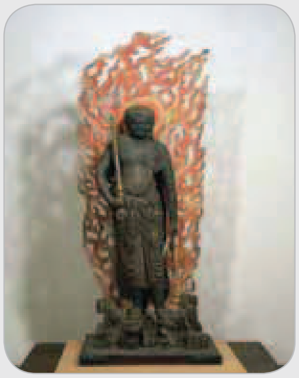
The Art of Packaging to Protect Cultural Assets



The Tokyo National Museum holds over 113,000 assets consisting of multiple pieces; assets include paintings, calligraphy, sculptures, ceramics and swords.

Simulation tools isolate the cause of undesirable **shipping loads** on museum's **cultural treasures.**

By **Nobuyuki Kamba, Ph.D.**

Simulation technology is commonly used in advanced manufacturing industries to "virtually" analyze and optimize the performance of new products to streamline development – and to provide the confidence that the manufactured products will behave and perform as designed.

Like manufactured products, over the years, the sophistication of packaging and transportation systems has significantly increased to enhance business profitability as well as product quality and consumer safety. Similar to their peers in product engineering, packaging engineers are required to evaluate the performance of packaging systems under structural and thermal loading, fatigue, the dynamic performance of multilayer packaging systems and packaging designs for consumer appeal and brand image. For improved sustainability, many are now considering the use of new materials – as well as the design of thinner, stronger packaging designs.

With the importance and design complexity of today's packaging systems, computer-aided engineering (CAE) technologies and simulation-driven design approaches have moved beyond advanced manufacturing into non-traditional industries like packaging. This is the case at the Tokyo National Museum (TNM), where CAE is used to evaluate the performance of packaging systems designed to protect Japan's cultural assets.

Founded in 1872, the TNM preserves a range of archeological objects and artworks from Japan and the surrounding Asian regions. The museum holds over 113,000 assets consisting of multiple pieces; assets include paintings, calligraphy, sculptures, architecture, metalwork, ceramics and swords, among others.

Often, these art objects must be transported between locations, such as the TNM and temples. Packaging the objects, therefore, is serious business, as these items are priceless and cannot be replaced.

Unexpected vibration loading to precious Japanese artifacts transported via trucks spurred the Tokyo National Museum to re-evaluate its packaging system design.

As a result, the TNM places great importance on evaluating its shipping process and packaging systems. Through recent test trials and physical road tests, the TNM discovered an unexpected – and unacceptable – vibration loading to precious artifacts. Having little control over the vehicle dynamics of the shipping trucks, it was clear the TNM needed to re-evaluate the packaging system design.

It was at this time the TNM entered into a collaboration with Altair® and the consulting firm eXcearch LLC, to help pinpoint the root cause of the undesired vibration. Due to the complexity of the problem, the team mapped out a simulation-driven investigative approach incorporating both CAE and physical testing to identify the source of the problem as well as recommendations to redesign the system.

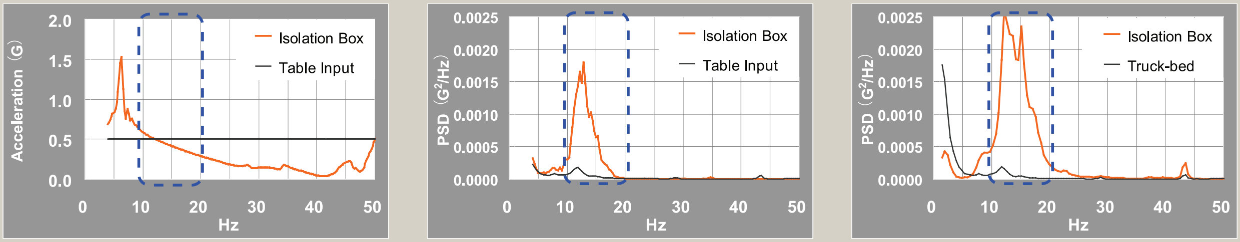
Surprising Results

The TNM had been using coil spring type "vibration isolators" for shipments of cultural assets. The isolators, or wire ropes, were positioned at the bottom of a shipping box, which contained the art objects. The purpose of the isolators was to minimize the transmission of road loads and vibrations to the art objects secured inside the shipping box.

