Mind-Body Column, Osaka

"I want to create a slender 15m high steel sculpture with velvet-like skin."

Introduction

Antony Gormley is an English sculptor known for creating steel sculptures using his own body as a motif, and most famous for the massive *Angel of the North*[1]. By contrast, this 2000 project was to be slender, resembling an obelisk, and using 20 steel castings stacked one on top of another (Figs 15, 16). The site was a public plaza in Osaka, amidst four office towers. The interaction began with some light-hearted questions from Arup as structural engineer to probe the meaning of the work: "Why are you using your own body as a motif?"; "Why must the sculpture be made of steel?"; "Why do you want to connect two forms back-to-back?"; "Why do you want to stack the forms one on top of another?"; "Why can there be no welding involved?"; "Why is a velvet-like skin necessary?"

Seismic design in Japan – a short history

1914 Prof Riki Sano's thesis on seismic-resisting structures proposes an applied lateral load – a certain percentage of the building mass applied at each floor level.

1923 Tokyo is hit by the Great Kanto Earthquake, which devastates the city and kills over 100 000 people.

1924 The Japanese "Code of practice for buildings in an urban area" is revised and a lateral load of 10% of the weight of the building is introduced for seismic design, in effect creating the world's first seismic code. This is based on observation of the lateral load on 30% of the mass in the downtown area in Tokyo, and on the allowable stress considered as 10% of the static force.

1947 This code is revised when building materials standards are introduced. Structural design now has to consider two cases – long-term and short-term load combinations – and the intensity of the lateral load is revised to 20% of the mass.

1963 31m total building height limit removed following the Great Kanto Earthquake.

1965 The Building Centre for Japan (BCJ) is established especially for technically challenging and innovative structures that don't comply with existing codes. The committee members are academics and expert engineers who report on technical acceptance to the Ministry of Construction. This procedure aids designers who desire unrestricted use of new materials/technology.

1968 The Tokachioki earthquake causes many column shear failures in reinforced concrete buildings.

1970-71 The building code responds by specifying reinforcing tie bar details for reinforced concrete columns.

1970 Japan's first really high-rise building (30-storey Kasumigaseki Building) completed.

1980 A new seismic code is introduced. The dynamic aspects of design are considered in detail, but some criticise the new code as too prescriptive. There are two criteria for design, one for possible occurrence once or twice during the building's lifetime, and the other for a possible severe event estimated from the historic data at the site.

1980 New structural systems using isolation and seismic energy control (damping technology) develop rapidly.

1993 The Japan Society of Seismic Isolation is established to centralise the research, education, further promotion, design, construction, and maintenance of seismic isolation devices.

1995 South Hyogo Prefecture Earthquake (aka "Kobe earthquake") hits Kansai, and some buildings designed under the new code sustain unpredicted damage. The seismically isolated buildings perform well, but one residential high-rise designed in the late 1970s has an unexpected brittle fracture of a main column built up from thick steel plates (the steel and the welds had insufficient toughness to take the required plastic elongation).

2000 To reduce waiting times, peer reviews from approved private practices become obtainable. Each city has an approval body, architecture division, that checks calculations, drawings, etc. The BCJ continues to provide approval for exceptional buildings.

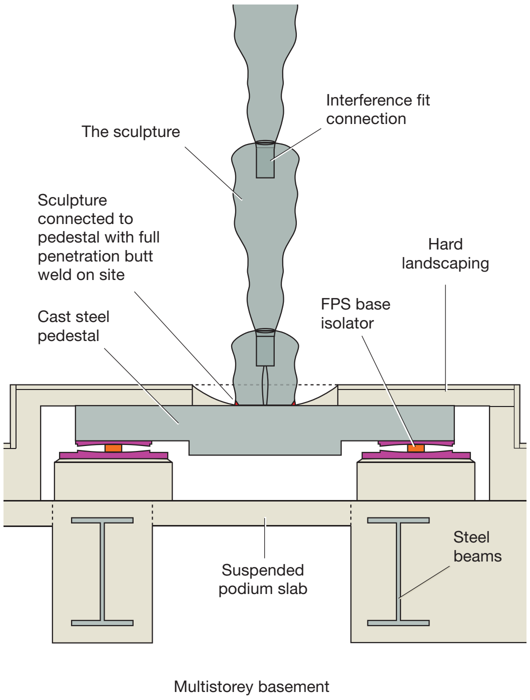
2007 A new structural review process is introduced with a requirement for structural and services engineers' qualifications.

