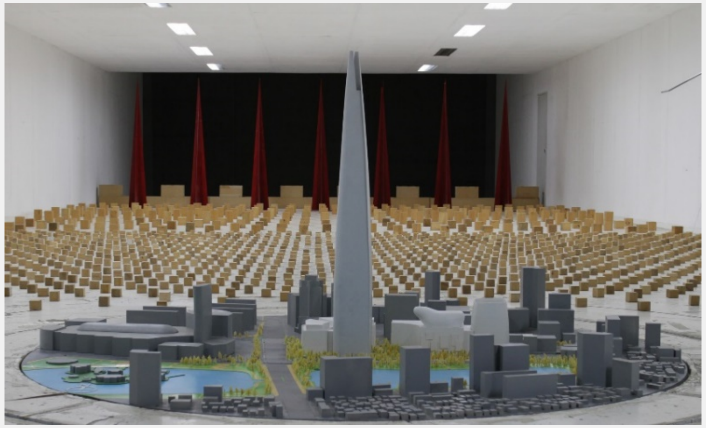


Pedestrian-Level Wind Environment Test

When new high-rise buildings are constructed, the wind environment surrounding the site is bound to change drastically. With such change, the safety of the pedestrian spaces must be secured against the strong wind and wind environment must be suitable with their usage. The Pedestrian-Level Wind Environment Test is conducted to assess the possibility of pedestrian-Level wind speed exceeding the standard and to evaluate the overall wind environment.

Major findings from the Pedestrian-Level Wind Environment Test are as follows.

- **Wind speed + wind direction occurrence frequency in relation to the climate data**
- **Wind speed ratio with respect to design wind speed**
- **Assessment of pedestrian level wind load**
- **Visualization of wind flow**



1.Lotte World Tower
2.Acro Seoul Forest
3.Kookje Bldg.
Sector 4

1
2 3

Topography Model Test

Topography model test is conducted to evaluate the characteristics of wind over the areas with complex terrain and topographical features.

Scale model of the area under study is used and wind speed and turbulence intensity over scaled-topographical model are measured with anemometer system. With the measured wind speed and turbulence intensity, the characteristics of the approaching wind to the construction site can be analyzed for evaluation of the effect of the surrounding topography.

- **Distribution of average wind speed (horizontal and vertical directions)**
- **Distribution of turbulence Intensity (horizontal and vertical directions)**
- **Topographic effects**

1.Everland Resort
2.Munhak World Cup Stadium

2
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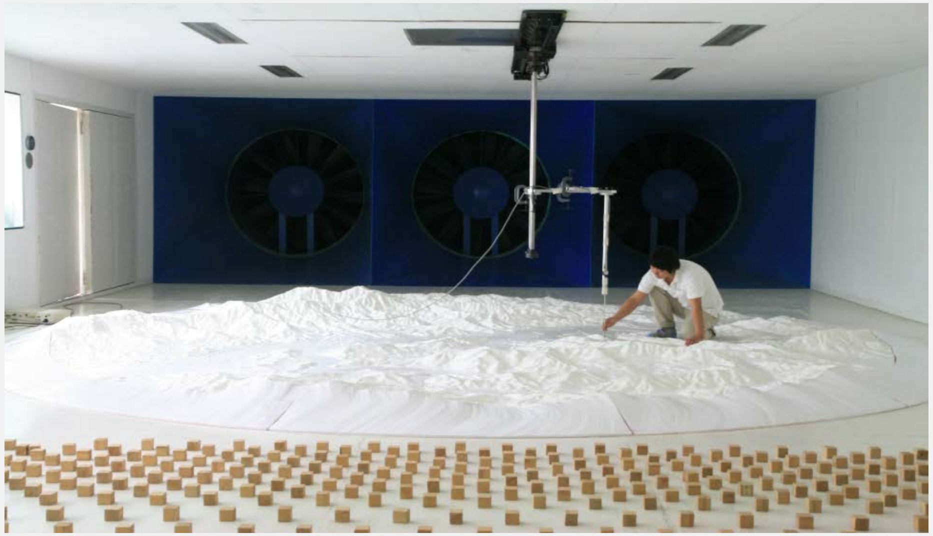
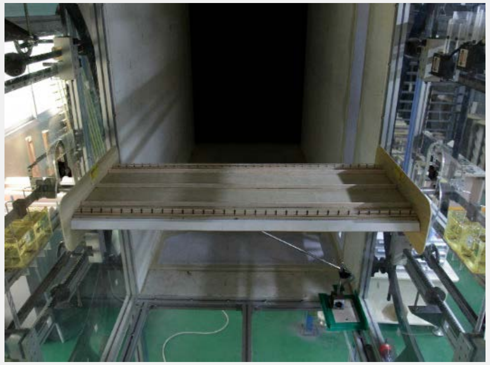


