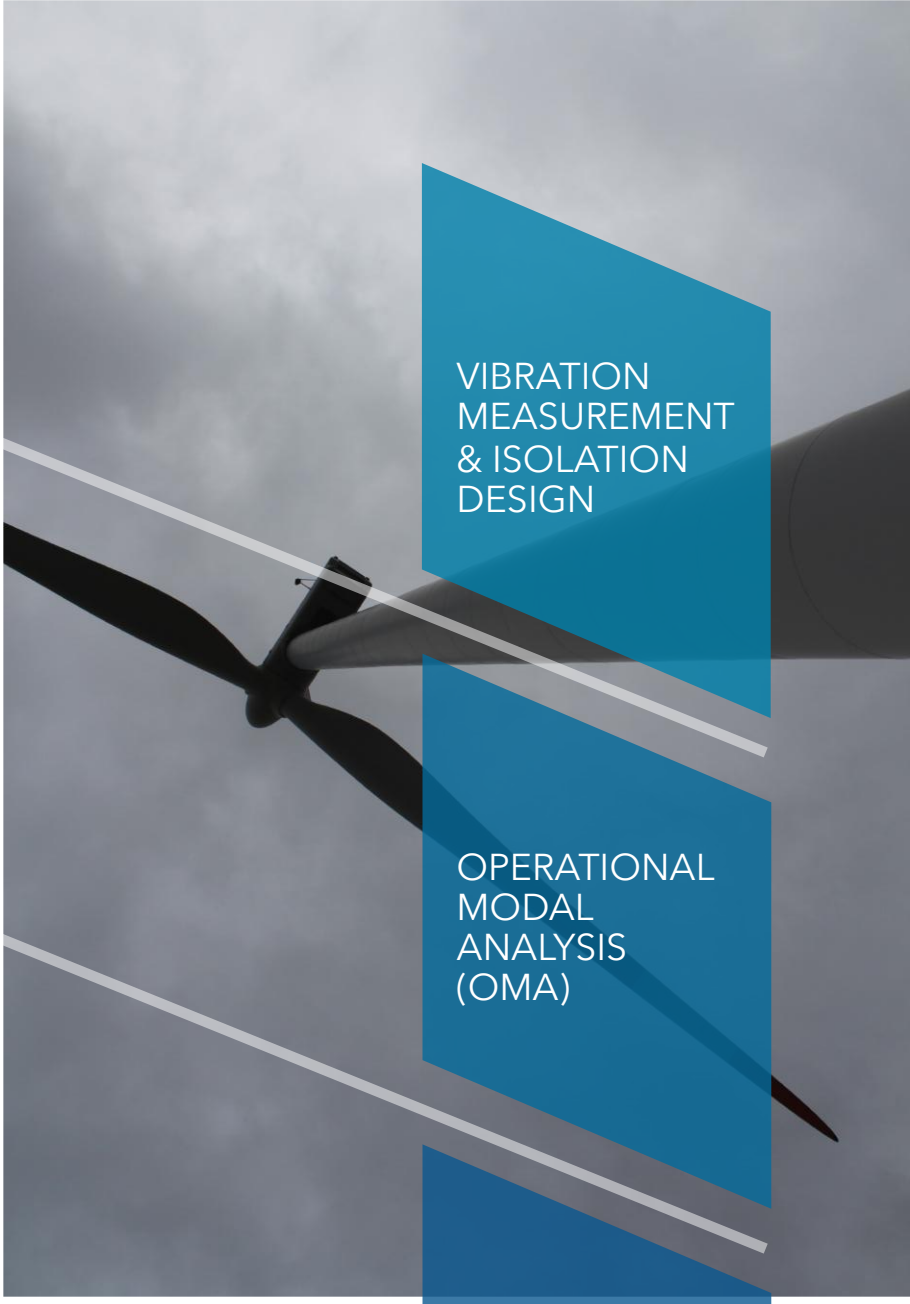



VIBRATION MEASUREMENT & ISOLATION DESIGN

OPERATIONAL MODAL ANALYSIS (OMA)

