"1.26": From Tsunami to Abstract Net Form

By Shane McCormick, P.E., S.E., Charles Keyes, P.E., S.E., and Peter Heppel

A monumental net sculpture was installed in Denver July, 2010, as a featured element of the Denver Biennial of the Americas. The sculpture, 85x63 feet in plan and 30 feet deep, was suspended 93 feet above the ground from a 203-foot long planer mesh tensioned between the Denver Civic Park Greek Theater and Denver Art Museum *(Figure 1)*. In generating the sculpture form, artist Janet Echelman drew inspiration from a map illustrating the effects of the February 2010 Chilean earthquake and its ensuing tsunami. The sculpture, fabricated of advanced lightweight materials, required the use of sophisticated non-linear structural analysis methods to accurately predict internal forces and deformations.

The Biennial was a month-long event celebrating the culture of the western hemisphere. The event included music performances, roundtable discussions, public lectures, and art exhibits. Attendees included current ambassadors, national cabinet secretaries, and former presidents. As part of the event, the Denver Office of Cultural Affairs commissioned Massachusetts-based artist Janet Echelman to design a temporary sculpture to be displayed in the southwest corner of Denver Civic Park. The sculpture would be the largest and most visible artwork of the Biennial.

Echelman is known for designing monumental public net sculptures animated by wind. Suspended in the air, the sculptures are made of modern lightweight fiber materials and illuminated at night. Recent work includes *Her Secret is Patience*, the new 145-foot tall civic icon in Phoenix Civic Space Park, and *Water Sky Garden*, a 75,000-square-foot immersive art environment with two net sculptures located at the Richmond Olympic Oval, the official venue for the speed-skating events of the 2010 Vancouver Olympic Winter Games.

Sculpture Design

Echelman's primary goal for the Denver sculpture was to represent natural phenomena linking the 35 countries of the western hemisphere. Additional goals included visually connecting the Denver Art Museum with a recently restored 1920s Greek Theatre in Civic Park, and creating a quickly deployable (and demountable) piece. She was further challenged to meet an extremely tight schedule: only four months separated artist selection and sculpture installation.

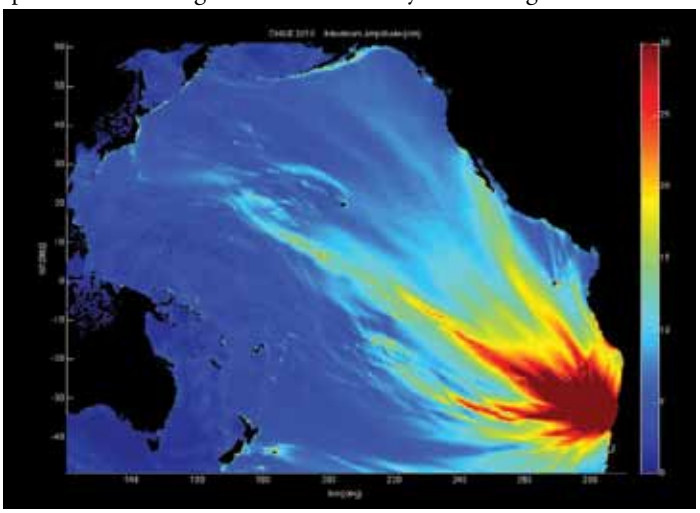

Figure 2: Map of wave amplitude increase caused by the 2010 Chilean earthquake. Courtesy of NOAA.

Figure 1: Artist's initial sketch showing the sculpture suspended between the Denver Art Museum and Greek Theatre, located in Civic Park. Courtesy of Janet Echelman, Inc.

In February 2010, an earthquake, measuring 8.8 on the Richter scale, struck Chile. The event, which lasted over 90 seconds, had an epicenter 71 miles north of Concepción, Chile's second largest city. Many buildings collapsed and 486 people perished. During the event, rapid movement of the ocean floor generated a tsunami that affected the eastern half of the Pacific Ocean. Scientists with the National Oceanic and Atmospheric Administration (NOAA) used data from a network of specialized ocean buoys to generate a map illustrating increased wave amplitude resulting from the earthquake *(Figure 2)*.