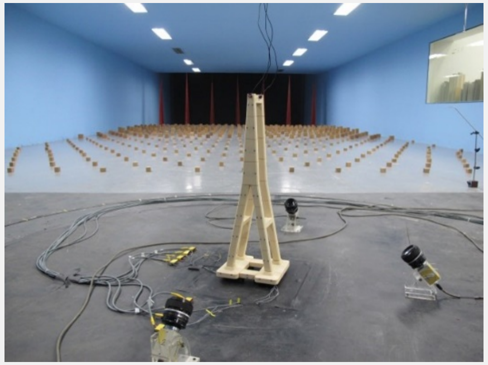
Wind Tunnel Tests for Bridges

Bridge structures have higher probability of suffering from wind-induced vibration due to their flexible characteristics. As the span of the bridge gets longer, wind load becomes more dominant design factor in the bridge design. Aerodynamic stability investigation of bridge is mainly conducted for the deck, pylon, and cables of the bridge. Aerodynamic stability of barrier, fence or road sign on the bridge are investigated as well.

TESolution has acquired experience in the field of wind engineering through numerous domestic and international projects from all over the world, such as Japan, Turkey, Vietnam, Indonesia, China, and Uganda for the past 20 years.



Section Model Test



Pylon Model Test

Full Bridge Model Test

Ulsan Bridge

Vamcong Bridge, Viet Nam

Chacao Bridge, Chile

Section Model Tests

The Section Model Test is conducted to evaluate wind-resistance stability of the bridge with a rigid scale model of a bridge section, including girders, barriers, and railings for inspection car. It is very basic, yet one of the most important tests that is also cost efficient.

Section model tests consist of three different test. The 1st is steady aerodynamic force test using two three-component load cells to measure the wind forces acting on the model such as drag, lift, and moment coefficients. The 2nd is aerodynamic stability testing to check the onset speed of vortex-induced vibration, flutter and galloping and their amplitude with the spring support system. The 3rd and the last is forced vibration test that measures unsteady aerodynamic force using forced oscillator. Our patented forced oscillator harmonically excites the bridge section model in heaving, swaying and pitching mode to measure flutter derivatives.

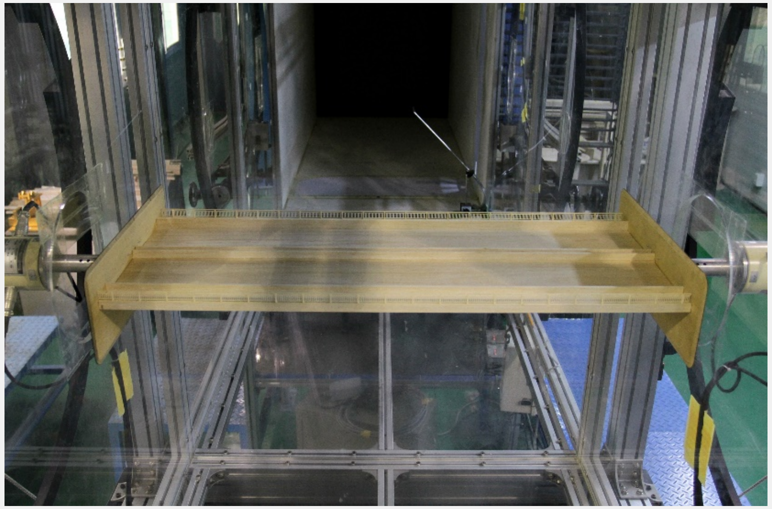
The test results show the main issues regarding wind-resistance design of the bridge, and with further analysis of the results, TESolution engineers can make suggestions on application of aerodynamic and/or structural countermeasures.

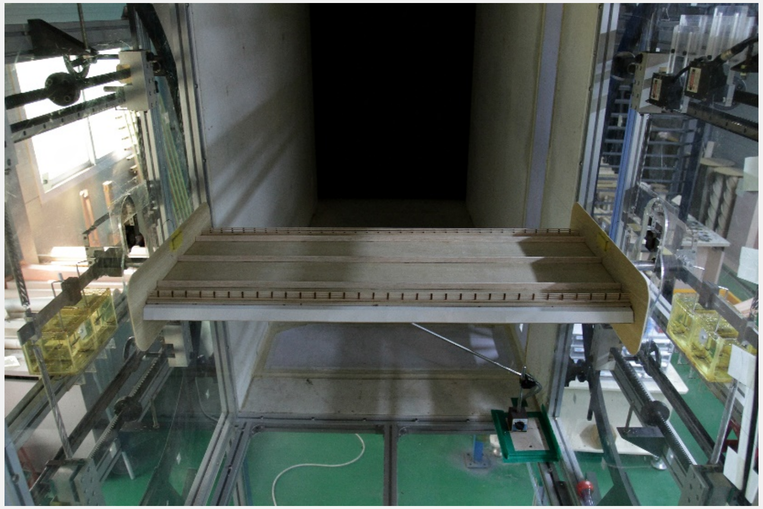
- **Aerodynamic stability: vortex-induced vibration, flutter, galloping onset speed and amplitude**
- **Steady aerodynamic coefficient: drag, lift, moment coefficients.**
- **Flutter coefficient: H1*~H4*, A1*~A4***
- **Suggestion on aerodynamic optimization of the shape or vibration control devices for unstable aerodynamic behavior of bridge.**