STRUCTURAL & SEISMIC MONITORING

# SENSO ENGINEERING

## SELECTED PROJECTS

The Netherlands

Turkey

Greece

Vibration Solutions
Senso

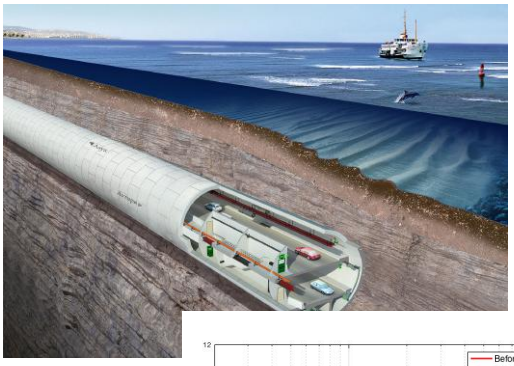
# DESIGN AND PROOF-TEST OF JET FANS IN AN UNDERSEA MULTI-STOREY ROAD TUNNEL

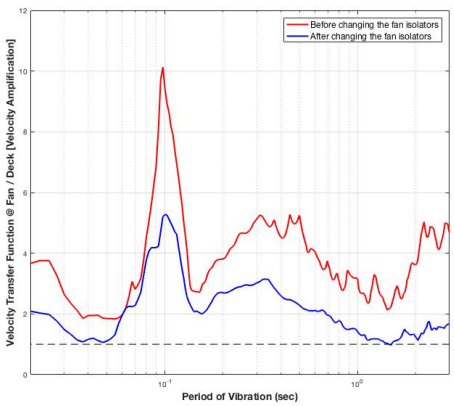
Jet fans are vital components of tunnel structures as they assure the air quality and safety in case of a fire. They are special equipment rotating with high frequency and require a precision in their support systems so that the rotation takes place safely, without a disturbance.

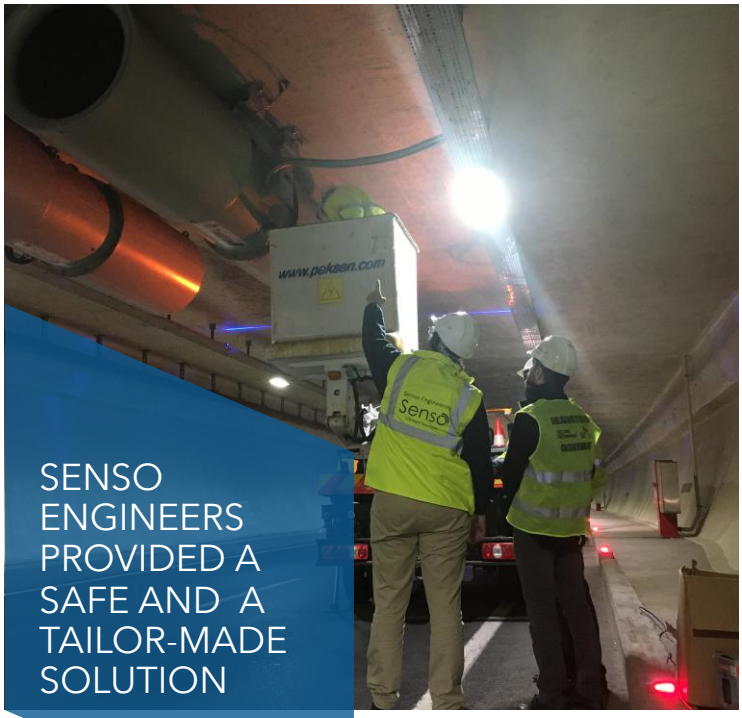
Eurasia tunnel is an underground tunnel that connects the European side of Istanbul to the Asian side, stretching from one continent to the other. The deepest point of the tunnel is 107m from the sea level. The tunnel consists of a 3.4km long TBM portion and total of 2km long NATM sections. The tunnel has two decks, creating three parts inside the tunnel. The upper deck has two lanes with direction from Europe to Asia, while the lower deck has two lanes in direction from Asia to Europe. The lower part of the tunnel is used a a service duct.

