Structure and Space of Serendipity Brought by Materials for Art

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Abstract

Material Speaks: How to effectively utilize materials energy [joules]. Architects, engineers and contractors all know and understand how to review and compare materials and skeletons of the same period. Reviewing and comparing the materials of different architecture and skeletons across time, however, was a different matter. Now, the “Material Speaks Energy Theory” has made it possible for everyone to review and compare not only different materials, architecture and skeletons across time, but the CO2 emissions of special structures, as well. The Material Speaks Energy Theory was formulated by categorizing, analyzing and summarizing the outcomes of more than 2,500 designs, and integrating the value of materials energy based upon the theory of structure design and recognition.

Keywords: tensegrity, serendipity, gravity, earthquake, typhoon, pin joint, art, folly, Nature of Structure, net playground equipment

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1. Introduction

Over the last 40 years I have designed 2,500 projects. 50 out of the 2,500, i.e. 1/50, are structural designs for artworks and monuments including follies (foolish structure).

2. Being Aware of Flexibility

As the most representative example of follies, I vividly recall a project by Elia Zenghelis for The International Garden and Greenery Exposition, Osaka, Japan, 1990, FOLLY FOR EXPO'90 #11 composed of a huge column and a huge beam connected to each other. (Figure 1) There, the column and the beam supported each other by utilizing frictional resistance generated on the surfaces touching to each other instead of normal rigid joint delivering bending/shear/axial force.

Folly #8 for the same expo by Morphosis was an asymmetric design. (Figure 2, 3) To balance the asymmetric object under gravity, the outermost end of the lighter side and the ground were connected by pin joint for preload to download. Even though, pin supported structure may become unstable when an earthquake or typhoon hits Osaka. In order to keep the asymmetrically loaded folly from collapsing, tie down belts were attached to each side with proper load for each. The huge 3 flower pots installed on top of the inverted triangle shaped structure were stable under gravity load, though when an earthquake occurs, they quake strongly even do not collapse. The artist brought such a design of art moving three-dimensionally to Japan, land of earthquakes, without knowing how huge earthquakes may occur in Japan. But in this way, the artwork was realized. In the event of
earthquakes, thin tie down belts of steel cables on both sides and inverted triangle truss, which was dynamically stable, worked together, as hybrid, to save the folly from collapse. This folly was approx. 10m x 10m.

Mycal Sanda Pororoca, designed with concept of pororoca (huge backward tidal bore), is another example. (Figure 4) Its 2 sloping roofs of 30m x 100m consist of 4,000 glass pieces, but none of the pieces was broken when The Great Hanshin earthquake occurred on January 17, 1995. We designed 3-D structure along with the sloping roofs using basic units of 3-pin structure, which is stable under gravity load but when earthquake occurs the joint solely deforms significantly. (Figure 5) Also, steel pipes of ○-250mm for sloping beams and bottom chords of originally shaped steel rods, which resist tensile stress effectively, were applied. Although these parts are made of steel, they have characteristics to deform flexibly under enormous load due to earthquake or typhoon. In other words, even the example projects above are made of rigid steel, when enormous load by the nature such as earthquake or typhoon is applied, their structure turns around and change their shapes as if soft materials, and once the earthquake or typhoon is over, they return to original position. Concerning materials used for art and its framework, it is material that creates new architectural structure if we find out potential of material and volume of load through listening carefully to invisible voice of material about what form the material wishes to be.

A lot of architects and structural engineers have been enchanted by Kenneth Snelson’s Nature of Structure. As its structure has wide variety of potential, diversified designs and technical challenges have been made. Since this Kenneth's invention has been named as “Tensegrity” by Richard Buckminster Fuller, it became known in the field of science and technology. Then it has been analyzed and classified by engineers and scientists over the world. Even though the structural design of Nature of Structure was originally expected to be enjoyed naturally and freely, today degree of freedom to design it seems less than before. This is because Nature of Structure has been classified as Tensegrity - 4 by scientists. I would rather, if I dare to classify it as Tensegrity Structure, Tensegrity – 0. Through structural design for Kenneth’s installation Dragon in Osaka in May 2001, he told me there were 4 aspects to understand materials in its designing concept; muscle, bone, joint, and skin to cover the other invisible factors. Physically, muscle deals with tensile stress, bone with compression stress, joint with stress processed by tensile and compression stress and also it keeps the balance between them. If stress over capacity of the joint is applied, it will be diagnosed with bone fracture. (Figure 6, 7, 8) Thus, for structure of Nature of Structure, Kenneth had animals and plants in the natural world in his mind. As shown on Figure 9, even it is neither an animal or a plant, it floats above a lake. (Figure 9) Nature of Structure draws us in the majestic nature. Needle Tower looks like a tower extended straight to the sky. (Figure 10) Works such as Easy-K are large
cantilever jutting out above lake or pond. (Figure 11) Dragon, which I worked with, is rising up from a lake to heaven. (Figure 12) These examples show the theme of Nature of Structure is nature in a broad sense.

