GLOSSARY OF TERMS

IN

CABLE DYNAMICS

(Revised)

Hiroshi Tanaka
University of Ottawa, Canada

and

Helmut Wenzel
VCE Holding GmbH, Austria

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Preamble

Glossary compiled here is an empirical collection of technical terms that frequently appear in literature on *Cable Dynamics*. It owes many ideas and descriptions to the web-searched documents that are publicly available, including the *Wikipedia*, for example. However, the definition of terms given in this document is rather subjective, mainly aimed at intuitive understanding of the matter and little attention is paid for mathematical rigour or linguistic precision.

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DAQ
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Dead Load
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De-Icing
*Deterioration
DFT
Discrete Fourier Transform (DFT)
DOF
Drag Crisis
Drag Force
Drawing
Dry Cable Galloping
DSS
Ductility
Duhamel Integral
Durability
Dynamic Excitation
Dynamic Stiffness

Eigen-Frequency
Eigen-Mode
Elastic Hysteresis
Elasticity
Elongation
Environmental Noise
Equivalent Young's Modulus
Expert System
Extensometer

Failure
Fast Fourier Transform (FFT)
Fatigue
FDA
FEM
FEMU
FFT
Fibre Optic Sensors
Filter
Finite Element Method (FEM)

Finite Element Model Updating (FEMU)
Flutter
Folding Frequency
Fourier Series
Fourier Transform
Frenet-Serret Formulae
Frequency Domain Analysis (FDA)
Frequency Response Function (FRF)
Fretting
FRF
Froude Number
Fuzzy Logic

Galerkin Method
Galloping
Galvanization
Global Positioning System (GPS)
GPS
Gust Factor
Gust Response
Ground Wire
Guy Wire

Health Monitoring
Heat Treatment
Helical Strands
Helix
High-Speed Vortex Excitation
High Strength Steel
Hysteresis

Ice Accretion
Impulse Response Function (IRF)
Indicial Response Function
Inclined Cable
Infrastructure
In-plane Vibration
In-Situ
*Inspection
Instability
Intensity
*Investigation
IRF

Jensen Number

Kalman Filter
Kármán Vortices
Kelvin-Voigt damper
Kink
Knot

Laminar Flow
Laser Doppler Vibrometer (LDV)
Lay
LDV
Leakage
Least-Square Method
Life Cycle

Lift Force
Limit State
Linear Variable Differential Transformer (LVDT)
Load
*Load Testing
LVDT
Locked-Coil Strand

Magneto-Rheological Damper
*Maintenance
Markov Process
Mass Parameter
*Material Properties
MATLAB
Maximum Likelihood Method
Maxwell Damper
Membrane Structure
MEMS
Micro-Electro-Mechanical Systems (MEMS)
Miner's Rule
Modal Analysis
Modal Crossover
Modal Damping
Modal Mass
Modal Parameters
Modelling
*Monitoring
Monte Carlo Method
Mooring
MR Damper
Multi-Wire Helical Strand

Natural Frequency
Navier-Stokes (NS) Equation
Neural Network
Node
Noise
Nonlinear Vibration
Nonstationary Process
NS Equations
Nyquist Frequency

Offset
Optical Fibre
Out-Of-Plane Vibration
Overhead Power Lines

Parabola
Parallel Wires
Parameter Estimation
Parametric Excitation
Participating Mass
Pattern Recognition
PDF
Peak Counting
Peak Factor
Penalty Method
Piano Wire
Piezoelectric Accelerometer

Plasticity
POD
Poisson's Ratio
Posterior
Post-Tensioning
Power Spectral Density (PSD)
Prestressed Concrete
Pre-Tensioning
Prior
Probability Density Function (PDF)
Proof Stress
Proper Orthogonal Decomposition (POD)
Proportional Limit
PSD
PVC
Pylon

Quasi-Steady Approximation

Rainflow Analysis
Rain-Wind Vibration
Random Decrement (RD) Technique
Random Process
Random Vibrations
Rayleigh Damping
RD
Rebar
Reduced Frequency
Reduced Velocity
*Reference Period
*Rehabilitation
Reliability
*Remaining Working Life
*Repair
Residual Stresses
Resonance
Reynolds Number
Riser
Risk Rating
Rivulet
Robustness

Safety
*Safety Plan
Sag
Sag-To-Span Ratio
Scruton Number
SDOF system
Seismic Waves
Sensitivity Analysis
Sensor
Service Life
Serviceability
Seven-Wire Strand
Shallow Cables
Shear Modulus
Shell Structures
Signal Processing
Similitude Requirements

Simulation
SI Units
Skew Angle
Smart Fluid
Smooth Flow
S-N Curve
Span
Spectral Analysis
Spectral Windows
Spectrum
Stall Flutter
Standing Wave
Stationary Process
Stay Cables
Steel
Steel Wire
Stochastic Subspace Identification
Stockbridge Damper
Strain Energy
Strand
Stress Concentration
String
Strip Theory
Strouhal Number
Subspan
Surface Roughness
Suspension Bridge
Symmetry
System Identification

*Target Reliability Level
Taut String
TDA
Tendon
Thermal expansion
Thimble
Time Domain Analysis (TDA)
Time Series
TMD
Torsion
Toughness
Transverse Wave
Trend Removal
Tuned Mass Damper (TMD)
Turbulence

*Upgrading
*Utilization
Ultimate Strength

Vibration
Vortex Shedding Excitation

Wake
Wake Galloping
Wave
Wavelet Transform
Weldability
Wind Load

Wind Power Input
Wind Tunnel
Windows
Wire Gauge
Wire Rope
Wöhler Curve
Writhe

Yaw Angle
Yield Point
Yield Ratio
Young's Modulus

Terms with * are definitions according to ISO 2394 and ISO 13822.

Acceleration: The rate of change of velocity with respect to time.

It is often the quantity most easily detected in vibration measurement. If the motion is ideally simple harmonic, the magnitude of acceleration is given by the amplitude of vibration multiplied by the circular frequency squared. Note that the mean of acceleration is supposed to be zero. The estimation of vibration amplitude from measured acceleration often involves significant errors.

Accelerometer: An instrument used for measuring the acceleration.

In particular, low frequency, low amplitude accelerometers are suitable for the application in bridge dynamics. The common types of accelerometers for this application are piezoresistive, capacitive, and force balance accelerometers.

The accelerometer, in principle, is usually a high frequency spring-mass system, for which the elastic spring is often made of a cantilevered beam of metal or ceramic material, which bends under given acceleration. The displacement is measured by strain-sensitive gauges placed on the beam, or detected by the change of electric capacitance. The gauges are usually connected in a Wheatstone bridge.

ACM: Advanced Composite Materials.

ACSR: Aluminium power transmission conductors with steel reinforcement.

Usually a galvanized steel strand makes the core which carries the cable tension and aluminium wires helically winding it carry the power transmission.

AD Conversion: Sampling process of analog data to digitally reconstructed signal.

It is accomplished by a *sample-and-hold* circuit. The output becomes a sequence of voltage levels, which are to be converted to digital readings.

Advanced Composite Materials (ACM): Materials which consist of a polymer matrix reinforced with high-strength fibres and, compared to other traditional materials, possess distinctly advantageous characteristics such as light weight and high strength.

Every composite has at least two components: reinforcements which are high-strength, high-stiffness fibres and are immersed in a matrix, which is usually a high-performance resin system and combine the reinforcement material together at a microscopic level. Three basic types of fibre reinforcement materials in use are carbon/graphite, glass fibres and aramid. Their major advantages in comparison to conventional materials include high strength and stiffness, light weight, fatigue strength, impact resistance and corrosion resistance.

Major users of ACM were traditionally the aerospace industry but the market has been gradually expending to sporting goods and civil engineering applications as well. Carbon fibre reinforced polymer (CFRP) is now extensively applied to bridges for strengthening, reinforcement and repairs, for example.

Aeolian Vibration: Cable vibration caused by the vortex shedding excitation.

An aeolian harp is a musical instrument that makes sound in wind by the same mechanism. It is named after the Greek wind god, Æolus.

Aerial Spinning: A method for erection of parallel wire cables.

After erection of all wires over the required span by running the spinning wheels, the cable is compacted into a circular shape by a hydraulic device and wrapped up by a galvanized steel wire. It has been a preferred erection method for major suspension bridges.

Aerodynamic Admittance Function: A transfer function to express how effectively the frequency characteristics of velocity fluctuation are picked up by the aerodynamic force components.

It is expected that the magnitude of this function is close to unity in low frequency range and quickly tapers off in higher frequencies. A classical example is the ***Sears function***, which reflects the frequency characteristics of aerodynamic lift force in relation to a sinusoidal fluctuation of vertical velocity component. In general, the aerodynamic admittance cannot be decided analytically and needs to be estimated experimentally.

Aerodynamic Instability: Dynamic instability of structures caused by aerodynamic forces.

A dynamic failure of aircraft wings caused by aeroelastic phenomena, called ***flutter***, was a serious engineering concern from the early days of flight. Though the excitation mechanism was not exactly identical, the infamous collapse of the Tacoma Narrows Bridge in 1940 was often compared to the aerofoil flutter. ***Galloping*** instability of ice-covered power transmission lines is another example of aerodynamic instability.

Aeroelasticity: A field of engineering science which studies the interaction of inertia, elastic and aerodynamic forces acting on a structure or its members.

Aliasing: See the *Nyquist Frequency*.

Allowable Stress: The maximum stress level assumed to be acceptable in elastic design of a structure. Usually defined by the material yield stress or buckling stress divided by the safety factor.

Allowable Stress Design (ASD): A method to design structures such that allowable stresses are not exceeded when the structure is subjected to specified working loads.

Also called the Permissible stress design. It is a viable alternative to the Load and Resistance Factor Design (LRFD) or the Limit State Design (LSD).

Alloy: A solid solution or homogeneous mixture of two or more elements, at least one of which is a metal, and the mixed material itself has metallic properties.

Ambient Vibration Survey (AVS): A method to determine the dynamic characteristics of a structure by measurement of small vibrations, mostly micro-tremors, caused by existing disturbances such as earthquakes, wind and traffic, while the structure is in service.

In terms of data reliability, the forced vibration tests using shakers is probably the best method for the evaluation of dynamic characteristics of bridges. However, it usually requires a large operation, which is naturally costly, and could also mean an interruption of services. The ambient vibration survey, without any control on the input, is consequently an attractive alternative. This method is based on a few basic assumptions as follows: a) The input excitation is a broadband stochastic process which is adequately modelled by white-noise; b) The system characteristics are therefore well represented by the power spectral density function of dynamic response; c) The technique for measuring the dynamic response is sufficiently reliable; and d) The data acquisition and analysis are also sufficiently reliable. Hence, the reliability of this method is largely decided by these factors.

Anchorage: Structural details to fix the end of a cable.

One of the most critical design requirements for a cable-supported structure is to secure that the anchorage does not move or allow any creep deformation under expected magnitude of cable tension. There are a number of serious design considerations to ensure better creep resistance and/or high fatigue resistance.

ANPSD: Averaged Normal Power Spectral Density.

Antinode: A point where the vibration amplitude becomes maximum between adjacent nodes.

ARIMA Models: Autoregressive integrated moving average models. A more generalized version of the ARMA models.

Also called the Box-Jenkins models. In contrast to the ***ARMA models***, ARIMA can adequately model non-stationary time series by taking differences between the successively observed values rather than values themselves directly. A general model is referred to as ARIMA(p, d, q) where p, d and q are the number of autoregressive terms, non-seasonal differencing terms and lagged forecasting errors, respectively.

ARMA Models: Autoregressive moving average models. A statistical tool for modelling time series data for understanding its nature and forecasting the future values.

The model consists of two parts, an autoregressive (AR) part and a moving average (MA) part, and is referred to as the ARMA(p, q) model, where p and q are the order of each part, respectively. For a given time series of data point X_t, the ARMA(p, q) model is expressed by $X_t = \sum_{i=1}^{p} \varphi_i X_{t-i} + \sum_{i=1}^{q} \theta_i \varepsilon_{t-i} + \varepsilon_t$, where φ_i, θ_i are the parameters and ε_t, ε_{t-1},... are uncorrelated error terms. The ARMA models basically assume that the data are stationary.

ASD: Allowable Stress Design.

***Assessment: A set of activities performed in order to verify the reliability of an existing structure for future use.**

ASTM: ASTM International.

ASTM International: An international, non-profit organization that develops and publishes voluntary codes and technical standards for a wide range of materials, products, systems and services.

It was originally established as the American Society for Testing and Materials (ASTM). The organization now has more than 30,000 members in over 120 countries.

Autoparametric Resonance: Destabilization effect of a component subsystem induced by the vibration of another component subsystem, when both of them are components of a mechanical or structural system which consists of two or more coupled vibrating subsystems.

Parametric excitation is an important example of it.

Averaged Normal Power Spectral Density (ANPSD): A method to identify all the possible natural frequencies participating in the vibration at a time by taking the average of all the normalized power spectral density functions obtained from the multi-point records.

The method was developed by Felber (1993) as a fast and effective way to identify many structural vibration modes participating in the vibration measured in ambient survey. It is a convenient way to display the most significant frequencies at a single spot in a series of motions in a certain direction. However, it should be noted that not all the peaks identified in this method necessarily correspond to the natural frequencies.

AVS: Ambient Vibration Survey.

Bayesian Statistics: A statistical method that handles all uncertainties by probability. It provides a different paradigm for both statistical inference and decision making from the conventional statistics.

The name is after Thomas Bayes (1702-61) but it may not be following particularly his idea. Bayes theorem states that the probability of A given B times the probability of B is equal to the joint probability of A and B, or $P(A \mid B) = P(A \cap B) / P(B)$.

The major difference between Bayesian statistics and other statistical methods is that the traditional statistics examine the probability of the data given a model or hypothesis, while Bayesian statistics examine the probability of a model given the data. This significantly enhances the power of statistical analysis. In particular, Bayesian methods make it possible to incorporate scientific hypothesis in the analysis by means of the prior distribution. It can be then applied to problems whose structure may be too complex for conventional methods to handle. The Bayesian paradigm is based on an interpretation of probability as a rational, conditional measure of uncertainty, which closely matches the sense of the word "probability" in ordinary language.

There are three particularly important terms used in Bayesian statistics: the prior and posterior probabilities and likelihood. The ***prior*** is the observer's belief expressed by the probability $P(X)$ before any data (D) are observed. The ***posterior*** refers to the probability $P(X \mid D)$ after observed data have been taken into account. ***Likelihood*** is the probability with which D is expected to take place, that is the conditional probability $P(D \mid X)$ of the data given a particular model. Since the probability of D depends on the value of X, X is called the *parameter* of $P(D \mid X)$. Based on the Bayes theorem, the posterior probability is calculated as a product of the prior probability and likelihood divided by $P(D)$, which is called *evidence*. It also means that any events which were not observed are not involved in the computation. This is a key principle of Bayesian statistics: only what is actually observed is relevant in determining the probability that any particular model is true.

There has been a resurgence of Bayesian approaches in recent years and the methodology now plays a central role in many fields, from ***expert systems***, ***machine learning***, and ***pattern recognition***, to applications in finance and the law. The special situation, often met in scientific reporting and public decision making, where the only acceptable information is deduced from available documented data, is addressed by objective Bayesian methods, as a particular case. Thus it tells us, for example, the true likelihood of a person having an HIV infection if he tests positive, or that of person X being the murderer if his fingerprints turn up on the weapon.