Amplitude increased over four feet near Chile and one foot over 2000 miles west of the coast. This map served as the initial form generator for the sculpture.

Scientists calculated that the event shortened the length of the day by 1.26 microseconds, a figure which became the title of the piece. The earthquake, resulting from tectonic plate movement, redistributed mass closer to the Earth's core. To satisfy the law of conservation of angular momentum, the Earth's rotational speed increased, similar to what happens when a spinning ice skater pulls her arms closer to her body.

Echelman's studio created the net form using proprietary computer software. An outline, created by isolating the area from the NOAA map most affected by the tsunami, was extruded downward, cinched at the center, and subjected to gravity forces. The studio divided the resulting form into differently colored horizontal bands that correlated to wave amplitude.

Suspending the Sculpture

The net form was suspended from an inclined tensioned planer mesh extending from the North Wing of the Denver Art Museum to the ground in front of the Greek Theatre. The mesh consisted of twine spaced at 1¾ inches on center in each direction. Boundary ropes, 7/16-inch in diameter, were at the mesh edges, and 7/16-inch diameter

stay ropes connected to three points at each end of the mesh. The North Wing of the Denver Art Museum, designed by Italian architect Gio Ponti and completed in 1971, is an abstract castle form with artistically arranged slots and rectangular openings. Perimeter walls are 10-inch reinforced concrete and extend as much as 25 feet above the roof. Three openings in these walls above the 6th floor roof, 110 feet above grade, were used as anchor locations for the planer mesh stay ropes. Twelve-inch deep channels placed across the inside face of each opening were attached to the walls with concrete screw anchors. Stay ropes connected to D-rings, which were welded to the outside face of the channels.

At the base of the Greek Theatre, the contractor installed three inclined Manta Ray 2 ground anchors. These anchors are often used to support telephone pole stays and earth retaining systems. The anchors consist of a straight rod with an end plate that rotates perpendicular to the rod during installation, to permanently bear against the soil. Anchors are tensioned in place to confirm assumed design capacities.

The mesh, boundary ropes, and stay ropes consisted of Spectra fiber, a lightweight polyethylene material manufactured by Honeywell that has a strength-to-weight ratio seven times that of steel cable. The planer mesh was tensioned to limit vertical and horizontal deflections, with each mesh twine stressed to 5 pounds, and the boundary and edge stay ropes stressed to 3,000 pounds. The tensioned planer mesh is similar to the form of a spider web *(Figure 3)*. Both have a central area with closely spaced lines, edge lines to collect force from the interior, and primary lines anchored to adjacent structures. Both resist lateral forces by significantly deformed geometric forms.

The inclined mesh and suspended net were assembled using traditional net and braid detailing commonly used in fishing nets. Steel linking plates were eschewed in favor of knots, loops, and splices.

Figure 3: A spider web, similar in form to the included tensioned mesh used to support the net sculpture. Courtesy of David Kleinert Photography.

The artist has, in the past, supported sculptures using inclined masts and suspended steel armatures. This is the first installation with a tensioned mesh, a structure with much less visual mass, allowing the sculpture to appear to float in space.

Structural Analysis

The sculpture was designed according to IBC 2006 and assigned to occupancy category I, commonly used for temporary facilities that, in the event of failure, present a low hazard to human life. The design pressure was 15 psf, calculated using a wind speed of 90 miles per hour and a density reduction factor of 15%.

