American Concrete Institute®
Advancing concrete knowledge

International Session, Structural Concrete: An Art Form, Part 1

ACI Spring 2012 Convention
March 18 – 21, Dallas, TX

ACI
WEB SESSIONS

José M. Izquierdo-Encarnación is a Principal of PORTICUS, a consulting firm located in Rio Piedras, Puerto Rico. Izquierdo was elected ACI President in 2003.

He is a Fellow of the Institute, a member of ACI Committees 314, Simplified Design of Concrete Buildings, of which he chaired the review of IPS-1; 118, Use of Computers; 369, Seismic Repair and Rehabilitation; 375, Performance-Based Design of Concrete Buildings for Wind Loads; and E705, Educational Computer Activities. He also has served on the Educational Activities Committee, the Financial Advisory Committee, the Hot Topic Committee, the TAC Metrication Committee, and the Task Group on Centennial Activities. He co-chaired the Local Chapter Convention Committee for the ACI Fall Conventions in 1992 and 2007 in Puerto Rico and served as President and Board member of the ACI Puerto Rico Chapter.

He has held several professional, civic, and public positions in Puerto Rico, including serving as Secretary of State and Secretary of Transportation and Public Works for the Commonwealth; President and Board member of the Institute of Engineers and Land Surveyors; and serving on numerous committees during the last 27 years. He has also served as Board member and Vice President of the Puerto Rico Chamber of Commerce and Trustee of the Pontifical Catholic University of Puerto Rico.

ACI
WEB SESSIONS

(continued)

Izquierdo received his bachelor's (1980) and master's (1982) degrees in civil engineering from the University of Puerto Rico, San Juan, Puerto Rico. He joined Capacete-Martin & Associates, Architects and Engineers, San Juan, in 1980, serving as a Senior Structural Engineer for 5 years. He founded and worked for 15 years in the consulting firm Izquierdo, Rueda and Associates, providing services in the areas of structural engineering, infrastructure development, and historic preservation.

He has chaired the structural engineer's continuous education program in Puerto Rico for the last 25 years. He has written many papers and spoken extensively on structural engineering and analysis in over 15 countries, promoted the use of simplified methods for structural design, and has worked in numerous restoration projects.

ACI
WEB SESSIONS

Santiago Calatrava's Poetic Marriage of Structure and Form

José M. Izquierdo Encarnación
BSCE, MCE, PE, FACI
PORTICUS

ACI
WEB SESSIONS

Who is Santiago Calatrava?

- Santiago Calatrava is a world-renowned architect, engineer and sculptor. Already well-known in Europe for his unique design aesthetic, Calatrava is beginning to make a name for himself in the United States. Starting with the Milwaukee Art Museum, he has designed a number of public buildings and bridges in the U.S. in recent years. As both Engineer and Architect, his works take materials like concrete, glass and steel beyond the normal bounds.

Santiago Calatrava's Poetic Marriage of Structure and Form – ACI Spring Convention 2012

…Who is Santiago Calatrava?

- Santiago Calatrava was born in Valencia, Spain on July 28, 1951, and has been practicing on a professional level for only about 17 years. After only 10 years, he had already made a name for himself, establishing his work as the standard by which later engineering design should be measured.

Santiago Calatrava's Poetic Marriage of Structure and Form – ACI Spring Convention 2012

…Who is Santiago Calatrava?

- Before he was designing these amazing structures, however, he was a student of art, or architecture, then of engineering. In 1968, at the age of 17, he began his schooling in an art school at Valencia. after just one year, he switched to architecture school, at the "Escuela Técnica Superior de Arquitectura de Valencia." He also did post graduate studies there in Urbanism.

…Who is Santiago Calatrava?

- After a five year study of architecture, he went on to study civil engineering at the Swiss Federal Institute of Technology in Zurich. (In his words, the reason he decided to go from one area of study to the next, rather than double majoring, was that he is unable to think about more than one thing at a time.) After 4 years of engineering school, he continued his studies as a doctoral student at the same school. His thesis was entitled, "Concerning the Foldability of Spaceframes."

…Who is Santiago Calatrava?

- <u>In 1981, Calatrava began his professional practice by opening an architectural and engineering office in Zurich</u>. His first realized project was the Jakem Factory in 1983, in Munchwilen, Switzerland. <u>His second office was opened in Paris in 1989</u>.
- In his almost 30 years of practice, he was won countless awards, including the 1992 "Gold Medal of the Institute of Structural Engineers," and the 1987 "Auguste Perret UIA Prize."

