Utilitarian to Aesthetic: The Evolution of Base Isolation

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Summary
The paper examines the evolution of base isolation from its early utilitarian applications to its later applications that enabled elegant aesthetics in landmark works of architecture. The early implementations of base isolation arose from three motivations: providing high performance for emergency facilities; providing higher-than-code performance as desired by a building owner; or retrofitting historic buildings. The opening of Toyo Ito’s Sendai Mediatheque in 2001 marks an important milestone in the evolution of base isolation, since it introduced a new motivation: architectural aesthetics in a new building. Mediatheque employed base isolation to enable a visually striking structural system. Ito’s TOD’s Omotesando building, and the Tama Art University Library also use base isolation in this manner. Base isolation has evolved from a utilitarian technology to an aesthetic device to achieve architectural forms not otherwise be possible in a strong seismic region.

Keywords: Seismic design; base isolation; architectural design

1. Overview
Like any new building technology, base isolation was adopted slowly. It started at the Pestalozzi School in Yugoslavia in 1969, and gradually spread to several notable projects in New Zealand, Japan, and the US by the 1980s. The 1990s saw base isolation become widespread as an effective method to achieve excellent seismic performance by reducing structural accelerations [1]. Through the 1990s, base isolation was typically applied for one of the following reasons:

1. Providing immediate post-earthquake operability for disaster response.
2. Providing higher-than-normal levels of seismic performance as desired by the owner, because of the building’s function or contents.
3. Enhancing the seismic performance of an existing historic building with minimal architectural disruption.

Examples of critical disaster response facilities include the 1990 Los Angeles County Fire Command & Control Facility, California, the 1991 USC Teaching Hospital and the 1994 Los Angeles Emergency Operations Center [1]. In addition, base isolation was a strategy for businesses that wanted to maintain operability and protect valuable assets, such as the 1987 Evans & Sutherland corporate headquarters, and the 1991 Rockwell Corporate Headquarters. The high performance of base isolation has also been used to protect valuable artwork, such as San Francisco’s De Young Art Museum (2005).

The need for both performance and historic preservation emerged in government buildings on the west coast of the United States, first with the 1989 seismic upgrade of the Salt Lake City and County Building, followed by upgrades of city hall buildings in San Francisco (1998), Los Angeles (1999), Oakland (1994), and Pasadena (2007). Historic preservation and protection of building contents also drove the selection of base isolation for the renovation of San Francisco’s main library to the Asian Art Museum (2002). Historic renovation projects also include buildings that did not
have a critical function or contents, such as the Hearst Mining Building (2002) at the University of California at Berkeley, and Kerchoff Hall at the University of California (1995) at Los Angeles. Base isolation has demonstrated its effectiveness in maintaining building operations and protecting building contents. This paper addresses a different aspect in the evolution of base isolation, more closely related to its use in historic preservation, but concerning new buildings. Starting in the early 2000s, base isolation was used by some architects and engineers as a means to achieve aesthetic effects and architectural forms that would not otherwise be possible in a seismic zone. Base isolation has evolved as an aesthetic technology, rather than a purely functional one. The paper identifies several examples that demonstrate this trend, but emphasizes two key case studies: Toyo Ito’s Sendai Mediatheque, completed in 2001, and Herzog and de Meuron’s Prada Aoyama building, completed in 2003.

2. Toyo Ito’s Sendai Mediatheque

2.1 Overview

Located in north-eastern Japan, the Sendai Mediatheque is a cultural centre, with facilities for audio-visual media, libraries, and related functions. The design was awarded to architect Toyo Ito through a competition in 1995. Construction began in 1997, and the building opened in 2001 [2]. The nearly square plan is 49 meters by 50 meters, with seven stories above ground, and a height of approximately 35 meters. The storey heights are irregular, ranging from approximately 3 meters to 7 meters. Structural engineer Mutsuro Sasaki describes his reaction to Ito’s initial sketch of the building concept: “It showed a world of indeterminate seaweed-like tubes swaying freely as they supported floor plates, as though the architecture were without weight or dimension.” [3, p. 41].