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Peter Heppel Associates (PHA), specialists in aerodynamics and lightweight structures, completed structural analysis using proprietary non-linear software. The shape of the tensioned mesh was developed using form finding techniques *(Figure 4)*. Form finding is a process involving iterative analytical methods (or physical models) to determine a deformed shape in equilibrium with externally applied forces. The process is often used when structures have minimal bending stiffness and resist load primarily by internal axial forces. Loading on the net and tensioned mesh was estimated assuming that straight segments and knots had the classical aerodynamic properties of yawed cylinders and spheres, accounting for the appropriate Reynolds number. The drag coefficient varied based on wind direction, but was typically about 0.95. Dynamic effects were generally ignored – wind pushes nets downstream, aligns elements, and reduces projected area.

Fluttering, usually exhibited by fabric elements such as flags, does not typically occur due to nets' high aerodynamic damping properties. The calculated lateral deflection of the tensioned mesh under design wind load was two feet. The calculated lateral deflection of the net itself was ten feet.

Installation

JunoWorks, a Denver-based fabrication studio specializing in art and architectural metal works, installed the sculpture. JunoWorks first attached the stays to the Art Museum with a crane, and then lifted the tensioned mesh and net sculpture over trees and other obstacles using tall man lifts. Chains were attached to the ends of the stays to allow adjustment for tolerance and relocation of ground anchors due to conflicts with in-place utilities and trees. JunoWorks tensioned the chains with ratchet winches and monitored forces with in-line load cells. Construction lasted about a week, with the installation of the tensioned mesh and sculpture taking a single day.

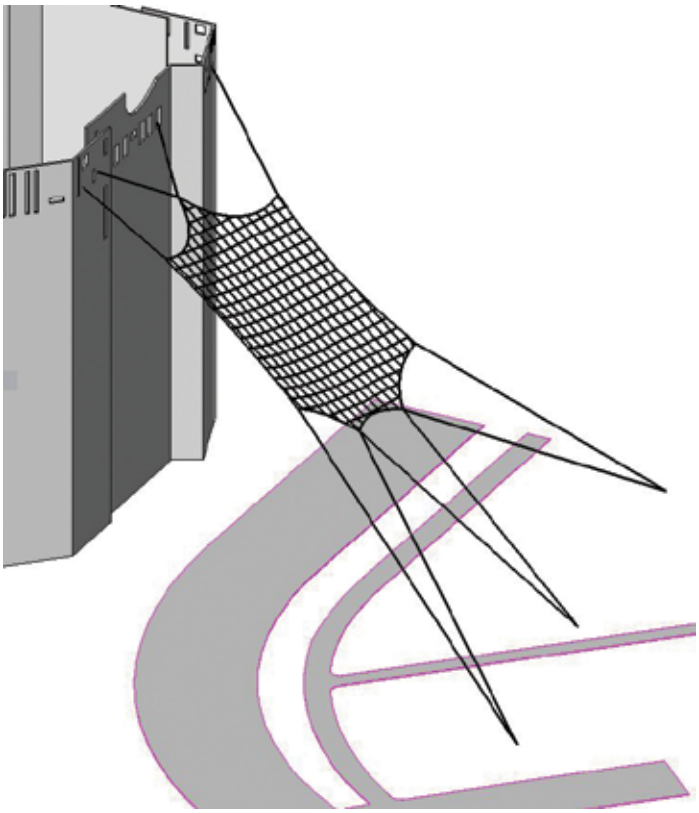

Figure 4: Inclined tensioned mesh form.

Figure 5: The sculpture illuminated at night, a fitting memorial to the 2010 Chilean earthquake. Courtesy of Janet Echelman, Inc.

From Diaster to an International Bond

Echelman's *"1.26"* is a unique fusion of traditional net technology, advanced modern materials, and refined aesthetics *(Figure 5)*. Representing wave patterns that affected the entire Western Hemisphere, it is a fitting memorial of the earthquake that struck Chile February 2010 and how that event joined 35 countries as one. The City of Denver currently plans to reinstall the sculpture during future Biennial Events.▪

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Project Team

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Sponsoring Agency:	Denver Office of Cultural Affairs
Architect of Record:	Fuse Studio Architects
Lighting Designer:	Richter Scale Productions
Artist:	Janet Echelman, Inc.