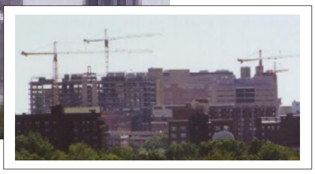
High Sensitivity Dynamic Rotational Sensors for Structural Monitoring

This article on the latest technology in respect of rotational (non-linear) data retrieval is contributed by Robert J. (Bob) Leugoud, President of eentec, USA who is an influential contributor in this field



Modern buildings and new construction incorporating the latest in architectural design increase rotational motion. The increased rotational motion should be monitored to model the structures strength, state of health and survivability of near field earthquake events
- Pictures courtesy of LCL

Introduction

For the past 40 years people have dynamically monitored structures using translational sensors such as force balanced accelerometers and velocity sensors. Until now, rotational data has largely been neglected.

Historical Challenges: Increasing Digital Resolution

In the earliest days of structural monitoring, film recorders were used. The advances that have occurred over time centered around increasing the digital resolution of the analog signals in the recorders. As the recorders' resolution increased, advances focused around decreasing the noise of the linear sensors, thereby increasing the total dynamic range of the data acquired. These changes allowed structural engineers to analyze smaller signals to look for anomalies in the response of a structure subjected to near field earthquake events, aging, or use. Data could also be used to compare the response of the structure to those of the design specifications. Various computer models have been developed to design and test responses when structures are subjected to various motions.

Components Of Motion

Nature, however, is always complicated -- never simple and straightforward. Motion of ground and structures are not only translational, up/down and side to side (L,T,V or X,Y,Z); there are always rotational components of motion. Non-linear site response further adds rotation and rocking beyond linear motions. This is not a new concept. Over the years there have been many technical papers published on the subject (Aki, Bogdanov, Graizer, Gupta and Trifunac, Lee and Trifunac, Trifunac, Wang, and Wong). Graizer, in 1989, published the equations of motion where the "right-hand side" of the equation represented contributions of tilting and angular acceleration on the three axis. In many software models, these "right-hand side" terms are usually ignored.

By definition, rotational forces arise when a uniformly distributed lateral force is not met by a uniformly distributed lateral resistance. In a perfect structure, all components would be perfectly symmetrical and homogenous, so a force in any direction would be met with an equal resistance. In such a structure, the magnitude of rotational motions would be insignificant. In the real world, architectural design advances utilize new and stronger materials resulting in very aesthetic but asymmetrical structures, thereby increasing the need for rotational data in monitoring.

Old buildings utilized a very symmetrical cube like design. This type of construction minimises rotational motion of the structure
- Pictures courtesy of LCL

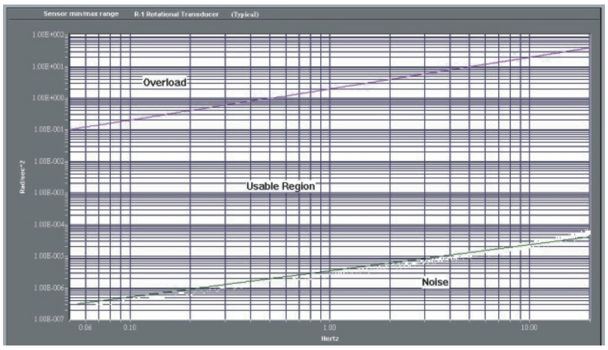
Monitoring Response & State Of Health Of A Structure

In earthquake engineering applications, rotational data can be used to explain and model a structure's response to an event. There have been cases in which a structure was undamaged by a first event, but then suffered damage in another event which the translational sensors recorded as smaller. It is suspected that these types of occurrences are a result of the non-linear movements. Further investigations consider the non-linear behavior of the ground around and beneath the structure to see if its anisotropic properties act as a "shock absorber," mitigating the full force of the wave.

