Total Engineering Solution in Wind Engineering & Vibration Control

TESolution. Co., Ltd.
www.tesolution.com
**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
  - Aerelastic 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
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.

“Dr. Yun-Seok, Kim – CEO, TESolution

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

<table>
<thead>
<tr>
<th>Composition</th>
<th>Control Room</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heights</td>
<td>Level 5 (20m Height)</td>
</tr>
<tr>
<td>Description</td>
<td>Performance testing for active type vibration control devices under development.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Composition</th>
<th>Excitation Room</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heights</td>
<td>Level 4 (16m Height)</td>
</tr>
<tr>
<td>Description</td>
<td>vibration exciter that can excite the test tower in various ways is installed inside.</td>
</tr>
</tbody>
</table>
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**

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

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

TESolution 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

<table>
<thead>
<tr>
<th>Type</th>
<th>Test Section Dimension</th>
<th>Wind Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eiffel-type</td>
<td>1.5 m (W) x 2.0 m (H) x 7.5 m (L)</td>
<td>0.3m/s ~ 25.0 m/s</td>
</tr>
</tbody>
</table>

### SMALL-SIZE 2D WIND TUNNEL

<table>
<thead>
<tr>
<th>Type</th>
<th>Test Section Dimension</th>
<th>Wind Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eiffel-type</td>
<td>1 m (W) x 1.5 m (H) x 6 m (L)</td>
<td>0.3m/s ~ 21.0 m/s</td>
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</tbody>
</table>
**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

![Pendulum-type Tuned Mass Damper](image1)
![Sliding-type Tuned Mass Damper](image2)
![Active Mass Damper](image3)
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.
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.
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.
Wind Tunnel Tests for Buildings

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

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 conducted 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.)
**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.

**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
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

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
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 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 tests. 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**: $H_1^*\sim H_4^*$, $A_1^*\sim A_4^*$
- **Suggestion on aerodynamic optimization of the shape or vibration control devices for unstable aerodynamic behavior of bridge.**
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
Full Bridge Model Test

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.

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
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.

Example of Field Application

- 4th Songdo Bridge (2015)