Beating: A phenomenon where the magnitude of vibration varies regularly with the differential frequency of the two component vibrations.

When two vibration components are present at the same time and same place and if their frequencies are very close to each other, the combined signal of them will vary its magnitude regularly with a rate equal to the difference of frequencies of these two components. This differential frequency is called the beat frequency.

Bifurcation: A sudden appearance of a qualitatively different solution, associated with a parameter change, of a nonlinear dynamical system.

It often accompanies the onset of chaos.

Bluff Body: A non-streamlined body often with a blunt front and/or sharp edges against on-coming flow. The aerodynamic characteristics of a bluff body are largely defined by the flow separation and formation of significant wake around the body.

The term is often referred to when talking about *Wind Engineering* and/or *Industrial Aerodynamics*, which covers the aerodynamics with non-aeronautical applications.

Boundary Conditions: A set of restraints at the boundary of its domain to specifically define an appropriate solution to a problem.

Idealized boundary conditions to identify a fixed end, a hinge, a free end or a spring support are often employed for solving the beam equations, for example.

Boundary Layer Wind Tunnel: A kind of wind tunnel which has a long test section to develop turbulent boundary layer flow as the simulated natural wind.

It is a means to simulate micrometeorological characteristics of natural wind in model scale. The idea was originally developed by Martin Jensen, a Danish engineer, who experimentally arrived at the conclusion that "the phenomena induced by natural wind can be reproduced only when the model tests are performed in a boundary layer which was created in a similar way as the case of natural wind and also when the linear scale of its turbulence coincides with the linear scaling of other models placed in it". This scaling factor, h/z_0 , is now called the ***Jensen number***, where $h =$ a linear dimension needs to be represented in the test, and $z_0 =$ the roughness length of the flow.

The idea of the boundary layer wind tunnel was extensively developed by A.G. Davenport and J.E. Cermak in the North America for large scale industrial applications.

Brittleness: Nature of a material which fractures without having appreciable plastic deformation.

Fracture of material in its elastic range is called the *brittle fracture*.

Buckingham Pi-Theorem: One of the fundamental theorems in dimensional analysis. It states that "when a physical phenomenon is defined by n variables that contain m primary dimensions, the equation relating all the variables will have p dimensionless parameters, where $p = n - m$".

The final equation will be in the form of $f(\pi_1, \pi_2, ..., \pi_p) = 0$, where π_i ($i = 1,2,..., p$) are the dimensionless parameters. Introduction of the concept is credited to an American physicist Edger Buckingham. It should be noted that though the theorem provides a way of generating sets of dimensionless parameters, they are not unique and hence not necessarily always the most physically meaningful choices. See also the ***Similitude Requirements*.**

Buckling: An instability failure mode of an engineering structure or its members mostly under compression.

The critical buckling load is decided by the stiffness against deformation and the effective length of the member. Buckling can also take place in torsion, a combination of torsion and bending or only locally in a small portion of a structural member. Infamous collapse of the Québec Bridge in 1907 was a well-known example of buckling failure in bridge engineering.

Buffeting: Dynamic structural response caused by wind turbulence, which either inherently exists in natural wind or was created by existence of upstream objects. Buffeting is usually considered and analyzed as a forced vibration caused by time-dependent aerodynamic forces due to velocity fluctuations.

Buffeting is a stochastic vibration, consisting of a wide range of frequency components, and its amplitude is randomly fluctuating. However, the buffeting of large structures, such as bridge decks and chimney stacks, often appears as a narrow-band response only in the first couple of modes and quite random in its amplitude. Its amplitude generally increases in parabolic manner with the mean wind speed. The peak response amplitude is usually three to four times greater than the root-mean-square response.

Consequence of having buffeting vibration is usually not immediately catastrophic to the structure but can be a nuisance in terms of the structural serviceability. Long-time influence of it, such as fatigue damage, can be a serious engineering concern.

Bundle Conductor: A number of conductors placed together in parallel orientation by using rigid spacers between them to maintain the geometrical arrangement.

Bundle conductors are advantageous in carrying the greater amount of current for a given weight. Also, they result in lower reactance compared to a single conductor.

Cable: A flexible metal wire or a group of wires, used as a structural member against tensile force.

Cables employed as structural tension members are usually one of the following five types: a) A single ***piano wire***; b) ***Seven-wire strand***; c) ***Multi-wire helical strand***; d) ***Parallel-wire strand***; and e) ***Locked-coil strand***. A piano wire has much higher tensile strength at the order of 3000 MPa and much smaller ductility compared to ordinary structural steel. Young's modulus is around 205 GPa. It is usually assembled to form wire strands.

Cables are primarily assumed to be perfectly flexible and resist only against tension. However, in reality, there is stiffness against both bending and torsion. Because of its large flexibility, cable often exhibits a relatively large static deflection and, as a result, nonlinear structural characteristics. Once in vibration, cable has very low structural damping, usually an order of magnitude less than that of other types of structural members.

Cable Equation: A mathematical equation to provide a compatibility relationship between change in cable tension and the geometry of the cable.

This condition is required when the elastic extension of the cable is considered and also when the time-dependent change of cable tension comes into consideration in dynamic analysis.

Cable Length: A nautical unit. A cable length is equal to one-tenth of a nautical mile, or 185.3 meters.

Cable Plane: A plane in which a freely suspended cable from two points would stay.

Cable-Stayed Bridge: A type of bridge suitable for medium to long span crossings. Load bearing deck is supported by stay-cables, which are anchored to the deck itself so that the horizontal cable tension is introduced to the deck as an axial force.

Cable-stayed bridges are often compared with ***suspension bridges***. A simple analogy of a cable-stayed bridge in terms of its mechanical principle is a continuous beam on elastic supports provided by having multiple cables, whereas a suspension bridge can be considered as a beam with an additional bending stiffness provided by the axial cable tension.

For the span length of 0.5 to $1km$, the cable-stayed bridges are generally less expensive than suspension bridges. It is generally regarded at this point in time that the cable-stayed bridge span would not exceed $1.5km$ or so because the elastic stability of the stiffening girder due to axial force becomes really critical. Besides, beyond the span length of $1km$, the suspension bridges tend to become more economical than cable-stayed bridges, so long as the cable anchorages can be properly secured.

Currently the longest span of a cable-stayed bridge is a little over $1km$ of the Stonecutter crossing in Hong Kong.

Cable Structures: Long-span or large-space structures supported by cables, including suspension bridges, cable-stayed bridges and cable-supported light weight membrane roofs. Guyed masts and cable supported towers could be included in this category, too.

Carbon Steel: Ferrous alloys with approximately 0.02 to 2% of carbon in mass. Also, small amount of other alloying elements such as *Mn*, *Si* and *Cu* often exist.

Low carbon or mild steel with less than 0.3% carbon content has a relatively low tensile strength but less expensive and malleable. Its surface hardness can be increased by heat treatment. Medium carbon steel with 0.3 to 0.6% carbon content is widely used as structural steel because of its well-balanced strength and ductility and also good wear resistance. Its density is $7861 kg/m^3$, Young's modulus is $210 GPa$, the yield strength and tensile strength are typically $250 MPa$ and $400 MPa$, respectively. High carbon steel with 0.6 to 1% carbon content is very strong but brittle. It is used for springs and high-strength wires. Steel with carbon content of higher than 1% is used for special purposes such as making cutleries.

Catwalk: A narrow cable net pathway for workers, often high in the air along a bridge or cables.

Catenary: The shape of a suspended cable under the action of its own weight, which is assumed to be uniform along the cable itself. The cable is also assumed to be perfectly flexible and inextensible.

The word *catenary* is from the Latin for ***chain***. Mathematically, it is expressed by using the hyperbolic cosine function and the only parameters coming into the equation are the cable tension, the weight per unit length and the span length. Neither elastic modulus nor the cable diameter is involved.

In reality, however, cables are stretchable and the stiffness in bending and/or twisting would also modify the catenary form. Mechanics of *elastic catenary* has been studied by Irvine (1981). Elastic cables with bending and/or torsional stiffness are considered to be *elastic rods* and the mechanics of them is a more contemporary research topic; see, for example, Bowden (2004).

CDF: Cumulative distribution function.

CFD: Computational fluid dynamics.

Chain: A connected, flexible series of metal links.

Compared to an elastic cable, a chain carries the same tensile force with no elongation. It can be considered as an idealised cable of $EI \rightarrow 0$ and $EA \rightarrow \infty$, which would form a catenary shape when freely suspended.

Chaos: An aperiodic and yet deterministic behaviour of certain dynamical systems, in which the systems appear to be random and unpredictable because of their high sensitivity to the initial conditions, typically termed the *butterfly effect*.

Chord: A line joining two supports of a cable.

The horizontal projection of the chord length is called the ***span***. The chord length is equal to the span length if a cable is stretched horizontally, or the angle of vertical inclination is zero.

Clamp: A device used to hold an object in a fixed position.

Computational Fluid Dynamics (CFD): A branch of fluid mechanics that uses numerical methods and algorithms to analyze problems that involve fluid motion.

Large capacity, high-speed computers are employed for numerically analyzing the discretized Navier-Stokes, continuity and energy equations under given boundary conditions to obtain variables such as instantaneous pressure, velocity components, fluid density and temperature at each assumed grid point.

One of the most critical challenges in CFD is a question of turbulence modelling because turbulent flow produces fluid interaction at a wide range of length scales and the direct numerical simulation of the NS equations is very expensive, even if it is physically possible at all. Various turbulence modelling methods have been attempted to a wide range of practical problems including one or two equation models such as $k - \varepsilon$ model simulation, Reynolds stress models, large eddy simulations, detached eddy simulation and so on.

Convolution: A mathematical operation for determining a system output in an integral form using an input signal and the system impulse response function.

It is defined as the product function of $f(t)$ and $g(t)$ by $(f * g)(t) = \int_{-\infty}^{\infty} f(\tau)g(t-\tau)d\tau$. For discrete functions, $(f * g)(n) = \sum_{m} f(m)g(n-m)$, which is evaluated most commonly by using ***FFT*** algorithms.

Corona Discharge: An electric discharge caused by the ionization of air surrounding an electrode such as power lines.

Coronas can generate various effects which could be annoying or even disadvantageous to human health, including the power loss, ozone production, generation of audible noise, electromagnetic interference and/or insulation damage and failure of electrical equipment.

What is known as *St. Elmo's fire* is an electrical weather phenomenon, where luminous plasma is created by a corona discharge caused by thunderstorms.

Correlation: A measure to indicate how much two variables are statistically related.

Correlation is one of the most fundamental concepts in describing the statistical relationship between two signals. It can be the relationship between the excitation force and dynamic response, or between dynamic deflections at two different locations of the same structure, for example. As a special case, the correlation of a signal with the same signal itself, but with a given time interval in between, can be taken and in this case it is called the auto-correlation as opposed to the cross-correlation with the same operation between two different signals.

The correlation between two signals can be described in various forms with different degree of sophistication, including the correlation functions, cross-spectral density functions and coherence.

Corrosion: Chemically induced damage to a material that results in deterioration of the material properties.

It is difficult to perfectly prevent corrosion but it needs to be minimized by proper choice of material and design, coatings and/or environmental control, as much as possible, since corrosion will eventually results in failure of the component. ***Stress corrosion*** is a type of failure mechanism that takes place particularly when material is under tensile stresses, which are often ***residual stresses*** in the material, above certain threshold value, together with the environmental conditions. It is particularly sensitive to temperature environment. The collapse of the Silver Bridge, a 680m long eye-bar chain suspension bridge over the Ohio River, in 1967, is known to be a result of stress corrosion.

Corrosion Protection: Practice to guard materials employed for engineering purposes from degradation or deterioration of their physical, mechanical or aesthetic properties due to environmental chemical attacks such as oxidation.

Being exposed to very aggressive natural and industrial environment, corrosion protection of cables is often a very serious engineering issue. Corrosion protection measures are taken in variety of ways including a) Zinc coating or colouring of steel wire; b) Wrapping of wires by polyethylene tapes and other plastic covers; c) Coverage of assembled wires by high density plastic or steel sheath; d) Grouting of grease, cement, wax etc. between wires; and e) Forced ventilation.

Coulomb Damping: Nonlinear damping as a result of dry frictional rubbing that often exists due to sliding at structural joints and supports, or cable wires.

Creep: A slow flow of metal under large normal stresses or high temperature.

As a transient stress-strain status, it is called ***creep*** if strain is increasing under the same stress level, whereas if the stress is decreasing while the strain remains constant, it is called ***relaxation***. Method of determining creep or stress relaxation behaviour is called a creep test. Standard creep testing procedures are defined by ASTM standard E-139 etc.

Critical Damping: Magnitude of damping beyond which the energy dissipation is so large that vibratory motion would not exist any more.

In ordinary structural vibration, the magnitude of damping is indicated by the fraction of critical. For many of the civil engineering structures, the overall structural damping is the order of 1% of critical.

Critical Reynolds Number: Reynolds number at which the transition of separation shear flow takes place, resulting in a sudden drop of drag force and existence of less organized wake flow.

For the case of a circular cylinder against transverse flow, the transition is known to take place at $(\mathrm{Re})_{cr} \approx 3\times10^5$. However, in reality, the critical Reynolds number can only be indicated by a range rather than a definite number, since it is easily influenced by many factors including the ***surface roughness*** of the cylinder and the level of flow turbulence. Experimentally, it is evidenced by a sudden drop of drag force on the body and loss of more regular flow pattern in its wake.

Cumulative Distribution Function (CDF): A function to represent that the probability of an event is less than or equal to a certain value.

For a continuous random variable $X(t)$ defined for $-\infty < t < \infty$, the cumulative distribution function is defined by $P(x) = \Pr ob[X(t) \le x]$. It is related to the ***probability density function*** $p(x)$ by $P(x) = \int_{-\infty}^{x} p(\xi)d\xi$.

Curvature: A measure to indicate how sharply the tangent of a curve changes its angle.

The reciprocal of the curvature is called the *radius of curvature*. For a shallow cable suspended between two supports, the curvature is approximately given by the second derivative of the deflection. See also the ***Frenet-Serret formulae***.

***Damage: Unfavourable change in the condition of a structure that can affect structural performance.**

Damage Detection: On-site, non-destructive identification of structural damage.

Periodic visual inspections provide a generally economical means for assessing the structural conditions. However, they are inherently subjective so that the reliability of outcome is often less than desired. Also, most of non-visible degradation of the structural functions would remain undetected by visual inspection alone.

The structural health monitoring (SHM) system should be inexpensive, non-invasive and automated, so that subjective differences by operator can be avoided. In particular, it must be able to detect all of significant structural damages without an exception.

The detection of damage need to be ideally in four levels; a) If any damage is present? b) Where is it located? c) How severe the damage is? and d) How long the remaining service life of the structure would be?

Damper: An artificial device to augment the effective damping of the structure.

Controlling the adverse effects of structural vibration can be achieved either by a) reducing the influence of external disturbances applied to the structure, or by b) increasing the damping force to dissipate dynamic energy out of the system. Improvement of aerodynamic performance by adding edge fairings to a bridge deck is typical of the first category. A typical example of the second category is the installation of the artificial dampers. They can be simply an addition of viscous materials or frictional mechanisms at the movable joints. The World Trade Center Towers, New York, had nearly ten thousand viscoelastic damper elements installed in their frames in each building.