The jet fans of the low deck hang from the deck structure, which is simply-supported with 12m span. The jet fans are supported on vibration isolation units for isolating the high-frequency vibrations induced by the operation of the fans. Senso was commissioned to evaluate the existing design, and finally re-design the isolation units to assure that the jet fans function both in the high- and low-frequencies induced by the vibration of the slender deck. Senso diagnosed the issues, designed new isolators, produced the isolators in collaboration with Arsan, witnessed the replacement, and provided post-replacement

## DIAGNOSIS, DESIGN, PRODUCTION OF ISOLATORS AND PROOF TESTS






SENSO ENGINEERS PROVIDED A SAFE AND A TAILOR-MADE SOLUTION

*vibration measurement & design*

Customer: Yapı Merkezi & SK Engineering, Turkey

# DESIGN OF VIBRATION ISOLATION PADS FOR THE SLENDER TUNNEL DECK

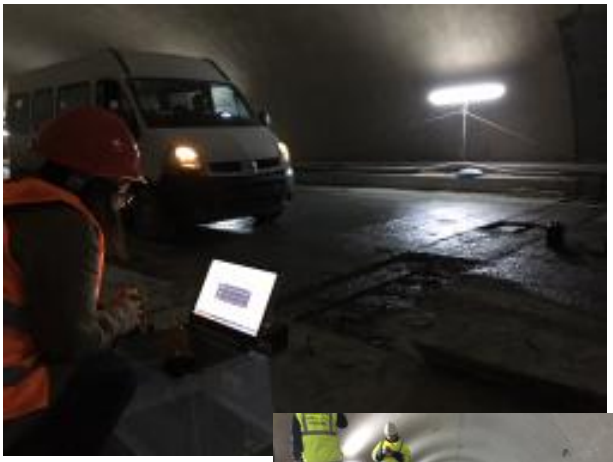
Eurasia tunnel is an underground tunnel that connects the European side of Istanbul to the Asian side, stretching from one continent to the other. The deepest point of the tunnel is 107m from the sea level. The tunnel consists of a 3.4km long TBM portion and total of 2km long NATM sections. The tunnel has two decks, creating three parts inside the tunnel. The upper deck has two lanes with direction from Europe to Asia, while the lower deck has two lanes in direction from Asia to Europe. The lower part of the tunnel is used a a service duct.

The upper deck of this tunnel structure is one of its kind since it is the only known floating deck in a TBM section, with such a large diameter (14m) and with such close proximity to a major fault (less than 10km distance to the Marmara Sea section of the North Anatolian Fault). The deck itself is quite slender with 12m span length and only 34cm of section depth. The vibrations of the deck during heavy traffic were thus of major concern.

Senso designed vibration pads on which the deck sits. The vibration isolation pads run over the corbels that support the deck, and these corbels are attached to the TBM section.

The main goal of the project was to make sure that the motorists do not feel the vibrations when passing over the deck. ISO vibration comfort standards are used for the design. Senso also designed a test procedure and verified the design after the construction, prior to the inauguration of the tunnel.