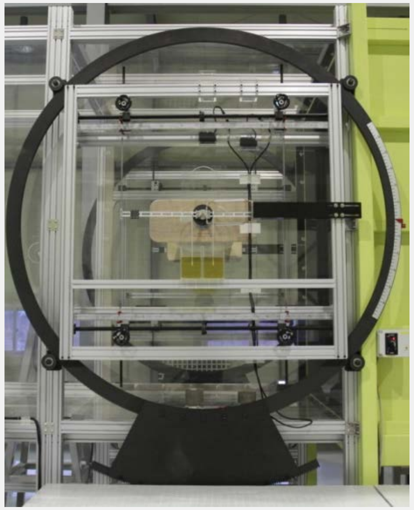
1.&2. Bridge Deck Model
3. Spring Support System
4. Forced Oscillator

4

1 2 3







Pylon Model Test

Pylons for cable-stayed bridge and suspension bridge are generally in slender figure, which make them vulnerable to the wind load. Pylons are especially vulnerable when stood alone during the erection stage, prior to the installation of cables, due to their low structural damping properties.

Wind tunnel tests of pylon include aeroelastic model tests and wind force tests under various construction stages. Aeroelastic model tests are conducted to evaluate aerodynamic stability of free standing pylon. Wind force tests are conducted to provide wind force coefficients of pylon legs or whole pylon.

- **Aerodynamic stability : vortex-induced vibration, flutter, galloping**
- **Base shear force, base overturning moment, base torsional moment**
- **Aerodynamic optimization of the shape for unstable aerodynamic behavior of pylon**
- **Wind force of pylon leg : drag, lift, pitching moment coefficients**
- **Wind force of whole pylon : base shear force, base moment**

1. Chacao Bridge, Chile
2. Vamcong Bridge, Vietnam
3. 2nd Namhae Bridge

3
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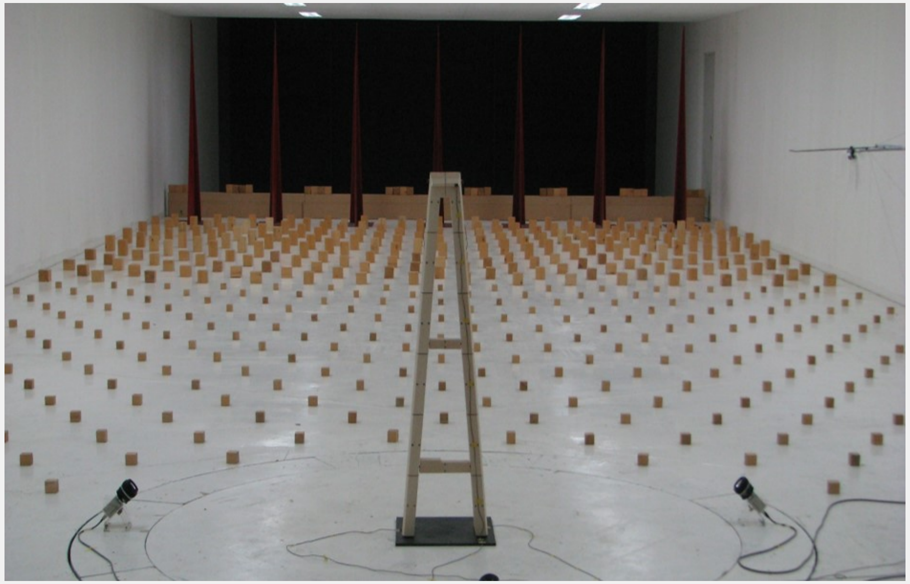
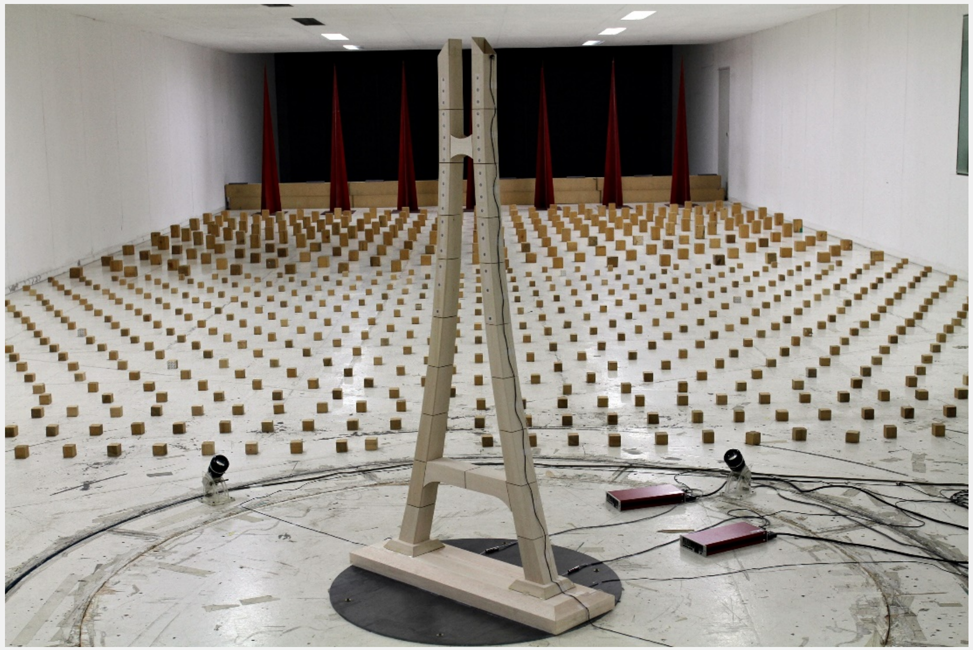