Artificial dampers can be also a fairly complicated mechanical system, which may need to be operated by supplying additional energy from outside. The damper system which requires the additional energy for controlling structural vibration is called an ***active control*** system. Gyro-stabilizer, a system to stabilize the rolling motion of a ship by rotating a gyroscope, is an example of active control system. Many of the artificial dampers often listed in references such as shock absorbers, hanging chains, water sloshing basins etc., on the other hand, usually do not require any energy supply from outside for their operation. Their action is triggered by the vibration of the primary structure itself and the induced action accordingly works in dissipating energy. This type of damper is called a ***passive control*** system. ***Tuned mass dampers*** can be either active or passive.

Damping: The capacity of structures to dissipate energy imparted by the external forces.

The dissipation of dynamic energy during vibration results from many different sources, such as the imperfect elasticity and internal friction of structural materials, friction of structural members at their joints and support mechanisms, aerodynamic and hydrodynamic damping due to surrounding environment, the nonlinear structural characteristics, energy dissipation through foundation and substructures, and so on. In any of these, theoretical evaluation of damping capacity is generally limited. For this reason, it is essentially important to consult to the results of the field experience as references.

Though the mechanism of damping is quite diverse, their overall effects on vibration is usually characterized by considering an equivalent viscous damping, crystallized in a single number of ***damping ratio*** (ζ) as a fraction of critical.

If the overall damping of the system is 1% of critical, for example, the free vibration amplitude will be reduced to a half after 11 cycles, whereas the 10% damping will reduce the amplitude to a half at each cycle. When damping is at or beyond critical, there is no vibration.

DAQ: Data Acquisition.

Data Acquisition (DAQ): Sampling and processing of signals, usually manipulated by a computer, to obtain desired information.

The components of data acquisition systems include appropriate sensors that convert any measurement parameters to electrical signals, which are acquired, displayed, analysed and stored on a computer by interactive control software and hardware.

Data Mining: Extraction of potentially useful, previously unknown, information from large database.

It is the practice of automatically searching large stores of data for patterns, which would not be recognized otherwise. In this sense, it is also termed as *knowledge-discovery in databases*. Data mining grew as a result of very rapid developments in storing massive amount of data and necessity for applying statistical analyses and search techniques to them for ***artificial intelligence***.

Dead Load: The weight of a structure when it is considered as the load applied on it.

Decision Support System (DSS): A computer-based information system that is designed to support decision making activities by compiling useful information from raw data, documents, personal knowledge and business models etc. to identify problems, estimate, evaluate and compare alternatives.

Note that a DSS is meant for supporting, not automating, in making decisions. It consists of a multidisciplinary training, including database research, artificial intelligence, human-computer interaction, simulation methods, software engineering and communication technology. A growing area of DSS application is in production and marketing for sustainable development, for example, including the management of structures.

Degrees-Of-Freedom (DOF): The number of displacements for describing the characteristics of a given vibration.

The concept of DOF is applicable only in terms of mathematical modelling of vibration. The same vibration of a structure could be considered a multi-degree-of-freedom (MDOF) or it may be approximated as a single-degree-of-freedom (SDOF) system, depending on how the structure is conceptually modelled.

De-Icing: The process of removing ice from a surface.

Anti-icing, on the other hand, is the process of preventing ice from forming on a surface.

***Deterioration: Process that adversely affects the structural performance, including the reliability over time.**

Deterioration of structural performance can be caused by various reasons, such as:
1) Naturally occurring chemical, physical and biological actions;
2) Repeated actions such as those causing fatigue;
3) Normal or severe environmental influences;
4) Wear due to use; and
5) Improper operation and maintenance of the structure.

DFT: Discrete Fourier Transform.

Discrete Fourier Transform (DFT): Fourier transform of a discretely indexed series. Usually executed by the use of the fast Fourier transform (FFT) algorithms, which are extremely efficient in computation.

DOF: Degree-Of-Freedom.

Drag Crisis: Aerodynamic instability of a circular cylinder in drag direction caused by a sudden change of drag force at the flow speed corresponding to the critical Reynolds number.

The critical Reynolds number is characterized by a sudden drop of the drag force with the increase in wind speed. If a circular cylinder exposed to the normal flow is swinging back and forth parallel to the wind direction, and if the change in the relative wind speed takes place at this sensitive speed range, it is possible to have the induced aerodynamic force acting in the same direction as the body motion, and thus generate the negative aerodynamic damping. In case of a smooth circular section, this is expected to take place at the Reynolds number of 2 to 5×10^5. Considering a typical cable diameter of 50 to $150mm$, possibility of having this instability is at the wind speed of 20 to $60m/s$.

Drag Force: Fluid dynamic force component taken parallel to the mean flow direction.

Drawing: A manufacturing process for producing a wire by pulling the material through a series of dies.

Dry Cable Galloping: Aerodynamic instability predicted for an inclined cable in some particular positions against wind.

This instability was identified not by field observation but by wind tunnel tests for very specific orientation of cables against wind. The cause of this instability has been related to the critical Reynolds number, the axial air flow along the cable, wake vortices etc. but the research community is not in full agreement yet regarding this point. Though the field observation of this instability has never been confirmed, its existence has been experimentally predicted, confirmed and stability criteria have been established by some researchers.

DSS: Decision Support Systems.

Ductility: The ability of a material to plastically deform without rupture.

Ductility is usually defined by tension tests but may also be considered in bending. More ductile materials show larger deformation before fracture, and hence, given the same strength and hardness, the material with the higher ductility would be more desirable. The lack of ductility is often termed ***brittleness***. The ductility of material may change if conditions are altered. A decrease in temperature tends to make the same material more brittle.

Duhamel Integral: See the *Impulse Response Function*.

Durability: The ability of a material, structure or its component to resist against actions caused by environmental or service conditions, which may give adverse effects or deterioration of the intended functions.

Dynamic Excitation: The extraneous sources which cause dynamic response of structures.

Civil engineering structures are usually designed to withstand the static loading, including dead load. However, in reality, the structures are often exposed to dynamic load as well. Main sources of dynamic excitation for ordinary civil engineering structures are moving vehicles and pedestrians, wind, earthquakes, ocean currents and waves, operation of machines, and possibly blast loading. It is standard design practice to cover these anticipated dynamic effects by either considering equivalent static forces or dynamic amplification factors, though sometimes more elaborate dynamic analyses would be required.

Dynamic Stiffness: The ratio of excitation force to the induced displacement, when an idealized system performing a steady-state simple harmonic motion is considered.

The concept is equivalent to an element of stiffness matrices in ordinary static analysis. The dynamic stiffness, however, is given as a function of the frequency of motion. General formulation of dynamic stiffness for an inclined cable was established by Starossek (1991).

Eigen-Frequency: Also called the *natural frequency*.

Eigen-Mode: Characteristic shape of amplitude distribution when a structure is freely vibrating at one of its natural frequencies. Also called the *vibration mode*.

Elastic Hysteresis: Difference between strain energy required to generate a given stress in a material and elastic energy at that stress.

Hysteresis exists when the dynamic strain of the system that does not instantly follow the applied stress, resulting in the stress-strain curve making a loop for each stress cycle. Since the area under the curve represents the ***strain energy***, the area surrounded by the clock-wise loop is the energy dissipated as heat in one cycle of vibration. Elastic hysteresis divided by elastic deformation energy is equal to damping capacity.

Elasticity: Ability of a material to return to its original shape when applied load that caused deformation is removed.

Elasticity is a concept opposed to ***plasticity***, which is a tendency to remain deformed. When a material is linearly elastic, the slope of the straight line portion of a stress-strain diagram is called the modulus, or coefficient, of elasticity. Since both stress and strain have the normal and shearing components in all three directions, in general, there can be 21 moduli of elasticity for any linearly elastic material. When the material is homogeneous and isotropic, because of symmetry, the number of elastic moduli is reduced to two.

Elongation: A ratio defined in a tensile test by the increase in gauge length measured after rupture to the original gauge length.

It is an important measure of the material's ***ductility*** and expected to be 35% or so for the case of ordinary mild steel. Elongation cannot be used to predict behaviour of materials subjected to sudden or repeated loading.

Environmental Noise: Unwanted sound that is loud, unpleasant, or unexpected.

It is disturbing, annoying, and even causing health or psychological problems to different extent, such as hearing damage, sleep disorder, high blood pressure or greater sense of frustration. It can come from a variety of sources such as factories, construction projects, vehicle traffic and aviation noise.

Philosophically, one difficult aspect of acoustic noise control is that the definition of noise itself is quite subjective; some sounds are considered noise by some but not by others. Even in musical scenes, a consensus may not be reached amongst those who are involved regarding what to be called noise.

On the other hand, noise control technology in reality is becoming a more and more serious engineering topic. Reduction of noise levels or controlling the airborne and structure-borne noise by the use of curtains and barriers, damping with absorbent materials, enclosure of sources or by isolation of vibrating structural elements are possible means often considered.

Equivalent Young's Modulus: The effective magnitude of Young's modulus of a suspended cable when both of its elastic and geometrical stiffness are considered. Formulation was introduced by M.J. Ernst.

When a cable of length L and the axial stiffness EA is vertically inclined by angle θ and subjected to tension T along its chord, the equivalent modulus of elasticity E_{eq} can be defined by $E_{eq} = E/\left\{1 + E \cdot (\gamma l)^2/12\sigma^3\right\}$ where $l = L\cos\theta$, $\sigma = T/A$ and $\gamma = w/A$.

Expert System: A software-based artificial intelligence system which analyzes information and upgrades the quality and quantity of database for specified purposes.

The primary goal of expert systems is to make knowledge-based artificial intelligence that is available to decision makers. A major feature of the system is reliance on the database comparable to that of human experts, whose knowledge is based on a theoretical understanding of the problem and a collection of heuristic problem-solving rules obtained through professional experience.

Extensometer: An instrument for measuring changes in linear dimensions.

Failure: The state or condition of a structure or its component that becomes unable to function for expected services.

Structural failure could occur because of various reasons, such as a) yielding; b) fatigue failure; c) corrosion failure; d) ductile or brittle fracture; e) creep rupture; or even too much deflection elastically, if the design was not appropriate or external loads exceed the expected magnitude.

Fast Fourier Transform (FFT): A highly efficient algorithm to compute the discrete Fourier transform (DFT) in high speed.

The method developed by Cooley and Tukey (1965) has been commonly used. However, some other algorithms are also known.

Fatigue: The adverse effect on metal of repeated cycles of stress.

The fatigue fracture is said to start with micro-cracks or defects, which cause a localised ***stress concentration***, resulting in growth or propagation of them but without any appreciable deformation of structure. Repetition of this process would cause decreased toughness, impact strength and tensile elongation, and eventually failure of the material at considerably lower stress level than the original tensile strength. When the number of cycles-to-failure (N) is tested and plotted against given constant stress levels (S), it is called the ***S-N curve*** or ***Wöhler curve***, which allows designers to make a basic estimate of the expected fatigue life of the structural part against expected stresses.

Fatigue failure can be influenced by a number of factors including the level of stresses, number of cycles, size and shape of the structural component, condition of the surface and operating environment. There have been some infamous accidents where the cause was attributed to fatigue failures, including the 1842 railway disaster in Versailles, crashes of three de Havilland Comet jets in 1954, and the loss of Japan Airline’s flight 123 in 1985.

FDA: Frequency Domain Analysis.

FEM: Finite Element Method.

FEMU: Finite Element Model Updating technique.

FFT: Fast Fourier Transform.

Fibre Optic Sensors: Highly sensitive sensors by the use of optical fibres.

When an ***optical fibre*** is bent, the light in the core no longer meets the cladding at an angle equal to or greater than the critical angle. This means that light escapes into the cladding and does not reach the other end of the fibre. It is called the *microbending loss* and the more the fibre is bent, the more loss takes place. The optical fibre thus works as a transducer by converting a measured quantity into a corresponding change in the optical radiation. Since light is characterised by intensity, phase, frequency and polarization, a change of any one or more of these parameters can be used for the detection of various quantities, such as temperature, stress and strain, angle of rotation or electromagnetic currents.

Some of the advantages of fibre optic sensors, on top of high sensitivity, are freedom from electromagnetic interference, wide bandwidth, compactness, geometric versatility and economy.

Filter: An electronic device or mathematical algorithm to process a data stream by means of separating the frequency components of signals.

There are various types of filters, such as low-pass filters, high-pass filters and band-pass filters. For the monitored data, low-pass filters are used to cut-off high frequency noise and to prevent ***ailiasing***, whereas the high-pass filters are used to reject low frequency noise such as the shift of zero reading.

Finite Element Method (FEM): A numerical method for solving static and dynamic problems of structures. It has been extensively applied to a variety of other engineering problems including fluid dynamics, heat transfer and material sciences.

The method was originally developed for working on dynamic analysis of aircraft structures. The basic idea is to subdivide a structure of any shape into a large number of simple elements. It is found that if the load-displacement equations for a single element are derived in matrix form, it is possible to use matrix algebra to combine the interacting effects of all the elements in a systematic and conceptually straightforward manner. Taking advantage of the rapid development of large capacity computers, the structural analysis thus became extremely simple and efficient.

Finite Element Model Updating (FEMU): A technique to optimize the finite element model by adjusting unknown parameters based on measured dynamic characteristics so that the model prediction agrees better with the measured results.

Flutter: An aeroelastic instability phenomenon which is typically characterized by a self-starting, rapidly growing coupled motion in bending and torsion of streamlined bodies.

A dynamic failure of aircraft wings caused by flutter was a serious engineering concern from the early days of flight and a development of the nonstationary aerofoil theory followed. Obtaining an analytical expression of the aerodynamic lift force on a harmonically oscillating flat plate was a challenge through 1920s, and the most complete solution to this problem was presented by Theodorsen in 1930.

Stall flutter is a similar but somewhat different type of aeroelastic instability. Unlike the case of classical flutter which is basically a potential flow phenomenon, it involves a pitching moment induced by a significant flow separation and, as a result, the body motion is primarily in torsion.

The term *flutter* is, strictly speaking, restricted to the classical flutter which is defined here but has been also used rather loosely without a clear definition. It sometimes means the catastrophic structural vibration caused by fluid dynamic forces, which are coupled with the body motion.

Folding Frequency: Nyquist frequency.

Fourier Series: An infinite series of sine and cosine functions that is, if convergent, equal to a variety of periodic functions.

Fourier series can be further transformed to a series of exponential functions by the use of the Euler’s formula. The study of functions given by Fourier series is called ***Fourier analysis*** or ***harmonic analysis***.

Fourier Transform: An integral transform particularly useful in relating the time domain and frequency domain variables for random vibration analysis.

Concept of the Fourier transform developed from Fourier series, which is the decomposition into frequency components of a periodic function. Fourier transform expands this concept to make it further applicable to the non-periodic functions. The analysis of measured data using the ***discrete Fourier transform (DFT)***, particularly in the form of the ***fast Fourier transform (FFT)***, is one of the most important techniques for the frequency domain vibration analysis.

Frenet-Serret Formulae: A set of differential relationships to define the 3D geometry of a curve.