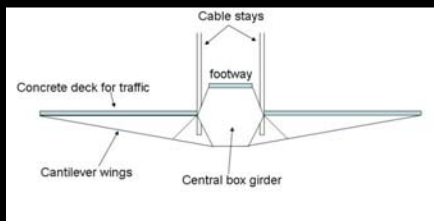
BRIDGES

Alamillo Bridge

- Originally proposed as twin bridges with a connecting viaduct, this design was to cross the Guadalquivir River in two locations, approximately 1 mile (1.5 kilometers) apart from each other. Because of the the curves of the river, the bridges would have been situated in such a way that their tall inclined masts would have reached toward each other, forming an implied triangle that had it's apex far above the earth.

…Alamillo Bridge

…Alamillo Bridge

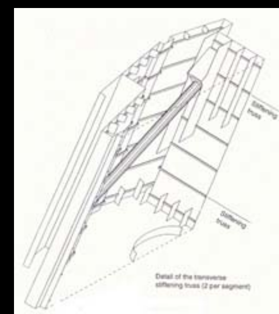


Simplified Cross Section of Alamillo Bridge

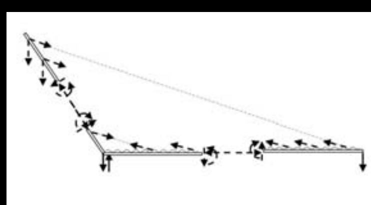
- Pedestrians walk on the top of the central box girder. The traffic travels on a concrete slab supported on cantilever arms out to each side of the central girder. The cables are attached either side of the box girder.

…Alamillo Bridge

- This is what you would see inside the tower if you cut through it and removed the concrete infill. It shows part of the outer steel plate with smaller steel plate stiffeners welded to it on the inside. The tube running from lower left to upper right contains one of the cables. The horizontal stiffening trusses are marked but not shown.



…Alamillo Bridge


Internal and External forces on the Alamillo Bridge

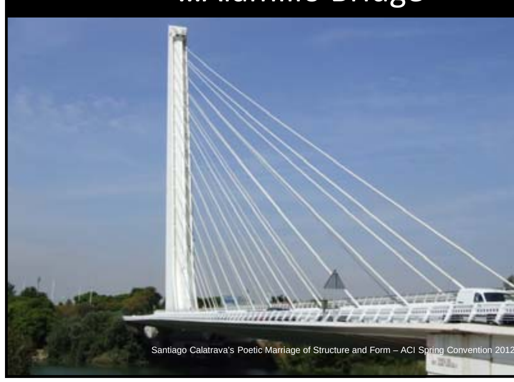
- The wavy line represents the external load on the bridge due to traffic and pedestrians. The full arrows are the external force reactions from the bridge foundations. The dashed arrows are the internal forces within the bridge.

…Alamillo Bridge

…Alamillo Bridge

- The diagram is a cross section through the leaning tower. You can see the horizontal trusses and the concrete infill. The hole in the middle contains the staircase. The two small elliptical holes on the left are where the cables pass through. They are anchored behind the far side of the tower.

…Alamillo Bridge



Bach de Roda bridge

- The Bach de Roda bridge was built as built as part of the revitalization of two poorer areas of Barcelona, Spain. Spurred on by the city's selection to host the 1992 Olympic Games, the bridge was one of the first stages of improvement for the Sant Andrea and San Marti areas of the city.

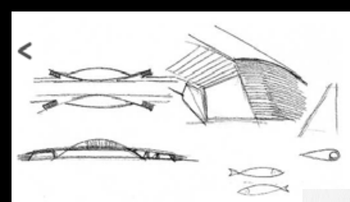
…Bach de Roda bridge

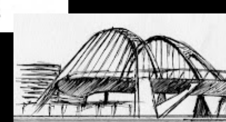
- Along with this bridge, a new rail station was built; all part of a larger plan to improve the infrastructure of the entire city of Barcelona. As with many of Calatrava's bridges, this bridge serves both pedestrians and automobiles, giving access to parks below on either side. To further accentuate the city, balconies allow pedestrians to stop along the bridge to enjoy a view of the city.