Full Bridge Model Test

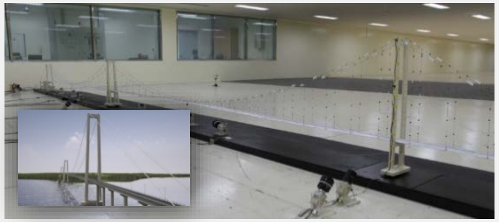
Full bridge models opens up the possibility for extensive exploration of prototype conditions, such as the effects of the wind at various approach angles, velocity profiles, special effects that may be caused by unusual topography and upwind obstacles, and etc.

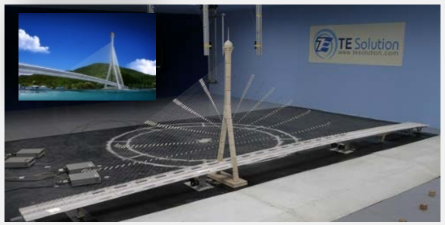
It is necessary to check three dimensional aerodynamic stability of the bridge due to changing dynamic characteristics of the bridge under the erection stage or at completed stage. Three-dimensional aeroelastic model is used for the vibration test of full-bridge.

- **Aerodynamic stability : vortex-induced vibration, flutter, galloping, and buffeting onset speed and vibration amplitude**
- **Aerodynamic stability of full-bridge during the erection / in-service stages**
- **Aerodynamic stability of full-bridge considering topography effect**
- **Aerodynamic stability of full-bridge considering construction facilities(derrick crane, etc)**
- **Aerodynamic optimization of the shape for unstable aerodynamic behavior of full-bridge**

1. 2nd Namhae Bridge
2. Chacao Bridge, Chile
3. Sungai Brunei Bridge, Brunei

2 | 3
1



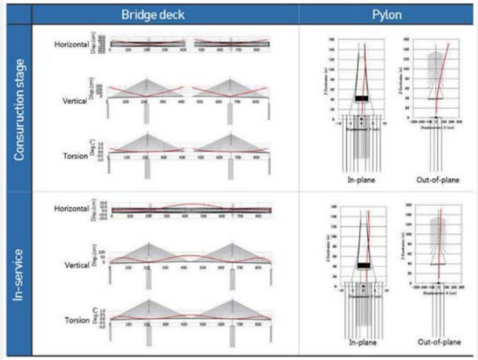


Buffeting Analysis

Buffeting responses are random vibrations caused by turbulent components of approaching flow. Static deformation by mean wind speed and buffeting response by fluctuating wind speed are computed during the erection stage and in-service stage.

Eigenvalue analysis results such as natural frequency and mode shapes are used for the buffeting analysis.