When a continuous and differentiable 3D curve is defined by the motion of a particle along the curve, parameterized by the arclength s, the following relationships are called the Frenet-Serret formulae:

$$\frac{d\vec{T}}{ds} = \kappa\vec{N} \qquad \frac{d\vec{N}}{ds} = -\kappa\vec{T} + \tau\vec{B} \qquad \frac{d\vec{B}}{ds} = -\tau\vec{N}$$

where $\vec{T}$ is a tangent unit vector pointing forward, $\vec{N}$ is a unit vector normal to $\vec{T}$, and $\vec{B}$ is the binormal unit vector given as the cross product of $\vec{T}$ and $\vec{N}$. κ and τ are called the ***curvature*** and ***torsion*** of the curve.

Frequency Domain Analysis (FDA): Dynamic analysis processed by taking frequency, rather than time, as an independent variable.

Vibration analysis was originally established by taking both the external forces and resulted displacements as functions of time as an independent variable. However, when the random vibrations came into the scope and the statistical treatment of the problem became imminent, another way to look at the problem by taking frequency as a variable was found to be an attractive choice.

FDA, as opposed to the ***time domain analysis (TDA)***, is a way of processing dynamic analysis by decomposing the external forces into frequency components by applying Fourier transform and evaluates the structural response by superposing its frequency components. Even a non-periodic force can be included by pretending its period to be infinity.

Frequency Response Function (FRF): The ratio of the induced response to the excitation force, when an idealized SDOF system is subjected to a simple harmonic fluctuation force.

FRF, sometimes called the ***mechanical admittance function***, shows the sensitivity of a structural system to the excitation frequency. The peak response is reached when the excitation frequency is very close to the natural frequency and its magnitude is almost inversely proportional to the total damping of the system.

Fretting: A worn or corroded spot due to abrasion or erosion at the contact area of metals.

FRF: Frequency Response Function.

Froude Number: A dimensionless parameter that is decided by the ratio of fluid inertia force to gravity force.

Froude number is defined by $Fr = V/\sqrt{gL}$, where V, L are the flow speed and a representative length, respctively, and g = the acceleration due to gravity. Hence, it is the square-root of the ratio of the fluid inertia force to the gravity force. It is an important dimensionless parameter for testing the wind-induced response of cable-supported structures, for example, where gravity is a dominant factor.

If the change of fluid density ρ is involved, such as the case of a stratified flow problem, the ***densimetric Froude number*** is defined by using the reduced gravity, $g' = g \cdot \Delta\rho/\rho$, in lieu of g, which gives the ratio of fluid inertia to buoyancy force. The *densimetric Froude number* becomes an important parameter also for describing the dissipation of airborne particles and sedimentation issues, where the density of particles differs from the fluid density.

The reciprocal of $(Fr)^2$ is equivalent to the ***Richardson number***.

Fuzzy Logic: A problem-solving control system by introducing the concept of *partial truth* rather than expressing everything in binary terms.

The concept was introduced by L. Zadeh in 1965. Degrees of truth are often confused with being imprecise or probable but they are not. It allows for set membership values between and including 0 and 1, based on vague or even missing information, but arrives at a definite conclusion.

Fuzzy logic is, by some engineers, still said to be controversial but has been applied to many practical purposes including the fields of artificial intelligence, neural network and pattern recognition.

Galerkin Method: One of the weighted residual methods for obtaining the approximate solution of a partial differential equation, where the modal functions are chosen as the weighting function.

Galloping: Aerodynamic instability in translational motion normal to wind, in which the structural motion itself is the cause of creating the negative aerodynamic damping. It is sometimes observed in structures with aerodynamically bluff cross-sections such as towers, cranes and ice-covered cables, and was so named because of its violent feature.

The main difference in characteristics of this phenomenon from the flutter instability is in the fact that a) galloping is a translational motion whose amplitude grows to a much greater magnitude than the linear dimension of the structural cross-section; b) the vibration tends to be strongly non-linear as a result; and c) the response is often strongly influenced by the existence of flow turbulence, in the sense that turbulence could trigger the instability which does not exist otherwise.

Since the galloping motion is usually with very large amplitude at high wind speed, it is known that the ***quasi-steady analysis*** is applicable to its response prediction, only if the aerodynamic forces on the given structural section can be identified. A well-known criterion for instability, introduced by Den Hartog (1933), states that the instability exists when the sum of the lift slope and drag is negative, or $\partial C_L / \partial \alpha + C_D < 0$.

Galvanization: Zinc coating of steel or iron to prevent corrosion, specifically rusting.

Steel wires are either electro galvanized or hot-dip galvanized.

Global Positioning System (GPS): A world-wide radio-navigation system formed from a constellation of satellites and their ground stations. The system uses the network of reference points to calculate any positions on the ground with good accuracy.

The GPS provides a means of measuring position or displacement that does not require the component that is being tested to be physically connected to a fixed reference location. The working principle of the GPS involves triangulation of the location using radio signals from satellites as reference points. Depending upon the direction of measurement, GPS accuracy ranges from metres to centimetres.

GPS: Global Positioning System.

Gust Factor: The ratio of the peak to the mean wind speed.

The same term is often used for the ratio of the peak to the mean of wind-induced dynamic response as well. Wind induced buffeting motion often has the ***peak factor*** of 3.5 to 4 and the coefficient of variation of about 0.3, resulting in the gust factor of approximately 2 or slightly higher than 2.

Gust Response: Dynamic structural response induced by gusty wind. See also the *Buffeting*.

Ground Wire: A wire to provide a conducting path to the ground, which acts as a voltage reference.

Together with a fuse or breaker, it generally makes up a standard safety device against electric shock. For the case of power transmission lines, it provides shielding from outside electric interference.

Guy Wire: A cable or wire which is used to hold, guide or secure something like masts.

Health Monitoring: Tracking of various aspects of a structure's performance and integrity in relation to the system's expected safety and serviceability.

It is desirable if the structural health monitoring system is inexpensive, non-invasive and also automated, so that subjective differences by operator can be avoided. In particular, neither the implementation nor operation of the system should involve interruption of services.

Carden & Funning (2004) lists the attempted levels of structural identification as follows: 1) Presence of damage in the structure; 2) Location of the damage; 3) Severity of the damage; and 4) Prediction of the remaining service life of the structure; the last item being practically most important.

Heat Treatment: A procedure of heating and cooling a metal or alloy to obtain desired characteristics such as increased hardness, better machinability, improved ductility or reduction of residual stresses.

There are basically four techniques in heat treatments of steel: a) *normalizing* to make the internal structure of the material more homogeneous; b) *annealing* to make the material more malleable; c) *quenching* to make it harder and stronger; and d) *tempering* to make it less brittle or more ductile and also to relieve internal stresses.

Helical Strands: Frequently employed type of structural cables, made of round galvanized wires having a diameter of 4-6 mm with a minimum tensile strength of 1,500 to 1,600 MPa. A helical strand consists of one or more of successive spinning of layers of stranded wire around a straight core.

The direction of helical lay alternates from one layer to the next to offset the torque which develops as the cable is tensioned. The nominal modulus of elasticity of helical strands becomes somewhat lower than the value for straight wires. Due to twisting of the layers, the helical strand tends to self-compact and hence there is no need of wrapping or applying bands to hold the wires together. Helical strand cables are often anchored in a metal cast material in a steel block.

Helix: A three-dimensionally spiral shape, which commonly forms a screw edge. It can be either right-handed or left-handed.

If clockwise rotation of the helix corresponds to axial movement ahead, it is a right-handed helix, and *vice versa*.

High-Speed Vortex Excitation: A type of cable vibration with limited amplitude, considered to be triggered by vortex shedding, though the range of Reynolds number is much higher than that of ordinary aeolian vibrations.

The concept was proposed and intensively studied by Matsumoto et al. particularly in relation to that of the ***dry cable galloping***. However, the mechanism of this type of vibration is not fully understood yet.

High Strength Steel: A class of steels with higher tensile strength than ordinary mild steel.

Minimum tensile strength of higher than $500MPa$ is often a criterion to be identified as the *high strength steel*. In reality, steels of as high as 800 or even $1000MPa$ level are already commercially available. This category of steel is generally expected to have higher strength in both tension and compression with a high modulus of elasticity as well. High strength is often obtained by adding other alloying elements such as *Mn*, *Si*, *Ni*, *Mo* and applying ***heat treatments***. For the use of high strength steels, it is important to keep in mind that ***ductility*** and ***weldability*** of the material could be the engineering concerns.

Hysteresis: A nonlinear phenomenon in which the output takes different values even if the input value is the same, depending upon its past history, such as the case of increasing and decreasing input, for example.

Many physical, biological or social phenomena, including electromagnetic effects, fluid-structure interactions and/or stress-strain relationship of materials, have memory effects, exhibiting hysteresis. The term came from a Greek word meaning "lagging behind". It makes sense since hysteresis is due to the lagging of a physical effect on a body behind its cause.

Ice Accretion: Glaze formation and accumulation of ice on solid objects that are exposed to freezing precipitation. Ice accretion around a cable sometimes becomes a reason of inducing galloping instability of it.

Impulse Response Function (IRF): A ratio of the induced response to the excitation force, when an idealized SDOF system is subjected to a unit impulse load.

The ***convolution*** integral of IRF with an external force function, if available analytically, is called the ***Duhamel Integral***, which gives the induced response of the system by this force.

Frequency Response Function and Impulse Response Function make a Fourier transform pair.

Indicial Response Function: The response of an idealized quiescent SDOF system when it is subjected to a unit step load. Impulse response is obtained by differentiating the indicial response.

Inclined Cable: A cable with an inclined chord, or when it is suspended between two end supports located at different elevation.

Infrastructure: A set of interconnected structural elements that provide the framework for supporting the entire structure.

The term is often used in a very broad sense, as the ***social infrastructure***, including any life-sustaining social facilities required for municipal or public services, particularly for transportation systems such as roads, railways, airports and water surface transportation, public utilities such as flood control, fire services and waste management, emergency and security services, and even public education, health systems and social welfare.

In-plane Vibration: Vertical vibration of a cable whose displacements remain only in the plane of the cable defined by its static equilibrium position.

Strictly speaking, the in-plane dynamic displacements of a sagged cable are coupled with the out-of-plane motion because of the existence of the geometrical nonlinearity. However, with an assumption that the dynamic displacements are infinitesimally small, the nonlinear terms in the equations of motion may be ignored, and the in-plane motion for this case is regarded uncorrelated with the out-of-plane cable behaviour.

In-Situ: A Latin phrase meaning "in the place".

In-situ measurements, for example, require that the instrumentation be located directly at the point of interest, as opposed to remote sensing observations.

***Inspection: On-site, non-destructive examination to establish the present conditions of the structure.**

A visible inspection performed on regular base is called the routine inspection and a more detailed inspection usually performed as a follow-up to a routine inspection to identify any particular deficiencies discovered is called the in-depth inspection.

Instability: A failure mode of a structure by losing its structural integrity in static or dynamic equilibrium.

Buckling is a static instability. There are also dynamic instability phenomena such as parametric excitation and/or self-excited vibrations.

Intensity: The relative strength of physical quantity, such as electricity, light, heat or sound, usually considered per unit area or volume of the space it is exposed.

It is a measure of the time-averaged energy flux transmitted. Intensity of signal fluctuation is often expressed by the coefficient of variation, which is a ratio of the root-mean-square to the mean value.

***Investigation: Collection and evaluation of information through inspection, document research, load testing and other experimental methods.**

IRF: Impulse Response Function.

Jensen Number: See the *Boundary Layer Wind Tunnel*.

Kalman Filter: An efficient recursive filter which estimates the state of a dynamic system from a series of incomplete measurements with noise.

It means that only the estimated state from the previous time step and the current measurement are needed for making an estimate for the current state. One example is to provide a continuously-updated, accurate information about the position and velocity of an object, given only a sequence of observations about its position, each of which includes some error.

Kalman filtering is an important topic in control systems engineering. A variety of Kalman filters has now been developed, including Kalman's original simple filter, the extended filter, the information filter, and a variety of square-root filters.

Kármán Vortices: A trail of alternating vortices observed behind a circular cylinder which is exposed to the transverse flow. Also called the Kármán-Bénard vortex street.

Existence of a street of alternating vortices behind a circular cylinder, when it is exposed to the transverse flow, was known for quite some time and studied by many including Strouhal, Lord Rayleigh and Bénard. However, the name of von Kármán has been frequently remembered because of his work on the stability of vortex arrangement. He considered two rows of alternating vortices behind a cylinder and mathematically discussed a stability condition of this trail in terms of the geometrical pattern of vortices.

A very clear vortex street is usually recognisable at the Reynolds number range of 100 to 300 and these are the original Kármán vortices. However, even at much higher flow speed, even in the range far beyond the critical Reynolds number, the existence of alternating vortex shedding behind a non-streamlined object has been widely observed and they are also rather loosely called the Kármán vortices.

An engineering significance of this vortex shedding is the ***vortex shedding excitation*** of structures.

Kelvin-Voigt damper: A mathematical model of damper characteristics in which an elastic spring and a viscous damper are placed in parallel.

The stress σ for this case is expressed by a linear combination of the strain ε and its time derivative $\dot{\varepsilon}$.

Kink: A tight curl, twist or bend in a length of thin material such as wires or ropes.

Knot: A compact intersection or fastening made by interlaced material such as ropes.

Laminar Flow: The condition of a flow when it is not turbulent. See the *Turbulence*.

Note that it is different from the ***smooth flow***, which usually refers to the case where the flow is turbulent but the effects of turbulence is not counted for.

Laser Doppler Vibrometer (LDV): A highly sensitive optical instrument to measure displacement and velocity of a moving object.

It consists of an optical head that emits laser light and a converter that processes the Doppler frequency of the reflected laser light. The voltage signal from the converter is proportional to the velocity at which the object moves. There are different types of LDV for a) out-of-plane vibration; b) in-plane vibration; and c) three-dimensional vibration. A non-contact way of measurement is distinctly advantageous for the system, but care should be taken for the fact that the measured results are easily affected by the noise caused by the surface roughness of the target.

Lay: The direction of the strands of a rope or cable that are twisted in helix, or the amount of such twist.

Looking at the rope as the strands progress away from the viewer, if the strands appear to turn in clockwise direction, it is called a right-hand lay. If it appears counter-clockwise, it is a left-hand lay. When the lay of wires in each strand is in the opposite direction to the lay of the strands that form the wire, it is called the *ordinary lay*. When the lay of wires in each strand is in the same direction as the lay of the strands, it is called the *Lang's lay*.

LDV: Laser Doppler Vibrometer.

Leakage: See the *Nyquist Frequency*.

Least-Square Method: A process to quantitatively obtain a regression for a set of data by minimizing the sum of the deviations squared.

Polynomial functions are most commonly used for least-square curve-fitting. If more than one control parameters are involved, the multiple regression method can be applied, too. The method was first applied to an astronomical prediction by C.F. Gauss in the late 18th century.

Life Cycle: The total phases through which a structure passes from its birth to the time it ceases to exist. It involves all levels of engineering work, including design, construction, inspection, management, repair, improvement and demolition.

The concept has been developed from the needs to consider the overall performance of a structure, both in services and associated costs. The life-cycle assessment of a structure would include its cost-effectiveness, serviceability, environmental impacts and sustainability.

Lift Force: Fluid dynamic force component perpendicular to the mean flow direction.

Limit State: A limit state is a set of performance criteria defined in terms of deflection, vibration levels etc. as a reference state that must be met by a structure under factored loading.

It is a concept used for design of structures in lieu of the older concept of ***allowable stress design***. The most common limit states are the serviceability limit state and the ultimate limit state.