In structural engineering applications monitoring the health of the structure, rotational data can be used to determine the structure's dynamic rocking and twisting behavior. By dynamically monitoring this behavior, trends can be established. Reaching a certain level would trigger an alert for the engineer to visually check the selected monitored components of the structure and take appropriate remedial actions.

Many Attempts: Rotation Calculation

Over the years there have been many attempts to calculate rotation using data obtained from two or more linear sensors. The results were masked by large errors (up to and even greater thatn 100%) due to the nature of each individual linear sensor. It was found that each sensor had to be exactly matched across the entire passband, both electrical and mechanical characteristics, for the data to be useful. Unfortunately, due to the small variations in each electronic component and the minute differences in each mechanical part, this was not possible.



Graph of the R-1 sensitivity in Acceleration units required for structural monitoring

Other attempts included the use of the Coriolis Force Gyro chips. This technology was developed by Charles Stark Draper Labs and has been licensed to a number of industrial gyro manufacturers that produce a small, rugged IC chip which is sensitive to rotations. However the sensitivity of these chips is not useful for structural monitoring applications. At low frequencies these chips average a sensitivity of 7 X 10^{-5} rad/sec. To be useful in various structural engineering applications, the sensitivity would have to be increased by a factor of 10 to 100.

eentec's R-1 Sensor: Unique Benefits

eentec, a St. Louis, USA based instrument company, has introduced the R-1 rotational sensor. The R-1 design began by adapting the design of electrolytic wideband velocity sensors which have been on the market for over 10 years. The result is a highly sensitive, pure rotational sensor which is completely unaffected by linear motion.

The unit has a sensitivity of 5 x 10^{-7} rad/sec which provides useful data for structural monitoring applications. The standard frequency bandwidth is 0.05 Hz to 20 Hz., with no parasitic resonances.

The R-1 is available in a variety of packages. To augment existing monitoring systems, it is packaged as a free-standing unit in an environmental case. One of ***eentec***'s force balanced accelerometer EA models can be included in the free-standing package to provide data for all components of motion, translational and rotational. For new installations, the R-1 rotational sensor and/or the EA force balanced accelerometer are packaged with the portable ER12 recorder. Further information on these products can be requested directly from ***eentec*** at eentec@att.net.

Principals of Operation

The R-1 is an electrochemical sensor. A toroidal channel is completely filled with an electrolyte, within which is a microporous ceramic plug containing four platinum grid electrodes. Thin platinum wires connect the electrodes to the external electronics. The electrolyte inside the sensor cell moves only when subjected to rotation around the axis perpendicular to its plane. When an angular acceleration is applied around this axis, it creates a pressure differential across the sensor cell, which causes the electrolyte to flow. This flow, in turn, generates a current in the electrode bridge circuit. The sensitivity is proportional to the toroid radius. Tripling the toroids's diameter would result in approximately a tenfold increase in sensitivity, but the manufacturing of large sensor cells raises their costs. With this in mind, the R-1 was designed to provide the required sensitivity for structural monitoring applications at the lowest manufacturing cost.

The Future

For the first time, engineers will have meaningful rotational data available to them. As more and more installations add rotational sensors to their arrays, rotational data will become available for many types of structures and soil types. Actual data from the response of the structure can be compared to the theoretically modeled response to determine whether the foundations are as strong as they were intended. In turn, computer models can be further refined to reflect all the components of motion on a structure, both linear and rotational.

Company Profile

eentec, a St. Louis (Go Rams), USA company was formed to specialize in instruments that provide new and useful dynamic data to the structural engineering community. ***eentec*** and its partners have a combined experience of over 40 years in the design of innovative instruments. Products on the market or soon to be released include rotational sensors, value priced force balanced accelerometers and recorders.

About the Author

Robert J. (Bob) Leugoud is President of ***eentec***. Mr. Leugoud has over 20 years experience in the seismic research instrumentation market. He has been involved with the supply of instrumentation for seismic monitoring of structures such as dams and critical facilities and dynamic monitoring of complex structures such as bridges.