Driven to achieve Ito’s vision of lightness and transparency, Sasaki proposed an unprecedented structural system. To achieve the thinnest possible floor profile, the floor structure is a steel sandwich plate, 40 centimetres deep, spanning nearly 20 meters [3]. These plates are supported by 13 tubular latticework columns. The columns range in diameter from 8 meters to 1.4 meters, and are composed of an open latticework of round pipe sections. Figure 1 shows the plan arrangement of the columns, with four large columns positioned near the corners of the plan. Figure 2 shows an elevation view of one of the corner columns. These larger columns act as vertical cantilevers, and provide virtually all of the lateral resistance for the structure [3]. In these corner columns, the framework of members is triangulated to increase lateral stiffness, except at the basement level, where the structure is a moment frame, for reasons discussed below. The remaining gravity-only columns use a quadrilateral framework.

The layout of columns does not conform to a strict grid. Sasaki explains “we deliberately avoided the man-made appearance of a typical orthogonal structural layout in the Mediatheque by using a semirandom layout of columns that nonetheless maintains the rational efficiency of the structure.” [3, p. 45]. Review of the plan in figure 1 shows that the columns are organized along three major bearing lines, noted on the figure, with small random variations from those lines. These variations change from floor to floor, so the columns are canted from vertical. This canting is done so as to balance the resulting horizontal forces at each floor level [3, p. 46]. The randomness of the column layout and the canting of columns, creates a haphazard appearance which belies a rational organization of structure for both vertical
and lateral loads.

2.2 Lateral Resisting System and Base Isolation

Since the floor plates are extremely thin, and are pin-connected at all the columns, the plates do not bend in frame action when the structure is subjected to lateral loads; this allowed the floor heights to be distributed freely, since their position did not influence the lateral behaviour of the structure [3, p. 46]. All of the lateral resistance comes from the four corner columns, acting as independent cantilevers. Sasaki describes the strategy for keeping these corner columns as light as possible [3, p. 46]:

As a strategy against catastrophic earthquakes, we introduced an energy-absorbing mechanism into the upper basement floor structure. The structure of the four large corner columns changes at the basement level from a lattice truss above ground to a ductile-type rigid-frame structure below. At this lower level, the rigid frame of the columns connected with continuous beams is designed to dampen seismic energy by allowing plastic deformation in the beams. This simple device allows us to greatly reduce the earthquake load on the aboveground structure by absorbing most seismic energy (60-70 percent) at the basement level. Although the technology itself is not visible, this antiseismic strategy allows the upper structure of lattice columns to be realized with relatively thin members.

By placing the relatively stiff lattice columns on top of flexible and ductile moment resisting frames, Sasaki effectively introduced a soft story in the building: that is, a story with significantly less strength and stiffness than the stories above. Normally, a soft story is considered a poor configuration because of the possibility of a story collapse [4, p. 119]. By putting the soft story in the basement, however, the Mediatheque structure guards against this possibility. Instead, the structure uses moment-resisting frames in the basement as base isolators. Those frames reduce the seismic response of the above-ground structure by increasing the period of the building, and by absorbing energy. The basement is configured using typical details of a base-isolated building, with a covered dry moat around the perimeter to allow for large structural displacements at the basement level. This strategy is highly unusual, but quite logical.

More important than the novelty of this approach is its motivation. This building was conceived and designed in the mid-1990s. To that point, as discussed above, base isolation was typically employed to achieve higher-than normal performance, or in historic preservation, but these circumstances do not apply to the Mediatheque. The flexible and ductile structural layer in the basement, as Sasaki explains, allows “the lattice columns to be realized with relatively thin members.” The motivation for base isolation is this case was strictly visual: to achieve Ito’s vision of transparency and lightness.

This building appears to be the first case a such a celebrated building to use base isolation for this purpose, and it was quickly followed by other examples. One of most noteworthy of these is the Prada Aoyama building.