Linear Variable Differential Transformer (LVDT): A type of electrical transformer used for measuring linear displacement without physical contacts.

LVDT is a commonly used, reliable position meter. It consists of a hollow metallic casing with solenoid coils around a tube and a ferromagnetic core shaft, which is attached to the object whose position is to be measured and moves freely back and forth along the axis of measurement. An alternating current is driven through the primary coil, causing a voltage to be induced in the solenoid coils and thus measure the travelling distance of the core.

Load: The applied forces which a structure is subjected to and expected to resist against.

It generally includes the weight of the structure itself, traffic to be carried, effects of wind, earthquakes, temperature change, rain, snow, ice etc., and dynamic amplification of these loads due to their motion, possible collision and/or accidents.

***Load Testing: Test of the structure or its part by loading to evaluate its behaviour or properties, or to predict its load-bearing capacity.**

LVDT: Linear Variable Differential Transformer.

Locked-Coil Strand: A type of cable strand which consists of a helical strand as a core, surrounded by several layers of wedge shaped wires to form a smoother and tighter surface.

Because the outer layers are fitting tightly together, the density of a locked-coil strand is very high. Also, because of the specially shaped wires, this type of strand is less sensitive to side pressure, and is considered to be appropriate for relatively short span cable-stayed bridges. It was developed in Germany.

The wires would be anchored inside a steel socket by means of a hot poured zinc based alloy. However, the fatigue resistance of locked coil cables and their anchorages is recently considered to be too low for modern cable-stayed bridges, where the stays are subjected to high stress variations. Also, there have been some cases where cables failed due to insufficient corrosion protection and this type of cable is now deemed not appropriate for use on large bridges.

Magneto-Rheological Damper: A shock absorbing damper filled with magneto-rheological (MR) fluid, whose characteristics are controlled by the application of electromagnetic field.

MR fluid is a type of ***smart fluid***. It consists of the carrier oil with micrometer-sized magnetic particles suspended in it. When subjected to a magnetic field, these microscopic particles align themselves along the lines of magnetic flux, and the resulted chains of particles resist the movement of fluid, effectively increasing the fluid viscosity even to the point of becoming a viscoelastic solid. A great advantage of the system is such that the damping characteristics of the shock absorber can be continuously changed and accurately controlled by controlling the magnetic field intensity.

***Maintenance: Routine intervention to preserve appropriate structural performance at a desired level.**

Markov Process: A statistical process whose relationship to the past does not extend beyond the immediately preceding observation, or its most recent value.

It could be also said that the random events whose likelihood depends on what happed last in this process. The stream of events with this character is called the ***Markov chain***. A game of Monopoly or Snakes and Ladders, whose moves are determined entirely by dice, is a Markov chain, in contrast to the Poker game, where the cards represent a memory of the past moves.

Mass Parameter: A dimensionless parameter to indicate the significance of structural mass on dynamic response.

Mass parameter can be defined in different ways depending on the nature of the problems. In case of the wind-induced structural response, for example, it is defined by $\mu = m/(\rho B^2)$, where $m =$ structural mass per unit length of the structure, $\rho =$ the air density, and $B =$ the width of the structure. If the issue is the structural response in torsion, a similar mass parameter in torsion, $\nu = J/(\rho B^4)$, would be more appropriate, where $J =$ the polar mass moment of inertia per unit length of the structure.

***Material Properties: Mechanical, physical or chemical properties of structural materials.**

Engineering properties sometimes required, in the present context, include the following items: the material density, yield strength, elongation to failure, tensile strength, Young's modulus, Poisson's ratio, melting point, thermal expansion coefficient, specific heat capacity, electrical conductivity, etc.

MATLAB: A numerical computing environment, which is probably most widely used as a contemporary operating system. The same name can also mean its core language.

Shortened form of *MATrix LABoratory*. It was developed by Cleve Moler in the late 1970s and quickly spread and became popular through the community of applied mathematics. It allows easy matrix manipulation, plotting of functions and data, implementation of algorithms, creation of user interfaces, and interfacing with programs in other languages.

Maximum Likelihood Method: A procedure of finding the value of one or more parameters for the hypothetical probability distribution, or likelihood, to make it a maximum.

It is said to be a statistically robust method, or versatile and applies to most models and to different types of data. In addition, it provides efficient methods for quantifying uncertainty through confidence bounds.

The background theory is relatively simple. Suppose x is a random variable with PDF given by $p(x;\theta)$, where θ is an unknown parameter which needs to be estimated. After obtaining N independent observations, $\{x_r\}$ ($r = 1,2,..,N$), the likely function is defined by $L = \prod_{r=1}^{N} p(x_r;\theta)$ and the maximum likelihood estimator of θ is obtained by maximizing $L(x_1, x_2, ..., x_N \mid \theta)$, or $\partial(\ln L)/\partial\theta = 0$. There can be more than θ involved in this process.

Maxwell Damper: A mathematical model of damper characteristics in which an elastic spring and a viscous damper are placed in series.

The strain rate $\dot{\varepsilon}$ for this case is expressed by a linear combination of stress σ and its time derivative $\dot{\sigma}$.

Membrane Structure: A light weight structure constructed of membrane materials and cables to cover a large space.

It is an alternative to conventional reinforced concrete (RC) shells and steel frame space trusses, suitable for facilities that require a large open space such as sporting stadia, shopping malls, transportation terminals, airport hangers and storages. There are basically two types of membrane structures. One is the air-support type, for which the indoor pressure is maintained a little higher than outdoor pressure to make the membrane swell; the other is the suspension type, in which the reinforcement is incorporated into the membrane in much the same way as an umbrella, or cable support systems are provided.

MEMS: Micro-electro-mechanical system.

Micro-Electro-Mechanical System (MEMS): An integrated system of mechanical elements, sensors, actuators and electronics, of usually 1 to 100 micrometers in size, on a common silicon substrate through micro-fabrication technology.

Miner's Rule: A method for predicting structural failure due to cumulative fatigue damage.

Fatigue loading is seldom of constant amplitude and hence the method of its assessment for the cumulative damage needs to consider the mean rate of crack propagation under variable-amplitude loading. This approach yields to an empirically derived expression by Palmgren (1924) and Miner (1945), which is given by $\sum_j n_j / N_j \geq 1$ as a failure condition, where n_j = the number of stress cycles with stress range σ_j, and N_j = the number of stress cycles necessary to cause failure at stress range σ_j. It is a simple and convenient criterion but the usefulness of the Miner's rule is admittedly questionable.

Modal Analysis: Analysis of a structure in terms of its natural dynamic characteristics, which are the frequency, damping and mode shapes.

The basic assumptions are that each individual mode can be treated as an independent single-degree-of-freedom system, and also any dynamic deformation of the structure is comprised of a linear combination of the characteristic mode shapes.

Modal Crossover: Shift of cable vibration modes depending upon the magnitude of cable tension in relation to its extensibility.

The symmetric modes of cable vibration are significantly influenced by how the cable would be stretched, which is characterised by a dimensionless parameter that indicates the relationship between extensibility of the cable and the magnitude of given cable tension. When this parameter is increased, or the cable tension is reduced, to a certain critical range, the natural frequency of the cable together with its mode shape changes, and it looks like as if the mode shape is transferred to the higher symmetric mode of vibration by "crossing over" the immediately next asymmetric mode. In case of an inclined cable, however, it has been revealed that the vibration mode is not really shifted to a higher symmetric mode but gradually shifting to the next asymmetric mode, because of the non-symmetric mass effects.

Modal Damping: Magnitude of damping associated with specific vibration modes.

Damping may or may not be different for different frequencies.

Modal Mass: Structural mass which is participating in vibration for a given mode.

It is sometimes called the *generalized mass*.

Modal Parameters: The most fundamental information regarding vibration modes, namely the frequency of vibration, corresponding mode shape and damping for each mode.

The expected ***eigen-frequencies*** and corresponding mode shapes are analytically determined. ***Modal damping*** is more empirical.

It should be noted that the measured modal data are often influenced by environmental factors such as the live load conditions, thermally-induced variations and amplitude dependence. They may be also influenced by local structural damages. Sometimes the results are limited by the availability of instrumentations, and error and noise in measurement and data analysis. Thus the measured modal data are either incomplete or with remaining uncertainties. It becomes necessary then to address this uncertainty by applying probabilistic approaches.

The ***vibration-based structural health monitoring*** is to determine the existence, location and extent of structural damage by identifying these modal parameters. Two key areas where the research efforts are required are, therefore, on the following questions: a) if the measurements of these parameters yield consistently reliable results; and b) if the observed parameters are sensible enough reflection of structural damage that needs to be identified.

Modelling: The process of developing a conceptual system by physical, mathematical or logical representation to reflect the reality to be investigated for better understanding.

***Monitoring: Frequent or continuous observation or measurement of structural conditions or actions.**

Monte Carlo Method: A method to simulate a large variety of qualitative processes or to provide approximate solutions to mathematical problems by performing statistical sampling experiments on a computer by the use of random number generation.

The Monte Carlo method developed out of nuclear science, when the probabilistic problem of random neutron diffusion in fissile materials was a concern. The method is often envisaged as a statistical sampling technique to solve inherently probabilistic problems but it has been also applied to deterministic issues.

In the present context, it is referred to as a method to make use of random generation for the numerical simulation of functional relationships between random variables. It is known to be a useful and effective approach when the theoretical analysis of input-output relationship is too complicated, particularly in nonlinear problems.

Mooring: Securing a floating body by the use of a chain or a cable by connecting one end of it attached to the body and the other to a more secure anchorage.

MR Damper: Magneto-rheological damper.

Multi-Wire Helical Strand: A common type of wire cable, which is fabricated by successive spinning of layers alternately in opposite direction of helix around a straight core.

Since the helical wires change their geometrical shape when the cable is under tension, the overall axial stiffness of the cable becomes less than the case of a single wire, whose stretch is due to elastic elongation alone. The nominal Young's modulus of the strands becomes usually about $170GPa$. Also, an irreversible elongation due to compaction of the strand is known to be significant for this type of cables, and hence the pre-tensioning of cables with a force exceeding the expected maximum tensile force is needed to prepare the final service condition of the cable.

Natural Frequency: The frequency at which a structure is most easily excited into vibration.

Natural frequencies are uniquely decided by mass and stiffness of the structure and are rightfully termed the ***eigen-frequencies***. However, their magnitude also depends upon the way the structure vibrates, which is called the ***mode*** of vibration. For example, a bridge can vibrate in vertical bending, horizontal bending or in torsion. Even in vertical bending mode alone, the bridge can vibrate with its maximum dynamic deflection at the span centre, or with no deflection at the mid-span but the significant movement at the quarter-span points. Each vibration mode has its own natural frequency corresponding to it.

The mode of vibration is largely influenced by the way the structure is supported. The supporting conditions are called the ***boundary conditions***. For the design of the structure, they are usually assumed to be hinges, rollers, rigidly fixed, or sometimes elastically supported. However, these conditions, including the conditions of substructure and the ground, in reality are often somewhat different from their mathematical assumptions.

Natural frequencies are usually evaluated under the standard design conditions, in which the structure is free of live loads and extreme temperature effects. Since the instantaneous mass and stiffness of the structure in reality could be different from the design assumptions, the natural frequencies of the bridge in service can be different from the values calculated earlier.

Natural frequency is reduced a little with the increase of the system's ***damping***. However, in reality, this effect can be disregarded for the case of civil engineering structures. For example, even if the damping is as high as 10% of critical, the natural frequency is reduced only by 0.5% compared to the case with no damping.

The structure can be most easily excited into vibration if the excitation frequency coincides with, or is very close to, one of the natural frequencies. This phenomenon is called ***resonance***. If the excitation force contains many frequencies, the one close to the natural frequency would most effectively excite the structure. The sensitivity of a structure to different excitation frequencies is typically represented by the ***frequency response function (FRF)***, or the ***mechanical admittance function***.

When the structural system is ***nonlinear***, the natural frequencies are amplitude-dependent. For this case, the frequency observed at very small amplitude level is usually defined as the natural frequency.

Navier-Stokes (NS) Equation: Fundamental equation of motion to define the behaviour of fluid when it is deemed a continuous medium.

The NS equations are established by considering the 3D momentum conservation when the fluid medium is regarded a continuum and all relevant forces, including the inertia, viscous, pressure forces and any body forces are properly counted for. It is believed that any kind of fluid activities beyond the molecular level, including turbulence, can be all described by this expression.

Neural Network: An analytical technique to explore the relationship between variables by creating a network system conceptually similar to the biological cognitive system.

Neural network method is one of the ***data mining*** techniques, which is an analytical process to explore data in search of consistent patterns and/or systematic relationships between variables. The name obviously came from its conceptual resemblance to the biological cognitive system of brain and layers of neurons.

The method consists basically of three steps; the design of a specific, object-oriented network architecture, the training of the system by the use of existing data, and the generation of predictions once the network is ready.

A distinct advantage of neural networks is that the method can be applied to any continuous input-output relationship without assuming hypotheses particular to the underlying model. On the other hand, there is an important disadvantage that the final outcome of the work depends upon the initial conditions of the network and the experience-based solution does not really give any insight to theoretical explanation of physics.

Node: A point where the vibration amplitude becomes minimum, or virtually zero.

Noise: A random signal that does not convey any useful information.

The analysis of noise signal has been developed in the telecommunication field and became one of the most important tools in dynamics. A signal whose intensity is the same at all frequencies is called the ***white noise***, though an infinite-bandwidth white noise is a purely theoretical concept and, in reality, its frequency band has to be limited.

For acoustic aspect of noise, see the ***environmental noise***.

Nonlinear Vibration: When the structural restoring force and/or damping force are not linearly proportional to the displacement, or the external forces are amplitude dependent, the vibration becomes non-linear.

Nonlinear stiffness can be caused by material nonlinearity, such as plasticity, or structural nonlinearity, such as the case of cables. Structural damping ratio is usually higher when vibration amplitude is greater. In contrast, the aerodynamic damping is sometimes found drastically reduced, or even becomes negative, with greater vibration amplitude. This is because the excitation force is largely nonlinear with the displacement and/or displacement rate.

All of these factors indicate that the structural vibration is likely to be nonlinear, unless the dynamic amplitude is very small. However, they are often handled with linear approximation so long as it is acceptable for practical purposes. Generally speaking, the nonlinear vibrations can be analysed only by applying numerical methods since the closed form solutions for nonlinear differential equations are generally unavailable.

Nonstationary Process: A stochastic process whose statistical properties change when shifted in time or space.

NS Equations: The Navier-Stokes equations.

Nyquist Frequency: The highest frequency beyond which the signal contents cannot be properly represented by the data in discrete form.

Any time signal can be measured usually only for a limited time period. Consequently, the analysed results of the sampled data would be different from the expected results for which the whole infinite signal is intended. This difference is known as ***leakage***.

When the original continuous analog signal is sampled as a discrete time-series, usually with a constant sampling time increment Δt, the signal contents with any frequencies higher than $f_N = 1/(2\Delta t)$ cannot be accurately represented because of the sampling resolution. f_N is called the Nyquist (or folding) frequency.

The problem caused by the choice of sampling time increment for digitizing the data, as above, is called ***aliasing***. In order to reduce these errors, it is considered prudent to low pass the original signal at, or preferably even below, the Nyquist frequency, before analysis.