…Bach de Roda bridge

- The special thing about this structure is that there are two independent sets of arches and each is capable of carrying its own section of the bridge. Unlike steel bridges that have been built before, there is no structure above the roadway itself.
- Stability in the bridge is gained from the sloping outside arches, which have an extreme wide base at their ends.
- The bridge serves both pedestrians and automobiles and gives access to a beautiful park. He also made balconies, allowing pedestrians to stop along the bridge to enjoy the view.

…Bach de Roda bridge





…Bach de Roda bridge

…Bach de Roda bridge

…Bach de Roda bridge

- Of total length 129m, the 46m main span of the Felipe II / Bach de Roda Bridge, in Barcelona, is 8m above railway tracks and skewed at 30º.
- Its steel and concrete composite deck is suspended by steel tension rods, at 1.85m centres, from four triangular, welded, box-section steel arches, that rise 10m above the roadway.
- The two main tied arches and their associated sets of paired tension rods run parallel to the outer kerb lines of the carriageways.
- Secondary inclined arches are supported from inclined and moulded concrete stairways that provide direct access to the bridge from the low-level, landscaped parks adjacent to the tracks. These secondary arches are connected by ribs to the outer face of each main arch, thus providing lateral support.

…Bach de Roda bridge

…Bach de Roda bridge

- Torsion becomes a major consideration in the design of the cross-section. The 2.44m wide bridge deck of hardwood timber boards is supported on steel ribs cantilevered to one side of the 508mm diameter, 20mm thick, tubular steel tie beam. A 244mm diameter tube, of 10mm wall thickness links the remote ends of the cantilevers and this is set at 3.25m from the centre of the main tube. Cross-bracing runs between the two tubes in each bay between cantilevers to produce a rigid horizontal truss to resist lateral forces.
- Rising up to 6.5 metres above the tie, the arch is formed using a 267mm diameter steel tube, of 16mm wall thickness. This is linked to the tie/torsion beam by tapered arms that serve to transmit load (in tension) from the deck to the arch, prevent buckling of the arch and to permit the self-weight of the arch to balance the self-weight and load on the deck to some extent.

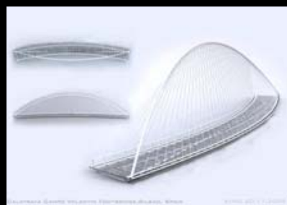
…Bach de Roda bridge

Campo Volantín Bridge

- The Developer Campo Volantín S.L. was the company that brought competition to build a bridge over the river not far from the site Nervión where today is located the famous Guggenheim Museum in Bilbao, designed by another internationally renowned architect, Frank O. Gehry. The main feature of this project was also that the bridge would be high enough to let the ships of medium or small scale under the underpass. Santiago Calatrava, who won the project with his beautiful proposal, designed a breathtaking runway thanks to the great parabolic arch of steel bent and split across the walkway from one side to another.

…Campo Volantín Bridge

…Campo Volantín Bridge



The architect gave to this walkway and innovative modern design by using a material with beautiful colors, the translucent glass, and along with artificial lighting by means housed under the dashboard lights, produce every night a truly unique visual spectacle and spectacular.

…Campo Volantín Bridge

Two ramps in two sections of 2 meters wide each, with a slope of 7%, saving the high slope that provides the bridge to cross from one side to another. Tensioned wires of 30 mm. in diameter, are anchored to the arch of an immaculate white for the support of the striking gateway.

…Campo Volantín Bridge

The split arch straps supporting the steel is anchored to a longitudinal beam that runs from the board off-center side to side, this steel beam with circular section is based on the stirrups that are formed by the upper ramps own to the catwalk

Reggio Emilia bridges

Located near the industrial zone Mancasale, Reggio Emilia bridges were commissioned as a major project that would solve various communications links and on the outskirts of this important city. The architect solved the project by <u>three cable-stayed bridges, two of them twins, and on both sides of a large central bridge</u>. The south bridge is located near a big roundabout while the principal, which saves the A1 Motorway at right angles, there are 50 meters high and is located in the middle of the other two main bridge consists of a huge steel tied arch characteristic with two eyes at their ends, another twin bridge similar to the roundabout is situated on the opposite side.