The type of isolator was originally selected based on the nominal frequency response characteristic for that particular packaging. The team was interested in identifying the "resonant frequency" of the isolators, that is, their tendency to oscillate at greater amplitude at some frequencies than at others. By measuring acceleration on the shipping box, the team would be able to see – for a given amount of input vibration – how much the cultural asset would vibrate.

Coil spring vibration isolators positioned at the bottom of a shipping box were designed to minimize the transmission of road loads and vibrations to art objects secured inside the shipping box.

Based on the frequency response characteristic obtained by the sine sweep test, the team expected a resonance frequency of less than 10 Hz, which is out of the truck's frequency range of excitation (10 Hz to 20 Hz). However, the results from both a random lab test and a trial truck shipment indicated a resonance frequency between 10 Hz to 20 Hz. The team realized that the sine sweep test was not enough to define the coil spring properties to isolate the resonant frequency of the system from the excitation frequency. Sine sweep tests establish the "frequency response



Graphs show in red (from left) the expected result from a sine sweep test; the unexpected result from a random test; and the unexpected result from the trial shipment.

characteristic" by starting at a low frequency and increasing in frequency at a set rate.

Shaking Up the Investigation

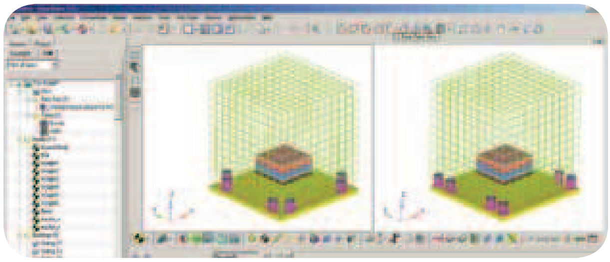
The team surmised that the high resonance was attributed to the nonlinear response characteristic of the isolators, that is, the change in stiffness that occurs as the isolators are compressed, leading to a higher vibration.

To prove this, the team devised physical experimental tests to quantify the baseline characteristics and behavior of the system to assemble a representative, high-fidelity, multi-body dynamics (MBD) simulation model. The team created a dummy packaging box 800 mm wide x 800 mm deep x 800 mm high with four isolators placed at 0-degree and 45-degree angles. They tested two weights, 176 kg and 88 kg.

The team mounted tri-axial accelerometers on the bottom of the dummy box and used a "shaker table" in the lab to measure the response of the system for controlled frequency excitations.

For the 88 kg box, acceleration input ranged from 0.1 to 1.0 g; for the 176 kg box, acceleration input was 0.1 to 0.4 g.

Altair collaborated with the Tokyo National Museum and the consulting firm eXcearch LLC to perform multibody dynamic simulations on the shipping container.



The frequency range of this sine sweep excitation was between 4 Hz to 50 Hz.

The team also conducted random excitation tests that are representative of actual road loads. The engineers gathered data for these tests by mounting acceleration data recorders onto trucks and measuring the resulting accelerations during actual road load tests.

Based on their physical tests, the team discovered that resonance frequency shifts to a lower range as the input acceleration increases. This change in resonance frequency reflects the change in isolator stiffness. When the acceleration is small, the operational range of the isolator is relatively stiff, which results in a higher natural frequency of vibration. The corollary is also true. The team then moved into simulation mode using the results of the physical test.

Dynamic Modeling

In the simulation phase of the study, engineers had two key objectives in mind: to identify the nonlinear property of the isolator and to build a baseline MBD simulation model that was representative of the experimental physical test results in order to accurately predict the performance and response of alternative packaging system designs.

The team began by applying MBD technology commercially developed by Altair. Using MotionSolve® software for mechanical systems simulation, MotionView® for model assembly and HyperView®/HyperGraph® for results visualization, they created a virtual model of the dummy box; the nonlinear properties of the isolator's spring were also defined. By capturing the physical characteristics inside the model, MotionSolve applies numerical analysis methods to predict the behavior of the overall system.

For the dummy box, they modeled the center of gravity, mass and inertia. For the spring, they modeled the nonlinear property in the vertical and two horizontal directions. The excitation (input) included a sinusoidal sweep in the vertical and two horizontal directions. Finally, the measurement points (output) were set up to correlate to the experimental measure points.