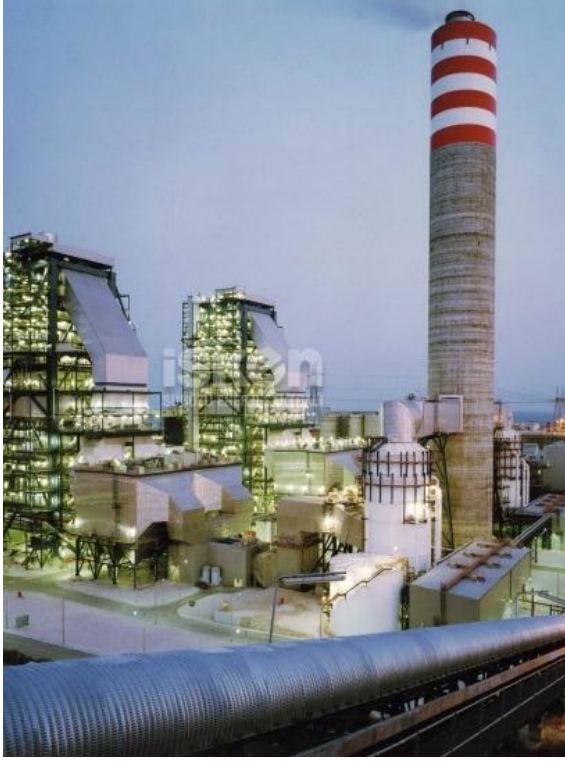
## DESIGN OF THE VIBRATION ISOLATION PADS AND ON-SITE PROOF TESTS




SENSO PROVIDED THE DESIGN AND TESTED THE ISOLATION PADS AFTER THE CONSTRUCTION

*vibration measurement & design*

Customer: Yapı Merkezi & SK Engineering, Turkey



*Senso Engineering mobilized in an extremely short notice, arrived to the site and conducted the required measurements with precision within the pre-defined schedule*

ISKEN is a two-unit 1210MW coal-fired power plant that produces approximately 6% of the electricity consumed in Turkey. As part of an extension of the production ring, the ID fans had to be replaced. This required evaluation of the existing foundations in terms of dynamic stiffness and strength. measurements are then required to be conducted with the correct sensors, sensitive data acquisition systems and with high sampling frequency up to 5KHz. Such a measurement also required the selection of correct physical filters adapted on the data acquisition system.

## MEASUREMENT WITH PRECISION IN THE HIGH-FREQUENCY RANGE

Estimation of the dynamic stiffness of the foundation is a difficult task as it requires forced-vibration measurements exciting the foundation within a desired frequency range.

Fans of this size are excited with a relatively high rpm and thus with a high frequency, exhibiting very low deformation amplitudes. Vibration

Following the instructions by the customer, this difficult task was achieved by exciting the giant fan with 1600rpm in various blade load positions. The vibrations of the fans in respect to its case as well as to the critical points in the reinforced concrete massive foundation were recorded and provided to the customer.

# OPERATIONAL MODAL ANALYSIS AND DAMAGE DETECTION IN A 9TH CENTURY STONE CHURCH

Operational Modal Analysis (OMA) is a useful tool for detecting the dynamic properties of structures. OMA is conducted in ambient vibration conditions by measuring and combining extremely low-amplitude oscillations of structures. The structure behaves in a fully elastic range during the measurements.

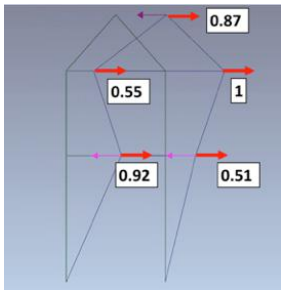
The outcome of OMA can be modal frequencies as well as mode shapes of the measured structure. These properties can later be used to calibrate structural finite element models or even to detect damages, if properly processed.

OMA requires an optimum placement scheme for sensors and correct use of sensor degrees-of-freedoms to be used for detecting the desired vibrational properties with a possible minimum number of sensors.

OMA principles were applied on a 9th century stone church by Senso. the church is built on mountains of Artvin, the North-Eastern most province of Turkey. The structure exhibits visible cracks and damage patterns.

Senso engineers studied the structure and detected the damages via visual inspection. The visual inspection concluded a damage scenario, which was later confirmed by using the OMA measurement results. In order to achieve this, Senso engineers conducted several trial tests and found the optimum sensor spatial distribution within the structure, taking into account expected in-plane and out-of-plane vibration modes.

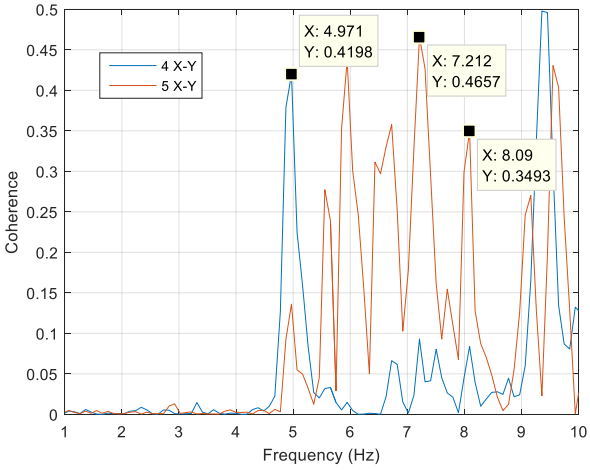
## OPTIMUM SENSOR PLACEMENT FOR DAMAGE DETECTION