…Reggio Emilia bridges

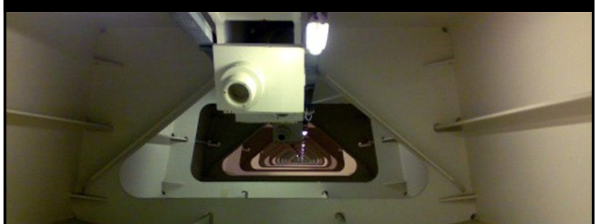
For the design of two twin arches in vertical height above the central bridge, because <u>they have height of 70 meters each</u>, Calatrava was inspired by the human figure, as it gives the impression that the bow is the human figure and cables are the arms that support the board

…Reggio Emilia bridges

…Reggio Emilia Bridges

… Reggio Emilia Bridges

… Reggio Emilia Bridges



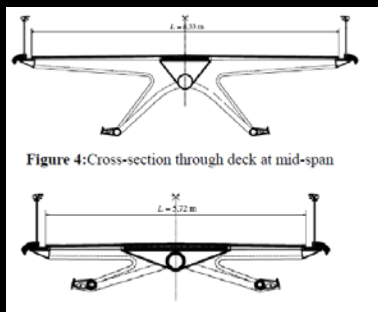
...Reggio Emilia Bridges

Ponte della Constituzione

…Ponte della Constituzione

The Ponte di Calatrava is a long, sweeping curve of glass and steel that is designed to complement both the historic buildings on the Piazzale Roma side of the canal and the 1950s modernity of Venice's main railway station. Now that it's open, travelers won't have to go out of their way to cross the canal via the Ponte dei Scalzi or pay to ride the vaporetto as they've been forced to do in the past.

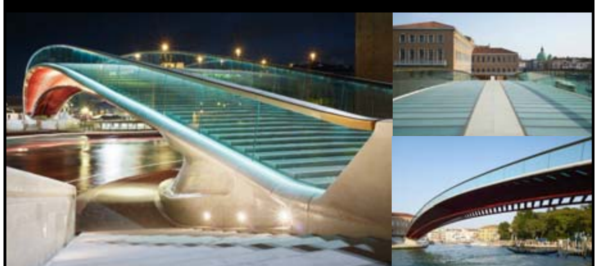
…Ponte della Constituzione



…Ponte della Constituzione

Santiago Calatrava's Poetic Marriage of Structure and Form – ACI Spring Convention 2012

…Ponte della Constituzione



Santiago Calatrava's Poetic Marriage of Structure and Form – ACI Spring Convention 2012

BUILDINGS

Santiago Calatrava's Poetic Marriage of Structure and Form – ACI Spring Convention 2012

Olympic Stadium, Athens

Santiago Calatrava's Poetic Marriage of Structure and Form – ACI Spring Convention 2012

Olympic Stadium, Athens

The principal architectural interventions included a new roof for the Olympic Stadium, a new roof and refurbishing of the Velodrome, entrance plazas and entrance canopies for the complex as a whole, a central Plaza of the Nations, tree-lined boulevards, a pair of arcade structures reminiscent of the ancient agora. The design of a central Olympic Icon, and a sculptural Nations' Wall.

Santiago Calatrava's Poetic Marriage of Structure and Form – ACI Spring Convention 2012

…Olympic Stadium, Athens

…Olympic Stadium, Athens

- The two giant arcs have a total span of 304m and a maximum height of 80m. They provide the support for the cables that hold the polycarbonate panels comprising the roof. Its total weight will be 16,000 tons and it will cover an area of 10,000 sq.m.
- Almost 95% of the seats will be covered (only 35% were before). The special coating of the panels will reflect 60% of the sunlight, something extremely important when considering the weather conditions in Athens during the summer.

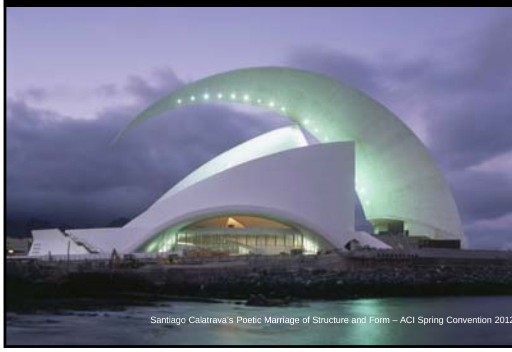
…Olympic Stadium, Athens

…Olympic Stadium, Athens

…Olympic Stadium, Athens


…Olympic Stadium, Athens


Auditorio de Tenerife, Spain



Santiago Calatrava's Poetic Marriage of Structure and Form – ACI Spring Convention 2012

…Auditorio de Tenerife, Spain

The auditorium is located on the waterfront in the Los Llanos are of Santa Cruz, the capital of Tenerife. Situated between the Marine Park and the edge of the port, the auditorium connects the city to the ocean and creates a significant urban landmark.