- **Buffeting response of girder and pylon during the erection / in-service stages**
- **Suggestion on countermeasures for unstable aerodynamic behavior of full-bridge**

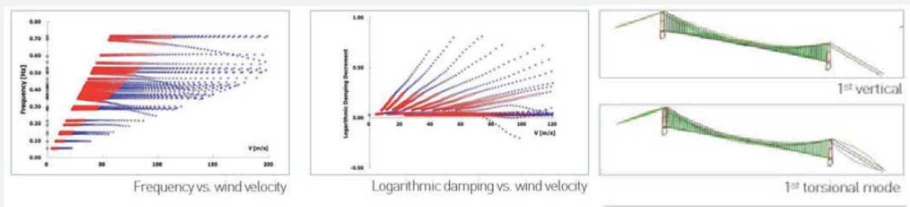


Flutter Analysis

Flutter is an aeroelastic instability involving coupling of different vibration modes. In other words, flutter occurs at certain range of wind speeds where energy exerted by wind flow interacts with the bridge, causing oscillation.

Multi-mode flutter analysis method is generally used as an analytical method to calculate the critical wind speed of flutter. Flutter derivatives, natural frequencies and mode shapes from eigenvalue analysis are used as input data. Flutter derivatives from forced vibration test are required for flutter analysis.

- **Flutter onset speeds of a bridge during the erection / in-service stages**
- **Various combination of bridge modes should be considered**



Frequency vs. wind velocity

Logarithmic damping vs. wind velocity

1st vertical

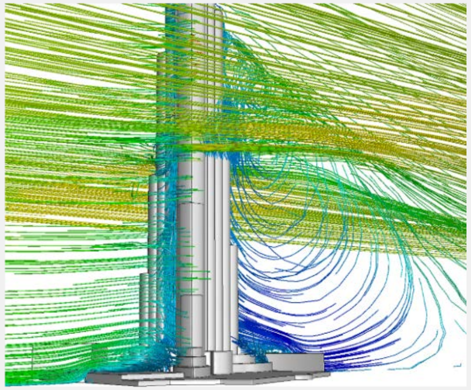
1st torsional mode

WTT for Bridges

Computational Wind Engineering

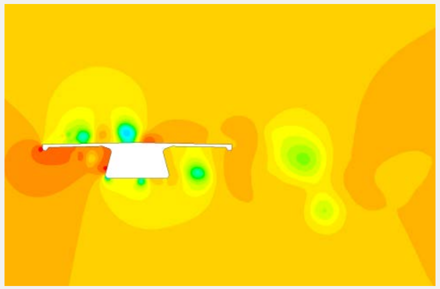
Computational Wind Engineering (CWE) uses Computational Fluid Dynamics (CFD) method to solve problems encountered in wind engineering. Numerical modeling with CFD can be a powerful alternative as it can avoid limitations of on-site measurements and wind tunnel tests. CFD can provide detailed information on the relevant flow variables in the whole calculation domain under well-controlled conditions.

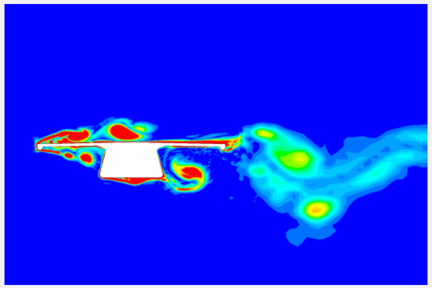
CFD is typically used for prediction of wind comfort, pollution dispersion, natural ventilation of building, wind load on buildings, static aero-dynamic force and flutter analysis of a bridge.



CFD/FSI Analysis

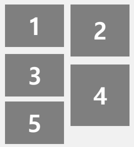
CFD is used to investigate static aerodynamic forces, wind velocity, vortex, and pressure distributions near the bridge. Also, the occurrence of flutter and vortex induced vibration are estimated with FSI(Fluid Structure Interaction) analysis.





Forced Vibration Test on Structure

When evaluating dynamic safety of the structure such as wind resistance safety or anti-seismic safety, forced vibration test on structure with vibration generator can be conducted to effectively obtain necessary data. TESolution has 4 different sizes of vibration exciters ranging from 42kN to 420kN ideal for vibration test from small footbridges to large structures to measure dynamic characteristics such as modal mass, natural frequency and structural damping ratio. Also, performance testing on vibration control devices installed on the structure such as TMD and AMD can be conducted with vibration exciters .