The following projects are all performance-based designs approved by the BCJ, which became more common after the South Hyogo Prefecture Earthquake. Structural engineers are now responsible for communicating directly with clients so as to set clear seismic design targets and agree them before the design.

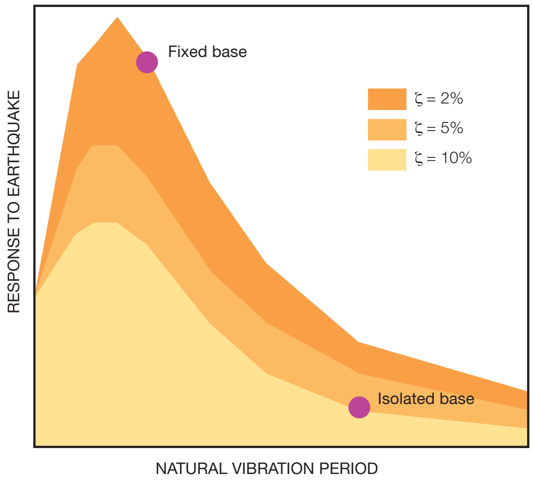
15. Completed *Mind-Body Column*.

16. Front and side elevation.

17. Wooden model.



18. Cast steel pedestal supported by four FPS base isolators.



19. Generic graph of response spectrum showing beneficial period shift and reduction in response if the structure is base isolated.

FPS base isolation system

The wood form that Arup received from Gormley was moulded exactly in his form (Fig 17). The ankle-width is 170mm, and the distance between the axes of each pair of opposing ankles is 265mm.

The overall height of 15.4m has a 1:90 aspect ratio – an extremely slender proportion – and the whole sculpture is also very heavy, at around 15 tonnes. It was clearly going to be difficult to make it as earthquake-resistant as it needed to be in such a seismically active country.

To solve this problem, four FPS (friction pendulum system) isolators were installed at its base under the pedestal. Each comprises a concave surface, an articulated bearing, and a cover plate. In an earthquake the bearing slides on the concave surface, allowing the structure to move relative to the base. FPS isolators – similar to lead-rubber or high damping rubber bearings – cause the vibration period of structures to change. Although dependent upon the scale of the supported structure, FPS offers some advantages over rubber-based bearings; it is not affected by temperature or aging, it is durable, and has a high vertical stiffness (Fig 19).

The FPS system reduced the response acceleration by approximately two-thirds, so that the sculpture would not be damaged or collapse even in the largest earthquake. Also, to prevent uplift and to stop the isolators being moved by wind, the pedestal was given a weight of some 25 tons (Fig 18).

This performance-based design by Arup needed, and was granted, special approval by Japan's Ministry of Construction.

20. Cast steel piece before machine processing.

21. Interior of vertical connection before insertion.

22. Portion of connection to be inserted.

23. Commencing shrinkage fit (fitting time two seconds).

Velvet-like skin

In Japan, with its harsh natural environment, base isolation and seismic control technology are well developed, and wind and earthquake resistance did not represent the greatest challenge. The biggest question was how to bring out the material's natural look, with a subtle artisan flavour.

Normally, cast pieces are produced by pouring molten steel into a sand mold. Imprints from this leave blemishes on the outer surface, so imprint resistor is brushed onto the mold surface beforehand. However, this in turn leaves unsightly brush marks that reduce surface quality. In addition, water blow holes, deformations due to heat treating, and weld flashes where separate molds are joined, are unavoidable. These marks could have been eliminated by grinding and using adhesive metal, but that would have spoilt the velvet skin quality.