OPTIMUM SENSOR PLACEMENT & DETECTION OF DAMAGES

Customer: Gürsoy Group Restoration, Turkey

*operational modal analysis*


*Masonry historical buildings of Yıldız Palace, Istanbul, have been measured and the findings were used in finite element modeling of these structures*

## OPERATIONAL MODAL ANALYSIS IN HISTORICAL MASONRY

Definition of the material properties is particularly difficult in historical masonry structures because of inability to perform destructive tests and the high scatter in material properties. Operational Modal Analysis is repeatedly used by Senso for defining the material properties of masonry historical buildings to be used in finite element analyses. The approaches and the output schemes developed by Senso allow engineers to update their computer models. This approach is suitable for all types of historical masonry structures provided that enough number of sensors is used in the measurements. Senso has a vast experience in this domain.

Three buildings of Yildiz Palace in Istanbul were measured prior to the extensive restoration works. The measurements were then used for calibrating computer models, that allowed engineers and the restaurateurs to avoid destructive material tests on the historical structure.

# STRUCTURAL MONITORING AND SAFETY ASSESSMENT ON WIND TURBINES

Wind turbines are dynamic systems with a relatively simple and non-redundant structural bearing system. They are also subjected to long working cycles and fatigue by time.

Structural safety of wind turbines needs to be checked after a certain life time is consumed. This structural safety often requires checking the structural situation as is, primarily by using on-site measurements and inspections, as well as comparing the measured response with the designed initial response. The structural connection and integrity of the turbine tower to the reinforced concrete foundation is the main issue in most cases.

Senso was asked to perform on-site measurements as well as a detailed safety check on a wind farm consisting of several wind turbines, approximately 9 years old. The on-site checks involved vibration measurements on the tower at various heights, as well as measurements of the differential displacements at the tower insert and RC foundation interface.

## COMBINATION OF ENGINEERING DESIGN WITH SITE MEASUREMENTS

The site measurements were then used to calibrate nonlinear structural models of each tower separately. Scenario wind speeds were run over the model to detect the residual moment capacity and the safe margin of wind speeds within which the turbines can safely operate.

The analyses and the site measurements were combined with a fatigue analysis using a rain flow spectrum, concluding varying safety levels for each turbine examined.


STRUCTURAL SAFETY BY USING VIBRATION TESTS

Customer: Akenerji Elektrik Üretim, Turkey

akenerji

*structural monitoring and safety assessment*

*The old above-ground station of Marmaray, Istanbul, was monitored for structural and seismic activities*

Marmaray is a partially operational transportation project with an immersed tube tunnel under Bosporus, Istanbul. The tunnel consists of two metro lanes. The construction of the above-ground stations and the railways still continue as of 2018. There are several old stations and other buildings along the alignment of the project. The historical Goztepe Station is one of such structures that need to be adapted to the requirements of the modern Marmaray project.

## STRUCTURAL AND SEISMIC MONITORING ON A HISTORIC STATION

Senso Engineering was hired to design and install a continuous monitoring system on the building. This monitoring system was designed to detect any further developments in the existing cracks due to the construction and piling works around the structure. The monitoring system was also used for detecting the damages on the old station due to earthquakes. Senso engineers regularly processed the monitoring data and informed the relevant parties about the current health of the structure, the results of heavy construction works close-by or any significant earthquakes occurred. Senso has also conducted ambient vibration tests on the structure, the results of which were used for FE model calibration.

Customer: OBS engineering and OHL

*structural and seismic monitoring*

# 24/7 SEISMIC MONITORING OF AVRASYA TUNNEL

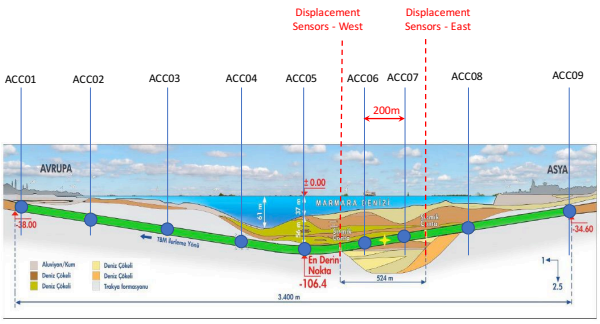
Avrasya Tunnel, a combination of TBM and NATM sections, connects Europe to Asia under Bosporus. It is monitored by several highly sensitive accelerometers as well as laser displacement sensors in critical locations. These data, collected from along a 5.4km tunnel stream into servers simultaneously, 7 days a week and 24 hours a day. The data that stream consist of tens of channels and gigabytes of numerical data.