Offset: A reading that is other than zero for a zero condition. Every reading thereafter is inaccurate by this amount, for which compensation is required.

Optical Fibre: A glass or plastic fibre designed to guide light along its length.

It is widely used in fibre-optic communication and also to form ***fibre optic sensors***.

Out-Of-Plane Vibration: Vibration of a cable whose displacement components do not stay in the plane in which the cable at its static equilibrium position is.

Overhead Power Lines: Electric power transmission lines suspended by towers or poles.

It is generally considered to be the least expensive means for high voltage electric power transmission. The conductors are often aluminium lines reinforced with steel (***ACSR***), suspended from the lattice towers or tubular poles made of steel, concrete or aluminium. For high voltages over 200 kV, two or more conductors are often bundled together by using rigid spacers to avoid ***corona discharge*** and audible noise. Also equipped are one or two ground conductors that are at the top of the supporting towers and expected to shield the system from lightning strikes.

Parabola: The trajectory of a particle in motion under the influence of a uniform gravitational field.

It is also the deflected shape of a perfectly flexible and inextensible cable, when its weight is uniformly distributed along the span. This is close to a situation of a horizontal shallow cable with a small sag-to-span ratio.

Parallel Wires: A type of wire cables that has all wires straight and in parallel so that there is no reduction of Young's modulus due to twist of wires.

Since there is no helical winding or twist of wires, the strength and stiffness of the strand is expected to be as high as the values for straight wires. It is the same way as used in normal ***prestressed concrete*** construction. Prestressing wires can reach the ultimate tensile strength of *1700 MPa* or more with a proof stress at 0.1% of *1400 MPa*. Elastic modulus is around *205 GPa*.

Parallel wires are either fabricated into hexagonal pattern, bound together by cable straps, wrapped in ***PVC*** cover or contained in polyethylene ducts, or prefabricated into parallel wire strand systems. This method is most suitable for main cables of long-span suspension bridges, for example. The use of parallel wire bundle in a polyethylene duct filled with cement grout as corrosion protection started about 40 years ago. Parallel strand cables have been used in major cable-stayed bridges, too.

Parameter Estimation: The process of finding parameter values that fit a mathematical model to experimental data.

Other terms such as ***system identification*** can be used for the present context. There are various heuristics developed for parameter estimation, particularly in the field of control engineering, such as ***maximum likelihood***, ***predictive estimation*** and ***Kalman filtering***.

Parametric Excitation: A type of self-excited vibration where the stiffness term is time-dependent, resulting in the instability of the system not only at the ordinary resonance point but also depending upon the combination of the system parameters.

Lateral vibration of struts and cables due to periodic fluctuation of axial force are two of the examples often referred to. The equation of motion takes the form of Mathieu's equation, whose solutions are known to become unstable under certain combinations of parameters.

Participating Mass: A part of the physical mass which is actually contributing to vibration. Also called the *modal mass*, since its magnitude depends upon the vibration mode.

Consider the sway vibration of an elevated mass, supported by an elastic column. If the structure vibrates in the fundamental mode of vibration, the heavy mass will vibrate with a large amplitude. However, when the structure vibrates in its second mode, the large amplitude is experienced by the thin column rather than the top mass. Hence, the effective mass contribution will be more substantial in the fundamental mode rather than the second mode, even if the physical mass distribution of the structure remains the same.

The modal mass is calculated by the integration of mass per unit length times the mode function squared, over the whole structure, and it is unique to each mode.

Pattern Recognition: The act of taking in raw data, extracting meaningful information to form the feature vectors out of them, and classifying the measured data into categories based on characterization of patterns.

It is a field within the area of machine learning or ***artificial intelligence***. It has been applied typically to the automatic speech recognition, classification of spam and non-spam email messages, and machine reading of hand-written postal codes on postal envelopes. Effective application of these techniques to structural ***parameter estimation*** is highly desired.

The most fundamental tasks in pattern recognition are a) to learn the probabilistic relationship between the feature vectors and presumed categories; and b) to make an inference as to which categories the recognized data should belong to, based on the Bayesian decision theory. Also developed in recent years is the application of ***neural network*** to pattern recognition as an effective tool for learning process.

PDF: Probability density function.

Peak Counting: A method of cycle counting to reduce a statistical summary out of irregular time-histories by counting the number of peaks and valleys.

The valuable outcomes of the field observation of structural behaviour are usually given as lengthy and irregularly fluctuating time-histories of acceleration, stress, deflection and so on. An absolutely essential matter for engineers then is to reduce a small amount of useful information out of them for fatigue analysis, for example. Counting the number of cycles of the record fluctuation is one of them.

There are a number of methods to perform this operation, such as counting of ***peaks***, ***level crossings*** and ***ranges***, which are defined by the difference between two successive extremes. All of these are called *one parameter methods* whereas two parameter methods called the ***rainflow analysis*** is known to be a state-of-the-art counting method successfully applied to fatigue analysis. Note that the cycle counting yields amplitude distribution with no regard to frequency information.

Peak Factor: The ratio of dynamic peak to its root-mean-square value.

Not to be confused with the ***gust factor***. If the dynamic signal is a simple harmonic fluctuation, the peak factor should be $\sqrt{2}$. If the signal has the normal distribution of its magnitude, the peak factor is known to be approximately 3.6. Some peculiar random signals have very high peak factors. Wind induced suction, for example, on a tall building sometimes shows the peak factor of even higher than 10.

Penalty Method: A class of algorithms to solve constraint optimization problems.

Piano Wire: A specialized wire characterized by high tensile strength, made for use in musical instruments and also for more general purposes. It is drawn from tempered high-carbon steel in various diameters, typically 0.5 to 5mm.

Thickness of piano wires is sometimes indicated by the *gauge* number, defined by the *US steel wire gauge* or *Washburn & Moen wire gauge*, for example. Note that the *American wire gauge* is a standard used for nonferrous electric wires and does not apply to steel wires.

Piezoelectric Accelerometer: A type of accelerometer that uses solid-state strain gauge elements that are physically attached to cantilever beams and electrically connected to a Wheatstone bridge circuit.

Plasticity: Tendency of a material to remain deformed, after the deforming stress is reduced to a value less than its yield strength.

POD: Proper orthogonal decomposition.

Poisson's Ratio: The ratio of transverse contraction strain to longitudinal extension strain in the direction of stretching force.

Virtually all common materials have Poisson's ratios in the range of 0 (such as cork) to 0.5 (such as rubber). Poisson's ratio of steel is approximately 0.29, resulting in the ratio of the Young's modulus to shear modulus to be 1.55.

Posterior: Following in time, or subsequent.

Post-Tensioning: A process to introduce prestress to reinforced concrete structures by applying compression after concrete is cast and cured.

A set of tendons for this case is either embedded in concrete or covered by protection to be free from concrete. Either way, the tendons are tensioned by hydraulic jacks after the concrete is sufficiently hardened, and thus the pressure is transferred to the concrete

Power Spectral Density (PSD): A function to represent a random process by the distribution of dynamic energy in terms of its frequency components.

PSD is a statistical function consisting of the average squared moduli of the Fourier transform at each frequency. It represents the random characteristics of the process in frequency domain. The ordinate of the function corresponds to the intensity of energy at that particular frequency and integration of PSD over the whole frequency range gives the variance of the process. Hence, the PSD function divided by the variance is called the ***normalised spectral density***.

When the structural system and excitation force are both linear and the principle of superposition is applicable, the PSD functions of input (force) and output (displacement) are related by the ***transfer function***, which is given by the square of the frequency response function (FRF).

Prestressed Concrete: Concrete with compressive internal stresses induced in it before use so that the tensile stresses resulting from the service loads are counteracted.

Prestress is introduced by stretching steel bars or wires, called tendons, placed in the concrete. Method was developed by E. Fressinet in 1928. Tensioning of tendons is done before or after concrete is cast, and they are called ***pre-tensioning*** and ***post-tensioning***, respectively.

Pre-Tensioning: A method of strengthening reinforced concrete structures in which the embedded tendons are tensioned before concrete is cast.

As opposed to the ***post-tensioning*** method, this method ensures good corrosion protection and effective introduction of compression for concrete. At the same time, however, it requires firm anchoring of the tendons at their ends, and in many cases therefore the elements are prefabricated in a factory. Necessity of transporting them to the construction site, as a result, tends to limit the size of the PC members.

Prior: Preceding in time, or order.

Probability Density Function (PDF): A non-negative function that represents the probability density of a variable.

For a continuous random variable $X(t)$ defined for $-\infty < t < \infty$, the probability density function $p(x)$ is defined by $p(x) = \Pr ob[x \le X(t) \le x + dx]/dx$. It follows that the mean value of $X(t)$ is given by $a_X = \int_{-\infty}^{\infty} xp(x)dx$.

Proof Stress: Offset yield strength. See the *yield point*.

Proper Orthogonal Decomposition (POD): A statistical method for system identification to provide modal decomposition.

It is essentially an attempt to extract characteristic information of a multivariate data set into an optimal set of uncorrelated variables called POD modes. The method was originally developed in analysing the spatial coherent structure in turbulent flow as a useful tool but it has been extensively applied to dynamics of structures, materials processing and many more fields of ***pattern recognitions***, including feedback control design for smart material structures.

Proportional Limit: Highest stress at which stress is directly proportional to strain.

It is the highest stress at which the stress-strain diagram is a straight line. It is usually a little lower than the yield stress and is equal to the elastic limit for many metals.

PSD: Power Spectral Density.

PVC: Acronym of polyvinyl chloride, a common synthetic thermoplastic material, often available in the form of soft flexible films and also as a hard plastic.

Since it is inexpensive, easy to handle, odourless, and insoluble in most organic solvents, there is a very wide range of application as a building and construction material, including the use for wrapping cables. Its physical properties are typically as follows: material density $= 1250 - 1700 kg/m^3$, tensile strength $= 50 - 80 MPa$, Young's modulus ≈ 3 GPa and melting point $= 212^0 C$.

Pylon: A tower structure for supporting cables.

There is a variety of structural configurations applicable as pylons for cable-supported bridges, such as portal frames, A-shaped frames, single or two poles. In all of them, pylons behave as a beam-column because of the axial forces induced by attached cables.

Quasi-Steady Approximation: An assumption often employed for the flow-structure interaction analysis, in which the aerodynamic forces at any time are dependent only on the instantaneous position of the body relative to flow at that particular moment. In other words, the temporal memory effect or the history of the motion in the aerodynamic model is to be ignored.

Rainflow Analysis: A cycle counting method to define an equivalent series of peaks and troughs for convenience of fatigue life prediction.

The general approach in fatigue life prediction needs to relate a random load fluctuation in real life situation to the ***Wöhler curves***, which are based on laboratory experiments of simple specimens subjected to constant amplitude load. The rainflow cycle counting analysis is a method proposed to overcome this difficulty, originally by Endo et al. (1968) and has been developed by many researchers, including Downing (1972) Rychlik (1987) etc., to a state-of-the-art method in fatigue analysis for reducing lengthy irregular time-histories to a small amount of useful knowledge.

Rain-Wind Vibration: A type of cable vibration observed under specific conditions of cable orientation, wind and light rain.

It is believed that the rivulets of rain water formed along an inclined cable, as a result of equilibrium between capillary, gravitational and aerodynamic forces, effectively change the cross-section of the cable and trigger the aerodynamic instability. A great majority of reported stay-cable vibration of cable-stayed bridges is considered to be of this type of vibration.

Random Decrement (RD) Technique: A technique to identify structural parameters by averaging out the random noise components.

RD was developed by H.A. Cole at NASA in the late 1960s, as an alternative technique to FFT, for identification of dynamic parameters and in-service damage detection of space structures. Its principle can be best explained by a simple example such as follows:

The random response of a structure at time $t_0 + t$ is composed of the following three parts: a) The component due to the initial displacement $x(t_0)$; b) The impulse response due to initial velocity $\dot{x}(t_0)$; and c) The zero-mean, random component due to random loading or noise in the period, t_0 to $t_0 + t$. If a time segment of $x(t)$ is picked up every time when the triggering condition, such as $x(t) = a$, is satisfied, the average of these segments will be a free decay response from the initial displacement, a. It is because c) above will be eventually averaged out and become negligible, and the sign of the initial velocity is expected to vary randomly with time so the resulting initial velocity will be zero, and so is b).

The method has a merit in the sense that it requires relatively short data length, though it is also suitable for transforming long-term observations into a small amount of data. It requires a high rate of digitization, usually the order of magnitude higher than the representative frequency. Also, the method has to be carefully applied when there are two or more outstanding modes and frequencies coexisting. It is desirable to band-pass filter the data before processing to isolate an outstanding mode, if it is the case. Particularly when co-existing frequencies are closely spaced, the application of least-square curve fitting to obtain a multi-frequency signature has been recommended.

Random Process: The process which generates a sequence of indexed random variables, or the sequence itself.

It is also called the ***stochastic process***. A set of random variables is often a time sequence, $X(t)$, sampled from continuous analog signals. The entire collection of all possible sets of sequences is called the ***ensemble*** and an individual set is called a ***sample function*** or ***realized function***. When the probability distribution of the random process does not evolve appreciably over a time of interest to the engineer, the process is called ***stationary***. When the temporal and ensemble averages of a random process are equal, the process is called ***ergodic***.

Random Vibrations: A type of vibration where the non-deterministic nature of excitation and/or of the structural system need to be counted for.

There are a number of examples. Wind induced vibration of tall buildings, earthquake excitation of buildings and dams, vibration of offshore oil drilling platforms by action of ocean waves and currents, aircraft vibration during its flight and taxiing, and traffic induced vibration of highway bridges are all random vibrations. Some of them are almost periodic but others are not. Some of them are stationary but others are not, transient or even impulsive. However, generally speaking, because of the non-deterministic nature of their processes, random vibrations are handled statistically.

Rayleigh Damping: Damping that is proportional to a linear combination of the system's mass and stiffness.

This assumption does not necessarily have any physical justification but it is mathematically convenient, since the orthogonality of mode vectors with the damping matrix can be concluded from this assumption. Physically it means that the mode shapes do not change due to damping.

RD: See the *Random Decrement Technique*.

Rebar: A steel bar used for reinforcement in concrete.

Reduced Frequency: A dimensionless expression of frequency often employed in wind engineering and aerodynamics.

Usually it is defined as $K = \omega B/U$, where $\omega = 2\pi f$ = the circular frequency, B = a linear structural dimension, and U = the mean wind speed. Sometimes, instead of the circular frequency ω, the frequency itself f is used for the definition. The inverse of the reduced frequency is often called the ***reduced velocity***.

Reduced Velocity: Reciprocal of the reduced frequency.

***Reference Period: Chosen period of time, which is used as a basis for assessing values of variables.**

***Rehabilitation: The work required to repair or upgrade an existing structure.**

Reliability: The probability that a structure will perform its intended functions during a specified period of time under stated conditions.

***Remaining Working Life: A remaining period of the expected life of an existing structure, which is intended or expected to operate with planned maintenance.**

***Repair: Improvement of the conditions of a structure by restoring or replacing existing components that have been damaged.**

Residual Stresses: Internal stress state of a structure or its components, as a result of the preceding thermal and/or mechanical processes such as pre-stressing or welding.

Resonance: Sympathetic vibration of a system in large amplitude caused by the fact that its natural frequency happened to be so close to the excitation frequency.