The all-concrete building is characterized by the dramatic sweep of its roof. Rising off the base like a crashing wave, the roof soars to a height of 58 meters over the main auditorium before curving downward and narrowing to a point. The building's plinth forms a public plaza covering the site and allows for changes in grade between the different levels of the adjacent roads.

Santiago Calatrava's Poetic Marriage of Structure and Form – ACI Spring Convention 2012

…Auditorio de Tenerife, Spain

Santiago Calatrava's Poetic Marriage of Structure and Form – ACI Spring Convention 2012

…Auditorio de Tenerife, Spain

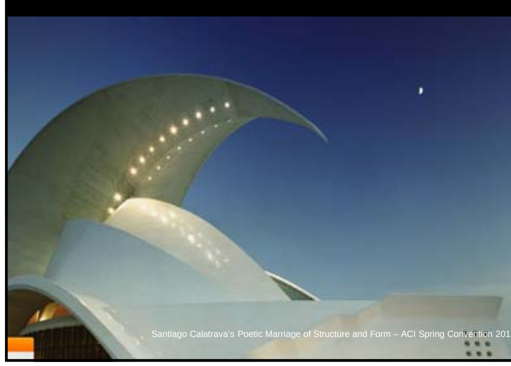
Santiago Calatrava's Poetic Marriage of Structure and Form – ACI Spring Convention 2012

…Auditorio de Tenerife, Spain

- Geometrically, the roof is constructed from two intersecting cone segments.
- The symmetrical inner shell of the concert hall, which is 50 meters high, is a rotational body, generated by rotating a curve to describe an ellipse. A wedge of approximately 15° has been removed from the center of this body so that its two segments (for acoustical reasons 60 cm thick) form a pronounced ridge.
- At its uppermost point it supports the sweep of the roof. The body of the auditorium thus contrasts with the smooth curves of the flanking tangential shells, whose exterior surfaces are decorated in coloured broken tile.

Santiago Calatrava's Poetic Marriage of Structure and Form – ACI Spring Convention 2012

…Auditorio de Tenerife, Spain

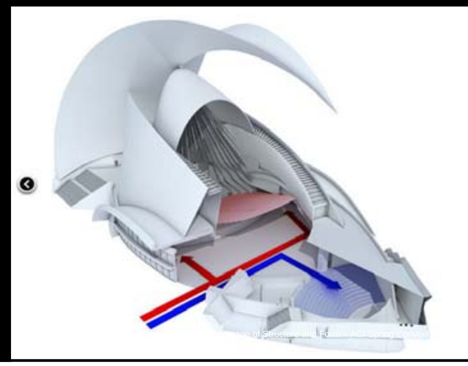


Santiago Calatrava's Poetic Marriage of Structure and Form – ACI Spring Convention 2012

Concrete

- Calatrava emphasized that the work is concrete because this material allows you to "mold forms and defy the laws of gravity, as the ridge that falls from the sky." Such a "wave" is lifted from the base of the structure, remains motionless in the air and turned maintains "a weight of about 3,500 tonnes."
- The white cement was used in the work of Tipo III. In the mixture, using a high proportion of sand and titanium dioxide enhances the whiteness of the mixture.
- Because of the forms, the cast was made with pallets and a table mesh surfaced that sometimes barely reached 12 cm in width, in which were implemented agents to avoid the "holes of insects."