- Giant Ferris Wheel under construction in Dubai (2016)
<table>
<thead>
<tr>
<th>Project</th>
<th>Frequency</th>
<th>Type</th>
<th>Control direction</th>
<th>Specification</th>
<th>Year</th>
<th>Type</th>
<th>Control direction</th>
<th>Specification</th>
<th>Services</th>
</tr>
</thead>
<tbody>
<tr>
<td>Taichung Treasure Garden,</td>
<td>0.237Hz(x-dir)</td>
<td>Pendulum type</td>
<td>Horizontal dir.</td>
<td>- Moving mass: 150ton&lt;br&gt;- Stroke: 0.6m(x-dir) 1.35m(y-dir)&lt;br&gt;- Optimal damping ratio: 12.3%</td>
<td>In progress</td>
<td>Hybrid Mass Damper</td>
<td>Horizontal &amp; vertical dir.</td>
<td>- Moving mass: 40t(TMD), 50t(AMD)&lt;br&gt;- Stroke: ±10mm(TMD), ±600mm(AMD)&lt;br&gt;- Optimal damping ratio: 4.63%(TMD)</td>
<td>Conceptual &amp; Detailed Design / Manufacture / Installation / Performance test</td>
</tr>
<tr>
<td>Taichung, Taiwan</td>
<td>0.230Hz(y-dir)</td>
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<tr>
<td>Techno Mart, Seoul, Korea</td>
<td>0.19Hz(y-dir)</td>
<td>Pendulum type</td>
<td></td>
<td>- Moving mass: 150ton&lt;br&gt;- Stroke: 2.7Hz(z-dir)</td>
<td>In 2013</td>
<td>Sliding type TMD</td>
<td></td>
<td>- Moving mass: Office A-80T, Office B-160T&lt;br&gt;- Stroke: Office A-±300mm, Office B-±250mm&lt;br&gt;- Optimal damping ratio: (A)4.5(X)(Y)(B)6.1(X)6.6(Y)</td>
<td>Conceptual &amp; Detailed Design / Manufacture / Installation / Performance test</td>
</tr>
<tr>
<td>Incheon, Korea</td>
<td>2.7Hz(z-dir)</td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>POSCO E&amp;C Office A &amp; B</td>
<td>0.26Hz(x-dir)</td>
<td>TMD</td>
<td>Horizontal dir.</td>
<td>- Moving mass: 150 ton&lt;br&gt;- Stroke: ±300mm&lt;br&gt;- Optimal damping ratio: 12.3%</td>
<td>2010</td>
<td>Active Mass Damper</td>
<td></td>
<td>- Moving mass: 20T(x-dir) 10T(y-dir)&lt;br&gt;- Stroke: ±600mm&lt;br&gt;- Optimal damping ratio: 20.6%(x-dir), 13.9%(y-dir)</td>
<td>Conceptual &amp; Detailed Design / Manufacture / Installation / Performance test</td>
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<tr>
<td>Incheon, Korea</td>
<td>0.24Hz(y-dir)</td>
<td>Hybrid Mass Damper</td>
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<tr>
<td>Ulsan Lotte Hotel</td>
<td>0.42Hz(x-dir)</td>
<td>TMD</td>
<td>Horizontal dir.</td>
<td>- Moving mass: 20T(x-dir) 10T(y-dir)&lt;br&gt;- Stroke: ±600mm&lt;br&gt;- Optimal damping ratio: 20.6%(x-dir), 13.9%(y-dir)</td>
<td>2007</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Ulsan, Korea</td>
<td>0.36Hz(y-dir)</td>
<td>Hybrid Mass Damper</td>
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<tr>
<td>Centumcity Busan, Korea</td>
<td>0.52Hz(x-dir)</td>
<td>Pendulum type</td>
<td></td>
<td></td>
<td>2004</td>
<td>Pendulum type</td>
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<td>Conceptual &amp; Detailed Design / Manufacture / Installation / Performance test</td>
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<tr>
<td>Centumcity, Busan, Korea</td>
<td>0.47Hz(y-dir)</td>
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</tbody>
</table>
Incheon International Airport (2nd)
- Frequency: 0.956Hz (y-dir) - 1st
  1.023Hz (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
- 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: ø-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), ±300mm
- Optimal damping ratio: 5.0%
- Services: Conceptual & Detailed Design / Manufacture / Installation / Performance test

Vibration Control Devices - Bridges & etc.
# Track Record of TESolution

- **Wind Tunnel Testing - Buildings**

<table>
<thead>
<tr>
<th>Project Description</th>
<th>Year</th>
<th>Services</th>
</tr>
</thead>
<tbody>
<tr>
<td>Haeundae Beach Resort, Busan, Korea</td>
<td>2017</td>
<td>- Cladding Pressure Study</td>
</tr>
<tr>
<td>CHP Stack, Wirye New Town, Korea</td>
<td>2015</td>
<td>- High Frequency Force Balance Test</td>
</tr>
<tr>
<td>Busan International Finance Center, Busan, Korea</td>
<td>2014</td>
<td>- Cladding Pressure Study - High Frequency Force Balance Test</td>
</tr>
<tr>
<td>Yongsan 3 Block Project, Seoul, Korea</td>
<td>2012</td>
<td>- Cladding Pressure Study - High Frequency Force Balance Test - Pedestrian Level Wind Study</td>
</tr>
<tr>
<td>Al Reem Island Four Vanes, Abu Dhabi, UAE</td>
<td>2009</td>
<td>- Cladding Pressure Study - High Frequency Force Balance Test - Pedestrian Level Wind Study</td>
</tr>
<tr>
<td>Lotte World Tower Seoul, Korea</td>
<td>2010</td>
<td>- Pedestrian Level Wind Study</td>
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