Reynolds Number: One of the dimensionless parameters to be kept consistent between two systems when their dynamic similitude is required. It can be defined as the ratio of the inertia force to the viscous force of fluid.

In many of the laboratory tests in fluid mechanics, including most of the wind tunnel tests, it is impracticable to expect the Reynolds number similitude be satisfied. Indeed the viscous forces are usually at least an order of magnitude smaller and relatively unimportant compared to the inertia forces in many of the bluff body aerodynamic problems. However, the consequence of distorting this requirement must be examined carefully at least from the following three points: a) the flow separation from solid surfaces; b) the wake flow pattern after separation; and c) similitude of turbulence spectra, the existence of inertia sub-range in particular.

Riser: A large diameter pipe which leads petroleum upwards from the wellhead on the ocean floor to the offshore drilling deck.

Risk Rating: A measure to classify the risk levels in different categories.

The risk levels are defined by assessing a) the potential threat, b) vulnerability of the existing or projected system, and c) the potential impact it could result.

Rivulet: A small stream of water.

Formation of water rivulets on inclined cable surface, as a result of light precipitation and equilibrium between gravity, wind and capillary forces, is considered to be an essential factor to induce the ***rain-wind cable vibration***.

Robustness: A desirable characteristic of a regulatory network to generate a certain qualitative response over a broad range of parameter values.

In the context of computer software or network system, it is the resilience of the system, especially when under stress or when confronted with invalid inputs. For example, the operating system is considered robust if it operates properly and correctly even when it starved of memory space, or confronted with an illegitimate application or bugs.

Safety: The condition of a structure being protected against failure, damage, error, accidents, or harm, in both causing and exposure.

Safety is the most overwhelming factor in structural design, construction and maintenance. However, in reality, it is a probabilistic concept and there is a need of a reliability method to decide if the condition is adequately acceptable. Reliability analysis based on appropriate modelling of parameters with reliability indices is a topic of ***Safety Engineering***.

***Safety Plan: A plan specifying the performance objectives, the scenarios to be considered for the structure, and all present and future measures such as design, construction, or operation such as monitoring, to ensure the safety of the structure.**

Sag: Static deflection of a cable at its midspan. It is inversely proportional to the cable tension.

For the case of a shallow horizontal cable, the sag δ is related to the horizontal cable tension H by $\delta \approx wl^2/8H$, where $l =$ the span length and $w =$ the cable weight per unit length.

Sag-To-Span Ratio: The ratio of the sag to span of a cable.

Scruton Number: A dimensionless parameter which indicates a combined effect of mass and damping on the vortex induced structural response.

Named after Kit Scruton, who was a pioneering British engineer in industrial aerodynamics. It is defined by $Sc = m\varsigma/(\rho D^2)$, in which $m =$ mass per unit length, $\varsigma =$ structural damping ratio, $\rho =$ fluid density, and $D =$ a representative linear dimension of the structure. Note that sometimes the Scruton number is defined by $2m\delta/(\rho D^2)$, which is 4π times greater than the above definition.

If the ***vortex excitation*** can be regarded as a resonance to a simply fluctuating excitation force, the induced peak response will be inversely proportional to the Scruton number.

SDOF System: A single-degree-of-freedom system. See the *degree-of-freedom*.

Seismic Waves: Elastic waves that are caused by earthquakes and travel through the Earth. There are different types of waves, body waves and surface waves.

Seismic waves can be also caused by explosions on or under the ground surface. The mechanics of wave motion in solid media, particularly with geological strata, are very complex.

There are two different body waves, P-waves and S-waves. P-waves are longitudinal or compressive waves and travel at the speed of sound, which is about $1.5\,km/s$ in water and 5 to $13\,km/s$ in hard rocks. S-waves are transverse or shear waves. They travel at about 60% speed of P-waves, only through solid. With S-waves, the ground moves perpendicular to the direction of wave propagation. The body-wave amplitudes decay at the rate that is inversely proportional to the square of radial distance from the hypocentre.

Two kinds of surface waves, Rayleigh wave and Love wave, are known, that travel along the ground surface or inter-surface of media. Surface waves are often direct cause of severe catastrophic consequences of earthquakes. They give ground surface motion in vertical and horizontal direction, respectively. Surface waves travel with the speed a little slower than S-waves and their amplitudes decay much more slowly than the body-wave amplitude, with the rate proportional to the square-root of radial distance.

Sensitivity Analysis: An analytical investigation to identify how sensitive the output of an assumed mathematical model is to the variation of model parameters.

Sensitivity analysis is very useful, for example, for determining the impact of using faulty data in forecasting. In more general terms, uncertainty analysis and sensitivity analysis would investigate the ***robustness*** of a study involving any mathematical models. While uncertainty analysis studies the overall ambiguity in the conclusions of the study, sensitivity analysis tries to identify what source of uncertainty weights more on the conclusions.

Sensor: A device that is designed to acquire information from an object and transform it into an electrical signal.

It usually consists of three parts: a) the sensing element, such as resisters, capacitor, transistor, piezoelectric materials, photodiode, etc.; b) equipment for signal conditioning and processing, such as amplification, linearization, compensation and filtering; and c) sensor interface to connect with other electronic components.

Service Life: The number of years a structure is intended to be in service.

Serviceability: The ability of a structure to be serving or capable of serving its intended purposes to the uses' satisfaction.

Seven-Wire Strand: A common type of wire cable, which consists of a single core wire and a single layer of six wires, all having the same pitch and direction of helix around the core.

Since the pitch of helical wires is relatively large compared to the case of multi-layer strand, the stiffness of the seven-wire strand is closer to that of straight wires. The nominal modulus of elasticity for this case is around $195GPa$, $5-6\%$ lower than that of a single wire.

Shallow Cables: Suspended cables with the sag-to-span ratio of less than $1/8$ (say).

The deflected shape of shallow cables can be regarded as a second-order parabola rather than a catenary for all practical purposes.

Shear Modulus: The ratio of the increase in stress to that of strain of a material subjected to shear loading.

For an isotropic, homogeneous elastic material, there are only two independent elastic moduli. The shear modulus (*G*), for this case, is related to Young's modulus (*E*) and Poisson's ratio (ν) by $G = E/2(1+\nu)$. For structural steels, $G \approx 80GPa$. The shear modulus of structural materials is determined by a twisting test, which is regulated in ASTM E-143.

Shell Structures: Light weight structures made of shell elements, that are typically curved and subjected to in-plane forces as well as bending moments.

In particular, when the shell thickness is much less compared to other linear dimensions of the structure, it is called a *thin-walled* shell structure.

Signal Processing: A data analysing system which includes data filtering, frequency domain transformation and statistical analysis.

Similitude Requirements: Scaling requirements in engineering model tests so that the scale model test results could be interpreted to the prototype situation with proper physical meaning.

The ***Buckingham Pi-theorem*** rules a method to establish a set of dimensionless parameters which consist of suitable combinations of the reference quantities. It is required that these dimensionless parameters to be invariant in model and prototype and with them the governing equations are also rendered dimensionless. However, the complete satisfaction of this requirement for all conceivable dimensionless numbers is possible only when the model and prototype are identical. It means that in any scale model tests, one or more of the similitude requirements need to be relaxed to make the model test possible. The real issue of experimental mechanics, therefore, becomes a matter of interpreting the test results, knowing that some of the requirements are actually distorted or disregarded in the tests.

The dimensionless numbers often treated in wind tunnel tests of civil engineering structures, for example, are ***Reynolds number***, ***Froude number***, ***Jensen number***, ***reduced frequency***, ***mass parameters*** and ***damping ratio***.

Simulation: Imitation of reality by a physical, mathematical or software-based means for modelling natural or human systems and also their behaviour as an interaction with the environment.

SI Units: The *Systeme Internationale d'Unities*. An international system of units that was established in an attempt to simplify the language of science.

The system was an outcome of a resolution adopted at the 9th General Conference of Weights and Measures, 1948, and has been gradually accepted by many countries over the world, replacing the traditional local unit systems. It is based on seven standard base units: length (*m*), mass (*kg*), time (*s*), electric current (*A*), temperature (*K*), luminous intensity (*cd*), and the amount of substance (*mol*), and all other units are derived from these. The system also specifies the standard prefixes to express multiples and submultiples, such as kilo (*k*), mega (*M*) and milli (*m*).

Skew Angle: An oblique angle deviated sideways from the assumed reference frame.

Smart Fluid: A fluid whose properties can be changed by applying an electromagnetic field.

These fluids can be controlled their viscosity (MR fluid) or yield point (ER fluid) or can be strongly polarised (Ferrofluid) by applying an electromagnetic field.

Smooth Flow: The condition of a flow which is actually turbulent but the velocity fluctuation could be disregarded for simulation purposes.

Note that smooth flow is not laminar, generally speaking.

S-N Curve: See the *Wöhler curve*.

Span: The horizontal distance between two supports of a structure.

Spectral Analysis: Dynamic analysis in terms of the frequency-based characteristics of the processes by the use of the auto- and cross-power spectral density functions (PSD).

Spectral Windows: Weighing functions to be applied in spectral analysis for processing only band-pass filtered data in frequency domain.

Windows are applied to obtain smoother spectra so that the physical interpretation of them would become easier. Basic requirements for the windows are: a) the integration of a window function over the whole frequency range should be unity; and b) the window function should be symmetric with respect to zero frequency. There are various types of window functions employed in engineering signal processing including the ***digital filters*** such as Hanning and Hamming windows.

Inverse Fourier transform of the spectral windows are called ***lag windows***, which are the windows in time domain and applicable to the autocorrelation functions.

Spectrum: Arrangement of a physical quantity, such as energy, as a function of frequency or wavelength, which is called a spectral density.

The concept of spectra came from optics, referring to the range of colours observed when white light is dispersed through a prism. The term is now applied to a much more general frequency-based presentation of various physical characteristics. It is an essentially important statistical tool for the exploration of cyclic patterns of data.

Stall Flutter: A type of dynamic instability typically observed with a thin aerofoil at high angles of attack. A significant flow separation around the aerofoil and associated pitching motion are characteristic to the phenomenon.

Standing Wave: A wave whose pattern remains in a constant position. Also called the stationary wave.

A wave that propagates is called the travelling wave. The speed of wave travelling along a vibrating taut string is given by $v = \sqrt{T/\rho A}$, where $T =$ the string tension, $\rho =$ the material density and $A =$ the cross-sectional area of the string.

Stationary Process: A stochastic process in which the probability density function (PDF) of a random variable does not change over time or position.

Stay Cables: Cables used as a brace or support for masts and poles. For the case of cable-stayed bridge, the stay cables extend diagonally from pylons to suspend the bridge deck.

The cables initially applied for steel cable-stayed bridges were characteristic to specific countries. Locked-coil ropes, spiral ropes and parallel wire strand cables were developed in Germany, UK and Japan, respectively. As the span of bridges increased, the number of stay-cables increased, along with cable tension, the number of ropes per cable, and the complexity of cable anchorage, as well as the difficulty of their erection. There has been also a development of prestressed concrete cable-stayed bridges, for which steel wires and cable bars are also used for cables.

Matters often considered as the requirements for the bridge stay-cables include: a) High load bearing capacity; b) High and stable Young's modulus; c) Compact cross-section; d) High fatigue resistance; e) Ease in corrosion protection; f) Ease in handling and installation; and g) Low cost.

Steel: Ferrous alloys with usually 0.2 to 1.5% (mass) of carbon and small amount of other elements such as *Mn, Cr, Ni, Mo, Cu, W, Co* and *Si*. Widely accepted as important structural materials because they are generally hard, strong, durable and malleable.

In many parts of the world, most of the structural steels are specified in local standards such as the European Standard, ***ASTM International***, JIS etc.

Steel Wire: A string of drawn cable steel with a diameter of typically 5 mm. It is the basic element of structural cables.

Cable steel has much higher carbon content of typically 0.80% and much higher tensile strength (typically $1600MPa$) than ordinary structural steel. It has very high yield strength ($1200MPa$) but low ductility, allowing the elongation of only 4% or so.

Stochastic Subspace Identification: A modal parameter identification method developed in a MATLAB environment, applicable to ambient vibration survey (AVS).

The method starts with a stochastic state-space representation of the dynamic behaviour of a structure under white noise excitation. The numerical procedures of matrix decomposition for identifying the state-space model are all handled by built-in functions of MATLAB.

Stockbridge Damper: A type of damper often used for suppression of conductor vibration.

It consists of two pear-shaped end-masses attached to a steel strand, which is referred to as the messenger cable, and the middle of the messenger cable is clamped and fixed to the conductor. When the end-masses vibrate in their natural frequencies, the messenger cable is bent and friction caused by slipping between wires dissipates vibration energy. Two masses and the strands are sometimes made non-symmetric to make the damper more sensitive to different frequencies. A possible problem of this damper is fatigue failure of the messenger cable, ironically particularly when the damper is effectively working. It was one of the earliest damping devices, and was already commercially available in 1924. However, it went through a series of development and modifications since then. There are also various size and models of it in different countries. The Stockbridge damper has been used for bridge cables, too.

Strain Energy: The mechanical energy stored in a stressed material under load up to fracture. It is equal to the area under the stress-strain curve, and is also a measure of the toughness of the material.

Strand: A number of fibres, such as steel wires, laid or twisted together to form a cable or rope.

Stress Concentration: A phenomenon where an object under load has higher-than-average local stresses due to its geometry.

The types of geometrical shape that cause these concentrations are: cracks, sharp corners, holes and narrowing of the cross-section. Ratio of the greatest stress in the local area to the corresponding average stress is called the *stress concentration factor*.

String: A cord usually made of fibre, used for fastening, tying or lacing.

Strip Theory: 2D analysis of a long structure, such as bridges or cables.

A thin slice of the structure, cut off by two parallel planes normal to the longitudinal structural axis, is to be considered as a representative model for the structural response calculation. Longitudinal variation of both external load and structural parameters are thus disregarded. It is a somewhat similar concept as the plane strain analysis in the theory of elasticity.

Strouhal Number: A dimensionless parameter to indicate the frequency of alternating wake vortices.

Formulated by a Czech physicist, C.V. Strouhal, it is defined as $St = fD/U$, where $f =$ the frequency of vortex formation, $U =$ the flow speed, and $D =$ a representative structural dimension, which is usually taken normal to the flow. The Strouhal number is generally a function of the ***Reynolds number***, $\mathrm{Re} = UD/\nu$. The Strouhal number of a two-dimensional circular cylinder, for example, is approximately 0.2 when the Reynolds number is in the sub-critical range. For many other bluff bodies, the Strouhal number is often less than 0.2.

Subspan: A span that is a subset of another span.

Surface Roughness: A measure to indicate the texture of a solid surface. It is given by the linear deviation of a real surface from the idealized nominal surface.

For the surface boundary layer wind, the roughness length z_0, an indicator of terrain roughness, is given by the height where the mean wind speed becomes zero, assuming the speed profile is given by the logarithmic law.

For the machined solid surface, surface finish is specified by various standards such as ASTM Y14.36M-1996 and ISO 1302:2001.

Suspension Bridge: A type of bridge which is most suitable when its span is very long. The load bearing bridge deck is suspended from the main cables.

Structurally, the most fundamental assumption of suspension bridge is that the whole dead load is carried by main cables alone and stiffening girder is to take only the live load stresses. Towers are vertical and only axial forces are working under dead load. The main cables are rigidly fixed to the anchor blocks at both ends, though the cable tension could be directly introduced to the stiffening girder, instead of having separate anchor blocks. The main cables are sometimes attached to the stiffening girder by centre-ties.