Structure

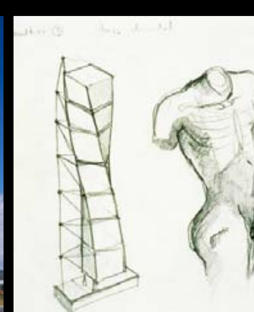


Construction

…Auditorio de Tenerife, Spain

…Auditorio de Tenerife, Spain

Turning Torso, Sweden



…Turning Torso, Sweden

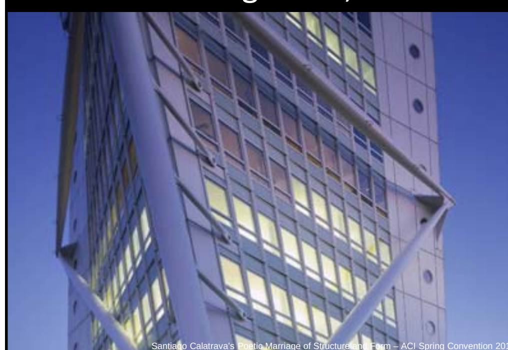
- The vision of HSB Turning Torso is based on a sculpture called *Twisting Torso,* created by Santiago Calatrava.
- The building is constructed in nine segments of five-story pentagons that twist as it rises; the topmost segment is twisted ninety degrees clockwise with respect to the ground floor.
- Each floor consists of an irregular pentagonal shape rotating around the vertical core, which is supported by an exterior steel framework.
- The two bottom segments are intended as office space.
- Segments three to nine house 147 luxury apartments.

…Turning Torso, Sweden


…Turning Torso, Sweden

- The framework consists of the core, shaped like a concrete pipe.
- Inside the core a concrete construction houses lift shafts and staircases.
- The structural slabs, shaped like slices of a pie that are fitted together to form an entire floor, are anchored in the core. Each floor is rotated to create the characteristic twist of the building.
- The facade is curved aluminum panels, with windows leaning either inwards or outwards, in order to follow the twist of the building.

…Turning Torso, Sweden

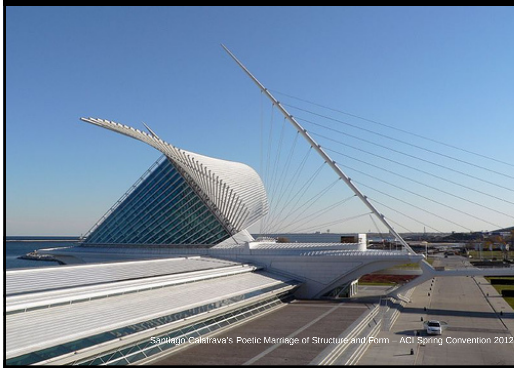


…Turning Torso, Sweden

- An exoskeleton around the building's front face is made of tapered white steel tubes.
- Following the concrete perimeter column, the exoskeleton's single upright is fixed to the tower between each module with horizontal and inclined tubes. These tubes reach back to steel anchors embedded in shear walls at the building's back corners.
- While the spine column takes perimeter vertical loads, the exoskeleton around it provides wind resistance and dampens the building's vibrations.

…Turning Torso, Sweden

Milwaukee Art Museum, USA



…Milwaukee Art Museum, USA

Brise soleil

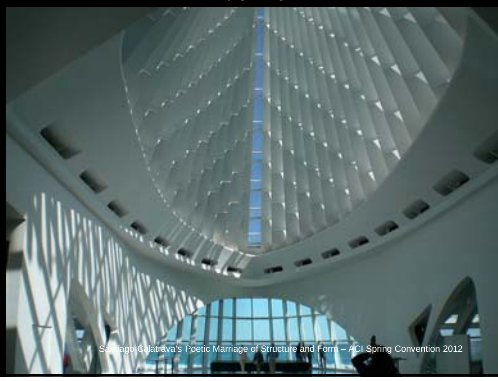
- The structure contains a movable, wing-like *brise soleil* which opens up for a wingspan of 217 feet during the day, folding over the tall, arched structure at night or during inclement weather. The brise soleil has since become a symbol for the city of Milwaukee.

…Milwaukee Art Museum, USA

…Milwaukee Art Museum, USA

…Milwaukee Art Museum, USA

Interior



Santiago Calatrava's Poetic Marriage of Structure and Form – ACI Spring Convention 2012

…Milwaukee Art Museum, USA

Santiago Calatrava's Poetic Marriage of Structure and Form – ACI Spring Convention 2012

References

- http://www.bristol.ac.uk/civilengineering
- http://www.calatrava.info
- http://www.calatrava.com/
- http://www.jmhdezhdez.com/2011/04/santiago-calatrava-bridges-puentes.html

Santiago Calatrava's Poetic Marriage of Structure and Form – ACI Spring Convention 2012