Simulation results confirmed that the smaller the input acceleration, the higher the natural frequency due to the reasons explained previously. The results matched that of the physical experimental tests.

However, a question still remained: Why was the natural frequency varying due to the excitation level? The answer lay in the stretch and compression properties of the wire rope, including stiffness and damping factors as well as the damping coefficient.

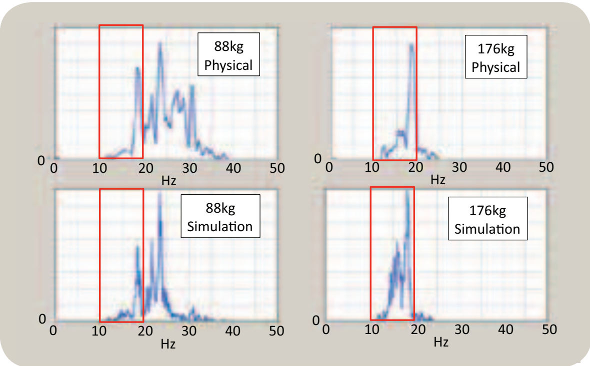
The team carried out further simulations to explain the isolators' behavior, which included analyzing the wire rope force, force from the wire rope property curve, spring deformation, damping coefficient and velocity. The data was then applied in the simulation of the random excitation test.

For instance, the team applied the time history of acceleration extracted in the shaker table physical test and then converted the time histories of acceleration of the dummy box to a mathematical representation called the power spectral density, or PSD. The simulation results matched well to the test results in the focused frequency range of 10 Hz to 20 Hz. What's more, the simulation model was effective in the random excitation (road) test.

Based on the results of physical and simulation tests, the team concluded that the 10 Hz-to-20 Hz frequency range acceleration was, indeed, attributed to the isolators – and steps would need to be taken to keep the resonant frequency outside of that range to protect the TNM's cultural assets.

The Power of Simulation

In this study, simulation played a key role in visualizing the troublesome frequency band. In that "zone," the peak vibration would result in cultural assets vibrating and potentially being damaged. The simulation studies enabled the team to model the problem without putting any cultural assets at risk.



Results of the simulations (bottom) correlated well with random excitation tests (top), indicating that the 10 Hz-to-20 Hz frequency range acceleration was attributed to the isolators.

In addition, this simulation approach lays the groundwork for the TNM to test new spring properties of isolators. The museum can apply the knowledge it gained through this study in selecting the optimum packaging system – including the appropriate cushions to absorb shocks. This study is useful in investigating a range of packaging solutions in the virtual world, not just packaging systems with coil springs.

Simulation, commonly used in advanced manufacturing sectors like automotive and aerospace, is branching out in ways that not only continue to improve our quality of life but also help protect and preserve our history for educating generations to come.

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For more information on Altair's multi-body dynamics solutions, visit c2r.altair.com/2012.

TNM 140th ANNIVERSARY

A Treasure Trove of History

The Tokyo National Museum (TNM), founded in 1872, is celebrating its 140th anniversary in 2012. Located in Ueno Park, Tokyo, the museum is renowned for its outstanding collection of Japanese art and for showcasing traditional Japanese culture from ancient times to the modern period. The museum also holds an extensive collection of Asian art.

The total number of items in the TNM collection exceeds 113,000. There are six exhibition galleries on the museum's premises. The Honkan (Japanese Gallery), Heiseikan, the Gallery of Horyuji Treasures and the Kuroda Memorial Hall are currently open to visitors; the Toyokan (Asian Gallery) and Hyokeikan are temporarily closed. The complex also includes the Research and Information Center, restaurants, museum shops and a garden with five historic teahouses.

The museum is dedicated to collecting, preserving, restoring and exhibiting cultural properties. It also conducts research and offers educational programs and events for the public. In honor of its 140th anniversary, the TNM has launched a campaign titled "Thanks to the Energy of Culture." Various exhibitions and events are planned celebrating the anniversary throughout the year, and information about them is available via iPhone or iPod touch applications as well as the museum's website (*www.tnm.jp*).