Natural world is greatly affected by gravity, earthquake, typhoon, heavy snowfall and rainfall, etc. Fundamental factors of relationship between such power of nature and Nature of Structure is can be represented by 3 points as below.

1. Despite pin-joint, it is stable under gravity. changes its shape but does not collapse.
2. Detail of joint determines life-span of material and structure.

Nature of Structure has numerous design possibilities and we applied it to realize structural designs for following projects. (Video A)

1. Prism of Light (Figure 13)
2. Recycle Art Pavilion by Jae-eun Choi for The Daejeon International Expo (Figure 14)
3. Foundation for Ambulance Service Development Tokyo Training Facility Gymnasium (Figure 15)

4. Soft But Firmly Hand Crocheted Huge Net for 80 Children Curved surface of 20m × 25m net made of thin 6mm-in-diameter nylon rope, crocheted into hexagon grids, can support 80 children playing on it. (Figure 16) Just like Nature of Structure, this 3-D structure performances as stable under gravity with deadweight. Once children begin to play with balls hung from top and bottom of the net, the surface starts swinging stronger than earthquake in more complicated ways. The curved surface is controlled by tensile stress and swings unpredictably. Forgetting about time, children enjoy the artwork being synchronized or swung by others. For this art work, 2 types of grid design are used. One is suspension net called “air pocket” formed with hexagon grids where each side is 2.5cm. (Figure 17, 23) The other is called as “space net,” HP (hyperbolic paraboloid) net made of square grids of 3.5cm x 3.5cm. (Figure 18, 24) This type of playground equipment installation is used in 15 countries today; in Asia, Canada, United States, and Europe. (Figure 19) Children can enjoy hanging, climbing, crawling, sliding, rolling, bouncing, swinging, swaying, balancing, jumping, and combination of them on these nets. (Video B) In structural mechanics, nonlinear analysis is used for structural analysis program and load case includes deadweight and uneven load. (Figure 21, 22)
4. **Soft But Firmly Hand Crocheted Huge Net for 80 Children**

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5. CO2 emission efficiency and Materials

Material Speaks Design, below is the function I use.

Structural Energy of Material and Space Function:

This Structural Energy of Material and Space Function makes possible to compare efficiency of framework in space, and moreover, CO2 emission efficiency until completion of the building beyond material, space, time and place. This means we can compare The Eiffel Tower made of cast-iron and wrought iron, burnt down The Crystal Palace of cast-iron, wrought iron, glass and wood, Villa Savoye of concrete, and “Silver Pavilion” Ginkakuji Temple of wood, located in different parts of the world. Another example, when planing Villa Savoye, originally built in suburban Paris with few earthquakes, in a country with frequent earthquakes, reaction of framework in space and material efficiency can be compared. This new function depends on \( E=mc^2 \). This method is based on the 2,500 projects I realized in 25 countries in 50 years.
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Structural Energy of Material and Space Function:

\[
E_{SS} = \sum_{n=1}^{\infty} mE_n \times mV_n \quad [kN/m^2] 
\]

Where:
- \( E_{SS} \): structural energy of material and space [kN/m^2]
- \( E_n \): Young’s modulus of material [kN/m^2]
- \( m \): material
- \( V_n \): quantity of used material (volume) [m^3]
- \( n \): number of kinds of used material

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Figure 26: Structural Energy of Material and Space Function Makes Possible to Compare Efficiency of Framework in Space, and CO2 Emission Efficiency