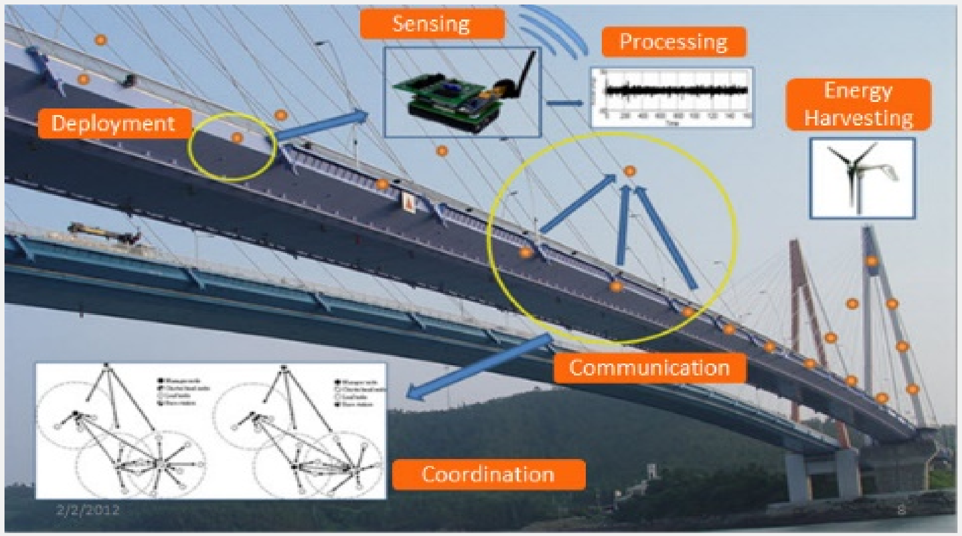
1.2. Seismic performance test of large smoke stack with large sized vibration generator (power plant, Nagoya Japan)
3. Forced vibration test on building with medium sized vibration generator(Tokyo, Japan)
4. Forced vibration test on footbridge with small sized vibration generator #1
5. Forced vibration test on footbridge with small sized vibration generator #2

Wireless Smart Sensor Networks (WSSN)

Recent advancement in the sensor technologies have enabled Structural Health Monitoring(SHM) using wireless smart sensor networks (WSSNs), which is a promising alternative to the traditional wired SHM approaches. The smart sensors are typically small, inexpensive, and capable of wireless communication and onboard computation, addressing many of the concerns regarding wired monitoring. For example, easy installation and the associated reduction in installation cost, multi-hop communication, and decentralized in-network data processing are available with recent advances in WSSN; these attractive features enable the development of scalable monitoring systems and dense sensor networks.

TESolution has extensive experience in setting up Monitoring System with wired/wireless sensors and also has proven track record of System Identification for structures for installation of vibration control devices as well as System Identification to check the performance of the vibration control device after the installation.

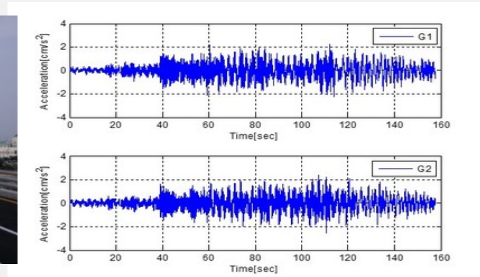
Most recently, TESolution provided the Monitoring System for the Spoke Cables (including 192 Wireless Smart Sensors) of a giant Ferris wheel currently being built in Dubai.



WSSN for Jindo bridge monitoring (Korea, 2009~2012)

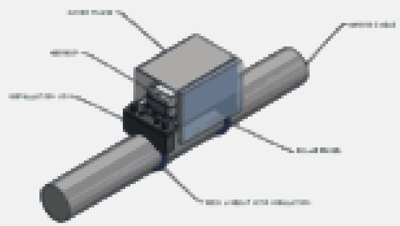
Example of Field Application

- **4th Songdo Bridge (2015)**



- **Giant Ferris Wheel under construction in Dubai (2016)**

Wireless Smart Sensor



Wireless Smart Sensor on clamping system with solar panel

Wind & Vib. etc

Track Record of TESolution

• Vibration Control Devices - Buildings

Taichung Treasure Garden, Taichung, Taiwan

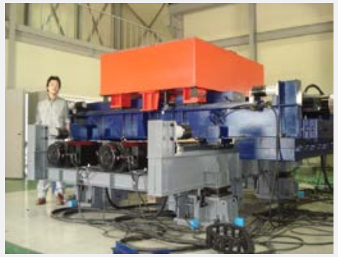
- Frequency
  0.237Hz(x-dir)
  0.230Hz(y-dir)
- Year: In progress
- Type: Pendulum type
- Control direction: horizontal dir.
- Specification
  - Moving mass: 150ton
  - Stroke: 0.6m(x-dir) 1.35m(y-dir)
  - Optimal damping ratio : 12.3%
- Services: Conceptual & Detailed Design / Manufacture / Installation / Performance test

Techno Mart, Seoul, Korea

- Frequency
  0.19Hz(y-dir)
  2.7Hz(z-dir)
- Year: 2013
- Type: Hybrid Mass Damper
- Control direction: horizontal &vertical dir.
- Specification
  - Moving mass: 40t(TMD), 50t(AMD)
  - Stroke: ±10mm(TMD), ±600mm(AMD)
  -Optimal damping ratio : 4.63%(TMD)
- Services: Conceptual & Detailed Design / Manufacture / Installation / Performance test