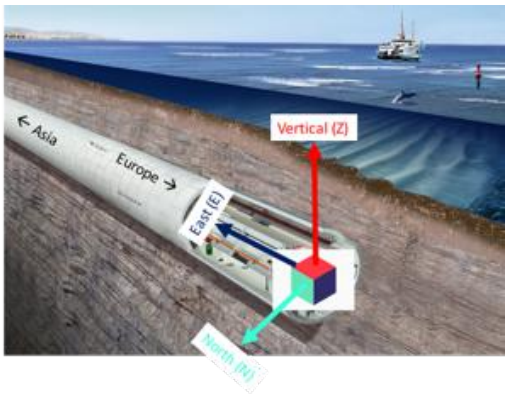
Senso Engineering is responsible for the processing of these data and producing regular and ad hoc reports after small, medium and large seismic events. These reports are aimed to check if the structural integrity is compromised after a seismic event, and they also help to decide if the tunnel should be closed to traffic.

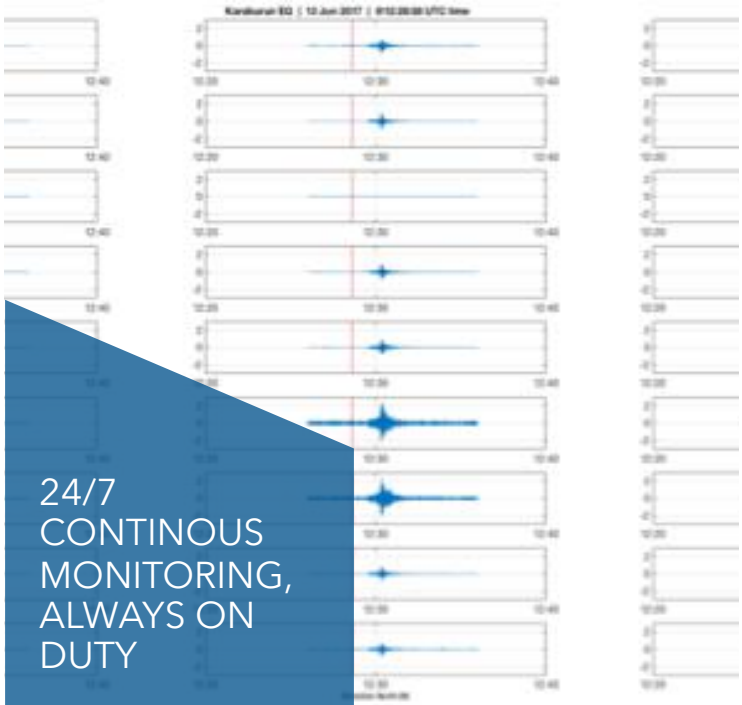
Senso Engineering has also prepared an alarm system that is used for warning the operators about the intensity of the earthquake and for possible actions to be taken. Senso has consulted the procedures to be followed after a major seismic event, after sequence of aftershocks. Criteria for deciding the scale of the seismic event as well as the relevant procedure to be followed has also been studied.

Senso has designed a redundant watchdog software running on two different servers simultaneously. These servers are geographically distributed to create a backup in case of a catastrophic event. The watchdog software checks the seismic data from 3 independent sources and compares with the streaming data, reaching conclusions about the effects of the seismic event instantaneously. Senso has also been working on implementing machine learning procedures on this watchdog.

# 24/7 CONTINUOUS MONITORING, ALARM AND WATCHDOG SYSTEMS



24/7 CONTINOUS MONITORING, ALWAYS ON DUTY

Customer: Egis Group

egis

*seismic monitoring*


# SENSO PROVIDES SOLUTIONS

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