How could a cast piece that needed no repair be created? Through simulation and trial-and-error, the team investigated all possible production processes, moving thereby from the realm of structural engineering into that of sculpture. Rusting of the surface was an important quality sought by the sculptor, so in the end ordinary structural steel was used and treated in accordance with his specification (Fig 20).

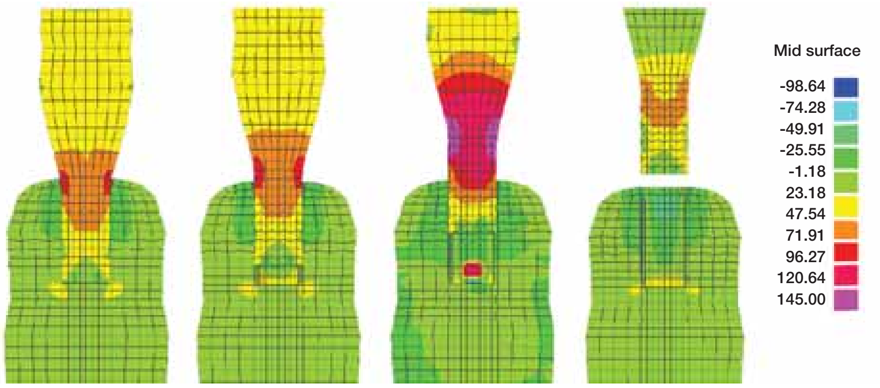
Interference fitting

The stacked figures needed robust connections, and for this the team chose interference fitting, a method commonly used to produce marine cylinders and camshafts. The upper torso sections were warmed by an electric heater for four hours to 240ºC, thus widening the neck holes. The lower ankle sections were immersed for 30 minutes in -270ºC liquid nitrogen, cooling them to -100ºC with resulting shrinkage. Each shrunken ankle could then be fit into a widened neck and then brought back to room temperature, resulting in a secure connection (Figs 21-23).

Normal interference fittings are applied to circular sections, not elliptical as here, so predicting prestress at the joint was difficult. The team used the analysis software *LS-DYNA 3D* to simulate and study the relationship between fitting area size and the shrinking pressure or tensile strength. Two models were made, with a contact surface between them having a specified friction coefficient and a prestress to model the contact pressure. The analysis results, later verified by a physical pull-out test, enabled the final joint size to be determined. The "female" element was 93 x 150mm, and the "male" only 1/600 larger, 93.15 x 150.25mm (Figs 24, 25).

Each cast "body" includes several different shapes, so an extraordinarily high degree of precision was required throughout, entailing many judgements and resolutions in every process from the mechanical production to the shrink fittings – a particular challenge each time (Fig 26).

24. Still images from the *LS-DYNA* tensile pull-out model show the connection between two castings being pulled apart. The results of the *LS-DYNA* analysis were later verified by physical testing.



25. Shrink-fitted test piece for tensile strength testing.

26. Cast steel elements connected.

27. Completed *Mind-Body Column.*

Mind-Body Column

The completed sculpture and its base are founded on a suspended podium slab over a multi-storey basement. The sculpture was craned into position as a unit and field-welded to the base.

Work on the project began in March 2000, and it was completed in June . The artwork was named *Mind-Body Column*, a continuous human body moulded from steel, symbolizing the earth itself, standing slender yet sturdy in a valley between high-rise buildings. Orange rust runs down the velvet-like skin, a permanent but continually changing patina (Fig 27, 28).

Reference

(1) BROWN, M, *et al. The Angel of the North, The Arup Journal, 33*(2), pp15-17, 2/1998.

Credits

Client: Rail City West Development, Osaka **Sculptor:** Anthony Gormley **Structural engineer:** Arup – Shigeru Hikone, Mitsuhiro Kanada, Ikuhide Shibata.

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