POSCO E&C Office A & B Incheon, Korea

- Frequency
  Bldg A-0.26Hz(x-dir), 0.24Hz(y-dir)
  Bldg B-0.25Hz(x-dir), 0.24Hz(y-dir)
- Year: 2010
- Type: Sliding type TMD
- Control direction: Horizontal dir.
- Specification
  - Moving mass: Office A-80T, Office B-160T
  - Stroke: Office A-±300mm, Office B-±250mm
  -Optimal damping ratio : (A)4.5(X),4.7(Y) (B)6.1(X)6.6(Y)
- Services: Conceptual & Detailed Design / Manufacture / Installation / Performance test



Ulsan Lotte Hotel Ulsan, Korea

- Frequency
  0.42Hz(x-dir)
  0.36Hz(y-dir)
- Year: 2007
- Type: Active Mass Damper
- Control direction: horizontal dir.
- Specification
  - Moving mass: 20T(x-dir) 10T(y-dir)
  - Stroke: ±600mm
  - Optimal damping ratio : 20.6%(x-dir), 13.9%(y-dir)
- Services: Conceptual & Detailed Design / Manufacture / Installation / Performance test

Centumcity Busan, Korea

- Frequency
  0.52Hz(x-dir)
  0.47Hz(y-dir)
- Year: 2004
- Type: Sliding type TMD
- Control direction: horizontal dir.
- Specification
  - Moving mass: 100T x3
  - Stroke: ±300mm
  - Optimal damping ratio : 6.0%
- Services: Conceptual & Detailed Design / Manufacture / Installation / Performance test

Track Record of TESolution

• Vibration Control Devices - Bridges & etc.

Incheon International Airport (2nd)

- Frequency
  0.9560Hz (y-dir) -1st
  1.0231Hz (x-dir) -2nd
- Year: 2017
- Type: Active Mass Damper
- Control direction: horizontal dir.
- Specification
  - Moving mass: x-dir : 10.4ton y-dir : 9.2ton
  - Stroke: ±70mm
  - Optimal damping ratio : 8.39%(x-dir), 9.89%(y-dir)
- Services: Conceptual & Detailed Design / Manufacture / Installation / Performance test

Ulsan Bridge, Ulsan, Korea

- Cable Frequency
  1Hz ~ 40Hz
- Year: 2015
- Type: Stockbridge Damper
- Control direction: horizontal dir.
- Specification
  - 120 Sets
  - Moving mass: 4.62kg +7.90 kg (1set x 120)
  - Messenger Cable:¢-16mm
- Services: Conceptual & Detailed Design / Manufacture / Installation / Performance test

2nd Jindo Bridge, Jindo, Korea

- Frequency
  0.437Hz (z-dir) -1st
- Year: 2012
- Type: Sliding type
- Control direction: Vertical dir.
- Specification
  - Moving mass: 3.25ton x4
- Services: Conceptual & Detailed Design / Manufacture / Installation / Performance test

Pylon of Geoga Bridge

- Frequency
  0.22~0.28Hz
- Year: 2010
- Type: Pendulum type
- Control direction: horizontal dir.
- Specification
  - Moving mass: 24ton x3
  - Stroke: ±3000mm
  - Optimal damping ratio : 2.23%
- Services: Conceptual & Detailed Design / Manufacture / Installation / Performance test

Eunpa Footbridge, Gunsan, Korea

- Frequency
  1.77Hz
- Year: 2006
- Type: TMD (2 sets)
- Control direction: vertical dir.
- Specification
  - Moving mass: 0.65T
  - Stroke: ±40mm(TMD),
  - Optimal damping ratio : 5.0%
- Services: Conceptual & Detailed Design / Manufacture / Installation / Performance test

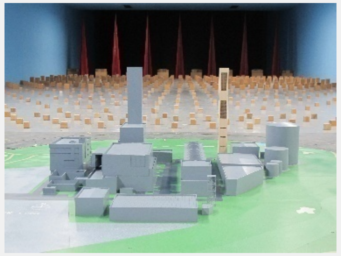
Track Record of TESolution

• Wind Tunnel Testing - Buildings

Haeundae Beach Resort, Busan, Korea

- Year : 2017
- Services:

- Cladding Pressure Study



CHP Stack, Wirye New Town, Korea

- Year : 2015
- Services:

-High Frequency Force Balance Test

Busan International Finance Center, Busan, Korea

- Year : 2014
- Services:

-Cladding Pressure Study
-High Frequency Force Balance Test

Yongsan 3 Block Project, Seoul, Korea

- Year : 2012
- Services:

-Cladding Pressure Study
-High Frequency Force Balance Test

Yongho-gulf Complex, Busan, Korea

- Year : 2012
- Services:

-Cladding Pressure Study
-High Frequency Force Balance Test
-Pedestrian Level Wind Study

Lotte World Tower Seoul, Korea

- Year : 2010
- Services:

-Pedestrian Level Wind Study

Al Reem Island Four Vanes, Abu Dhabi , UAE

- Year : 2009
- Services:

-Cladding Pressure Study
-High Frequency Force Balance Test
-Pedestrian Level Wind Study

Al Reem Island NAVI & SOHO, Abu Dhabi , UAE

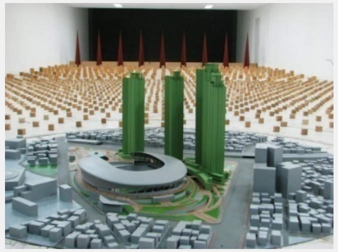
- Year : 2008
- Services:

-Cladding Pressure Study
-High Frequency Force Balance Test
-Pedestrian Level Wind Study

IFC Pnompenh Residencial B/D, Pnompenh, Cambodia

- Year : 2008
- Services:

-Cladding Pressure Study
-High Frequency Force Balance Test



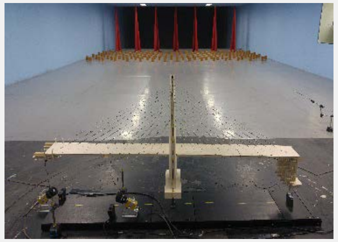
Sungui Arena Park & Complex, Incheon, Korea

- Year : 2008
- Services:

-Cladding Pressure Study
-High Frequency Force Balance Test
-Pedestrian Level Wind Study

Track Record of TESolution

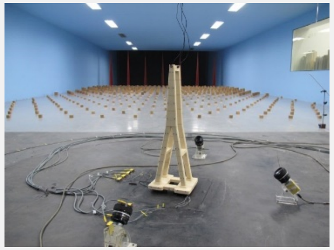
• Wind Tunnel Testing - Bridges & etc.



Temburong Bridge, Temburong, Brunei

- Client – Daelim
- Year : 2016
- Services:

-Section model test(deck, tower), Buffeting Analysis Wind shield test, Full bridge model test



Chacao Bridge, Chile

- Client – Hyundai & OAS
- Year : 2014
- Services:

-Section model test(deck, tower), Wind shield test, Free standing tower model test, Topographic model wind tunnel test, Full bridge model test

Sungai Kebun Bridge, Brunei

- Client – Daelim
- Year : 2014
- Services:

- Section model test, Buffeting analysis, Aeroelastic full bridge model test, CFD analysis, Wind environment test

Mersey Gateway Bridge Link, England

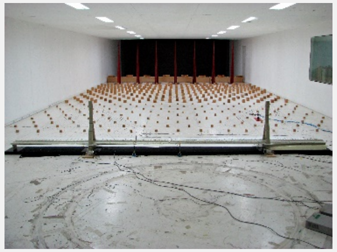
- Client – Samsung JV
- Year : 2013
- Services:

-Section model test(deck, tower), Wind shield test, Free standing tower model test

Vam Cong Bridge, Vietnam

- Client – Cuu Long CIPM
- Year : 2012
- Services:

-Cladding Pressure Study
-High Frequency Force Balance Test



New Nile Bridge, Uganda

- Client-Oriental Consultants
- Year : 2011
- Services:

-Section model, Aeroelastic full bridge model tests, CFD analysis

Hwayang-Jeokgeum Sector 3, Korea

- Client – Yooshin
- Year : 2011
- Services:

-Section model tests, Buffeting, Flutter, CFD analysis, Aeroelastic full bridge model tests, Aeroelastic free standing tower model tests

Namhae 2nd Bridge, Korea

- Client-Samsung T&C
- Year : 2009
- Services:

-Section model , Aeroelastic free standing tower model, Aeroeastic full bridge model tests, Buffeting analysis

Ulsan Bridge, Korea

- Client-Yooshin
- Year : 2009
- Services:

-Section model, Aeroelastic free standing tower model, Aeroeastic full bridge model tests, Buffeting, Flutter analysis

Chilsan Bridge (Hongnong-Baeksu), Korea

- Client-Namyeong E&C▪
Year : 2007
- Services:

-Section model, Aeroeastic full bridge model tests, Buffeting analysis

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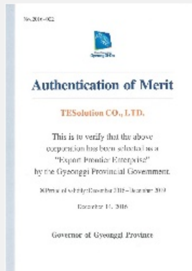

Export Frontier Enterprise