Currently the longest clear span of bridge structure is that of the Akashi Straight Bridge in Japan, which is a suspension bridge.

Symmetry: A relationship of a form, pattern or style to its own mirror image, expressed by exact correspondence of the original to the opposite side of a dividing line or plane.

There is also a case of *point-symmetry*, where the same pattern correspondingly exists at a position that is 180^o rotated about an axis. *Symmetry* is an extremely important element of thought in any artistic works. As an extended concept particularly in physics, *symmetry* sometimes means *invariance*. Note, however, that the mirror image may have different characteristics from the original, such as the case of *enantiomers*.

The autocorrelation function of a stationary process $x(t)$ is an even function, which is symmetric with respect to zero, or $R_X(-\tau) = R_X(\tau)$. It follows that, as a result, the power spectral density $S_X(f)$ of the same process becomes an even function of frequency. However, since the negative values of frequency do not make a good physical sense, the *one-sided* power spectral density, $G_X(f) = 2S_X(f)$, $0 \le f < \infty$ (otherwise zero), is often defined only for the positive range of frequency. Note that the area under $G_X(f)$ for the positive frequency is equal to the whole area under the original $S_X(f)$.

Vibration modes of a symmetric structure are often symmetric and/or asymmetric, or point-symmetric, with respect to the centreline of the structure.

System Identification: Technical determination of structural properties from the known response of the system.

Other terms such as ***modal identification*** or ***parameter estimation*** have been used for the same procedure in the present context. The goal of system identification is the opposite of classical dynamic analysis, where usually the structural properties are known and response of the system is to be determined under various excitations.

The approaches in system identification techniques are broadly classified into two groups; the time domain procedure, which includes the least-square fitting and the random decrement method, deterministic as well as stochastic subspace identification method etc., and the frequency domain procedure by applying Fourier transform, which includes the half-power bandwidth method, the maximum likelihood method and so on.

***Target Reliability Level: The level of reliability required to ensure acceptable safety and serviceability.**

Taut String: A string under large enough tensile force so that its configuration can be considered to be straight without the gravity effect.

TDA: Time Domain Analysis.

Tendon: A steel element such as wire, cable, bar, rod or strand, used for a PC structure to impart prestress to the concrete when the element is subjected to tensile force.

Thermal Expansion: Material characteristics specified by a linear expansion due to a unit increase in temperature.

A material constant defined by a strain corresponding to a unit increase in temperature is called the coefficient of thermal expansion. It is approximately 12×10^{-6} /^{0}C for structural steel and concrete.

Thimble: A device to put inside of a loop at the end of a wire rope to prevent too severe curvature or stress concentration.

Time Domain Analysis (TDA): Analysis of signals and their functions with respect to time as opposed to their handling in terms of frequency.

See also the ***frequency domain analysis (FDA)***.

Time Series: An ordered sequence of values of a variable at equally spaced time intervals.

Time series analysis is used for analysing and understanding the characteristics of discrete data systems sampled from continuous observations and also for fitting of time series models for forecasting of future values. There are many techniques of model fitting including ***Box-Jenkins ARIMA models*** and multivariate models.

TMD: Tuned Mass Damper.

Torsion: A measure to indicate how sharply the curve is twisting.

See also the ***Frenet-Serret formulae***.

Toughness: The ability of a metal to withstand shock loading.

The concept is the exact opposite of brittleness. Toughness can be explained as the ability of a metal to distribute, within itself, both the stress and strain caused by a suddenly applied load. Toughness is usually measured by the ***Charpy test*** but its indication is only relative, since toughness is also governed, in addition to the material composition, by the shape of the metal.

Transverse Wave: A wave in which the direction of material disturbance is perpendicular to the direction of wave propagation.

S-wave, for the case of earthquakes, is of this category.

Trend Removal: Removal of the data characteristics defined as any frequency component whose period is longer than the record length. Least square procedures or the average slope method are often used.

Tuned Mass Damper (TMD): A type of artificial damper sometimes mounted on a structure to augment its overall damping capacity.

A TMD system consists of an auxiliary mass, stiffness such as springs, and a damper to control the system's damping. The natural frequency of TMD is tuned close to the frequency of the primary structure. The device can be designed either as a passive or an active damper.

Turbulence: A flow condition characterised by unpredictably random nature of local velocity and pressure whereas an average flow is maintained.

There could be numerous different definitions for this item. It is probably the most interest but difficult task in the whole glossary to define this particular item and it will be less than perfect no matter how it is done. The concept of *turbulent flow*, of course, is in contrast to the *laminar flow*, which could be defined as follows: *Laminar flow* is a flow in which any local disturbances would be gradually suppressed by viscosity rather than developed due to inertia. Hence, the transition of flow condition from laminar to turbulent is decided by the magnitude of inertia force of the flow relative to the viscous force, which is characterised by the ***critical Reynolds number***.

Ultimate Strength: Highest engineering stress developed in material before rupture. Normally, changes in area due to changing load and necking are disregarded in determining the ultimate strength.

Ultimate strength of structural steel, high-strength steel and piano wires are typically the order of $400MPa$, $800MPa$ and over $2000MPa$, respectively.

***Upgrading: Modifications to an existing structure to improve its structural performance.**

***Utilization Plan: A plan containing the intended uses of the structure, and listing the operational conditions of the structure including maintenance requirements, and the corresponding performance requirements.**

Vibration: The periodic to-and-fro motion of a structure or of its members.

Vibration is characterised by three basic parameters: how quickly the motion is repeated (*frequency*), how large the magnitude of the motion is (*amplitude*), and how soon it dies out without new supply of excitation energy (*damping*).

Depending upon the sources of excitation, structural vibration in reality may be a regular periodic motion but is more often stochastic in both frequency and amplitude. The latter case is called the ***random vibration***, and it is often more convenient to handle the characteristics of vibration in statistical terms for this case.

The ***adverse effects*** of structural vibration are examined from various aspects. The structure should not collapse, must maintain its structural integrity so that it does not lose its serviceability. Even if the structure is safe and able to serve, if it produces any discomfort to the users and/or causes any mechanical problems such as overstressing, malfunctioning or misalignment, it is not acceptable. Also, even if there is no immediate problem, any troubles in future such as structural fatigue damage, possibly also compound with material corrosion, must be avoided as much as possible. The ***acceptance criteria*** are often defined by the combination of amplitude and frequencies but they are related to how often and how long the structure is exposed to dynamic excitation, too.

There are various sources of dynamic excitation for structural vibrations, including earthquakes, wind, moving vehicles and pedestrians, and sometimes even unexpected impact loads such as by machine operation, ship collision on piers and blasting.

Vortex Shedding Excitation: Vibration of a structure or its members excited by vortices of air flow created by the interaction of wind and the structure.

When an aerodynamically bluff body is exposed to wind, a trail of alternating vortices (the ***Kármán vortices***) is often found in its wake, formed by the flow separated from the body. There is also a fluctuating lift force acting on the body corresponding to the formation of vortices. As a result, when the frequency of vortex formation is close to the structure's eigen-frequency, there will be ***resonance***. This is the most fundamental concept of vortex excitation. However, once the vibration starts, the body motion itself will influence on the flow behaviour, which results in a more complicated interaction of flow and structure.

Unlike the case of ***buffeting***, the vortex excitation is usually observed in a limited range of wind speed and its amplitude decreases once it hits the peak value. The vibration is usually characterised by a narrow-band frequency spectrum and somewhat regular amplitude.

Wake: The region of fluid immediately behind a solid body which is in motion relative to the fluid. Usually low in pressure and turbulent.

Wake Galloping: Fluid dynamic instability caused by interaction of two cylinders in tandem arrangement, such as the power lines placed in parallel or bundled fuel tubes of a nuclear reactor.

Wake interference galloping occurs when two cylinders are either closely or largely spaced. For close spacing, the flow around two cylinders is significantly altered by fluid-dynamic interference by each other. Stay cable vibrations of cable-stayed bridges are of this kind. Extensive studies of instability of closely spaced cylinders have been conducted, particularly for heat exchanger bundles and bridge stay cables.

As spacing increases, the interference effects diminish until the next "large spacing" instability range is reached, where the interference effects are only on the downstream cylinder and the flow around the upstream structure is no longer affected by the second cylinder. The interference effects of largely spaced structures have attracted less research attention except for the wake galloping of bundled conductors. The separation of parallel conductors, typically in the range of 10 ~ 20 conductor diameters, is maintained by the use of spacers that usually divide the span into 50 ~ 60 m subspans. This becomes the reason of having a distinctively different type of cable vibration called ***subspan*** oscillation caused by wake interference.

Wave: A vibratory motion or disturbance that propagates and yet is not usually associated with mass transport.

Mechanical waves propagate through continuous media, including air, liquid or solids, which are recognized as sound, ocean waves and seismic waves, for example. There are also electromagnetic radiations, including visible lights, infra or ultraviolet rays, gamma rays etc., which can propagate through vacuum.

All waves have common characteristics that are experienced as reflection, refraction, diffraction, interference, dispersion and rectilinear propagation, though possession of these characteristics is only a necessary condition to be waves.

Waves can be described using standard parameters such as frequency, wavelength, amplitude and period. Waves remaining in one place are called standing waves and waves moving are called travelling waves. Material particles in mechanical waves can be vibrating in the direction of wave propagation or perpendicular to it. They are termed *longitudinal* and *transverse waves*, respectively. In the case of ***seismic waves***, they are also called the P-wave and S-wave, respectively.

Wavelet Transform: A tool for decomposing a signal into its time- and scale-dependent components, in terms of so-called wavelet coefficients. It is suitable for the analysis of non-stationary data.

Fourier transform is a very versatile tool in signal analysis, but it is not suitable for identifying non-stationary aspects of the signal. For example, since Fourier transform is applied to the entire signal length, the result cannot indicate at what time in the signal a specific frequency existed. It is really a tool for frequency resolution but not for time resolution. It means that if the method is applied to structural health monitoring, for example, the method may recognize damage occurrence, location, or even its severity, but not exactly when the damage happened.

Wavelet transform is basically an extended application of a windowing technique with variable-sized windows. It allows the use of long time intervals where low-frequency information is needed and shorter intervals for high-frequency information.

Weldability: Ability of a material to be easily welded without cracking the material, without losing adequate mechanical properties, and also to withstand degradation in service.

The strength of steels could be increased by adding various alloying elements. At the same time, however, the weldability of the alloy is often inversely proportional to its strength. High strength, low-alloy steels were developed especially for welding applications in the 1970s.

Wind Load: The wind-induced forces which a structure is subjected to and expected to resist against.

It includes not only the steady state lift, drag and pitching moment but also their dynamic components due to velocity fluctuation, the body motion, and possible interaction of it with the flow conditions.

Wind Power Input: An expression for the magnitude of energy input due to wind. This expression is often used in the field of power line vibration.

The specific power input $\tilde{P}$ is defined by $\tilde{P} = P/(f^3 D^4 L) = 2\pi^2 \cdot m/D^2 \cdot (a/D)^2 \delta$, where $P =$ the power imparted by wind, $D =$ the cylinder diameter, $L =$ cable length, $m =$ the effective cable mass per unit length, $f =$ vibration frequency, $a =$ vibration amplitude, and $\delta =$ the net logarithmic decrement.

Wind Tunnel: An experimental facility to examine the interaction between an air flow and solid objects that are exposed to it by placing a model of the object in an artificially created air flow.

Wind tunnel tests are carried out for the measurement of wind flow around the body, wind-induced forces or pressure on the body and/or static and dynamic behaviour of the structure induced by wind. Since the determination of wind-structure interaction is not easily done by any analytical means, particularly for many of the civil engineering applications, wind tunnel tests are attractive alternatives. However, care should be taken for proper simulation of both structural models and wind flow conditions in carrying out these tests so that the test results could be properly interpreted to the situation in reality. A set of rules required for carrying out the tests is called the ***similitude requirements***.

A wind tunnel in which an artificially developed turbulent boundary layer flow is used as a simulated natural wind is called the ***boundary layer wind tunnel*** (BLWT).

Windows: Weighing functions to be applied for required operations, such as band-pass filtering, smoothing and/or distortion of a given set of data.

Measurement of any data is a kind of windowing, too, since the measuring period cannot be infinitely long to cover the whole length of the original data, and the observed results are inevitably influenced by the characteristics of sensing devices such as the frequency response, resolution and precision of the measuring system.

The windowing operation can be carried out in time domain as well as the frequency domain. Windowing in time domain becomes a convolution in frequency domain.

See also the ***spectral windows***.

Wire Gauge: A measure to indicate how large a wire is, either in diameter or cross-sectional area of it.

It is a convenient way to show the wire size for both electrical and structural design purposes. A problem, however, is that there are many different gauge systems and they are not universal. Hence, it is important to make sure which wire gauge system is referred to, depending upon its material and purposes.

Wire Rope: A rope made of several strands laid or twisted together like a helix.

Wöhler Curve: A curve to indicate the relationship between the magnitude of a cyclic stress (S) and the number of cycles (N) to the material's fatigue failure.

It is also called the ***S-N curve***. A Wöhler curve is derived from the coupon tests in the laboratory environment, where an ideal sinusoidal stress of constant amplitude is applied to failure. Each coupon tests generates a point on the plot, though in some cases the time to failure exceeds the anticipated time frame. The Wöhler curves allow designers to make a basic estimate of the expected life of the structural part against expected stresses.

Writhe: To twist and turn.

Yaw Angle: The horizontal angle deviation of the vehicle's heading, for example, from the assumed reference direction.

Yield Point: The stress at which the metal changes from elastic to plastic in behaviour.

Structural steels usually exhibit the yield strength of 300 to $400 MPa$.

Offset yield strength is determined from a stress-strain diagram when it is not linear up to the yield point. It is the stress corresponding to the intersection of the stress-strain curve, and a line parallel to its straight line portion offset by a specified strain. Offset for metals is usually specified as 0.2%. It is equivalent to the ***proof stress***.

Yield Ratio: A ratio of the yield strength to the tensile strength of a material.

Young's Modulus: A ratio of increase in stress to that of strain, when the stress-strain relationship is linear.

Young's modulus of steel is usually taken as 200 to $210 GPa$. When a material exhibits nonlinear stress-strain relationship, the definition of an *equivalent Young's modulus* is sometimes convenient. Young's modulus in dynamic situation may not be always equal to the static value.

Note: Terms with * are definitions according to ISO 2394 and ISO 13822.

References:

Bowden, G., Stretched wire mechanics, *Proc.8th International Workshop on Accelerator Alignment*, Geneva, Oct. 2004.

Caetano, E., *Cable Vibrations in Cable-Stayed Bridges*, Structural Engineering Documents 9, IABSE, 2007.

Gimsing, N.J., *Cable Supported Bridges: Concept and Design*, John Wiley & Sons, 1997 (2nd ed.).
Irvine, H.M., *Cable Structures*, The MIT Press, 1981.
Proceedings of the International Symposia on Cable Dynamics, Liège 1995, Tokyo 1997, Trondheim 1999, Montréal 2001, Santa Margherita 2003, Charleston 2005 and Vienna 2007.
Starossek, U., Dynamic stiffness matrix of sagging cable, *Proc. ASCE* (117) EM12, 1991, pp.2815-2829.