3. Herzog and de Meuron’s Prada Aoyama

Completed in 2003, Prada Aoyama is the flagship store of the Prada boutique in Tokyo (figure 3). The building was initially planned by the architects Herzog and de Meuron, working with Swiss structural consultant WGG Schnetzer Puskas. The design was then fully developed by the Japanese construction company Takenaka, in collaboration with Herzog and de Meuron [5].

The perimeter diagrid structure is a key component of the building’s architectural façade, as well as the structural system. This diagrid carries virtually all of the lateral load, and approximately half of the gravity loads of the building. [6]. There are no vertical members in the diagrid; the horizontal members occur at the floor levels, and are behind the plane of the diagonals to supress them visually. The unusual features of the diagrid, the visual aesthetics of the building, and the seismic environment of Tokyo, led engineers at Takenaka to introduce base isolation into the design.

One of the unusual aspects of the diagrid is the configuration of the members relative to the floor plates. The diagonal modules are 2 meters high, while the floor-to-floor height is 4 meters, meaning that at the corner, there are diagonal members that meet halfway between floor levels (figure 4). At such a connection, it is not possible for all the members to be in compression, since it would violate
equilibrium; this means these members have zero force under gravity loads. The only members directly carrying vertical loads are those where both extreme ends connect to a floor plate. The remaining zero-force members, serve only as lateral bracing to increase the buckling resistance of the others. These zero-force gravity members occur not only at the corners between floor levels, but also at corner locations on the 2nd, 4th, and 5th floors where portions of the floor plate are removed to create atrium openings [6].

Because less than half of the diagonal members directly carry vertical loads, and because there are no vertical members, the external lattice has significantly less vertical stiffness than the interior load-bearing system, composed of conventional vertical columns. Analysis found that, at the top floor, the lattice had 3 cm greater vertical displacement under long-term loads [6]. Member lengths were adjusted in fabrication to account for this difference. In addition to its low vertical stiffness, the lattice structure has the characteristic low ductility of a concentric braced frame, with the additional issue that buckling of the seismic bracing will also compromise the ability of the system to carry gravity loads, since all the gravity-bearing members of the diagrid also resist seismic loads.

Thus, the reality of the façade is quite different from its appearance. At first glance, the lattice of diagonal members appears to be an ideal strategy for seismic resistance, but closer inspection reveals that the particular configuration of the lattice results in low vertical stiffness and low ductility. In addition, the architects wanted a glazing system with compact sashes for aesthetic reasons. The lattice had to limit seismic interstory drift to $h/300$ [5], in contrast to the limit of $h/200$ specified in Japanese codes [7].

The lattice of Prada Aoyama is designed more for its visual impact than for its structural efficiency. In contrast to the structural system of the Mediatheque, which is much more logical than its randomized appearance suggests, the Prada Aoyama structure is far less logical than its precise and regular diagrid appears. This situation led engineers from Takenaka to propose base isolation as a means to maintain structure’s visual lightness by reducing seismic demand. Writing about the Prada project, Masayoshi Nakai of Takenaka explains the decision as follows [5]:

Being freed from rationalism, recent architecture has a trend towards the integration of architecture and structure in the “façade” … and the trend has resulted in a number of buildings with free and novel appearances. However, in earthquake-prone countries such as Japan, … it is often difficult and calls for hard decisions by the structural engineer to meet design requirements … [T]he concept of “integration of façade and structure” has been achieved in earthquake-prone Japan by effectively utilizing base-isolation system.

This explanation makes clear that the motivation for base isolation in the Prada Aoyama is the same as that for the Sendai Mediatheque: to achieve a visual aesthetic effect, without special need for enhanced seismic performance dictated by the building function or contents.

The final section notes other architecturally significant buildings from the early and mid-2000s which employ base isolation. Some used it purely to achieve aesthetic goals, while others also had programmatic motivations.
4. Other buildings of the 2000s

4.1 TOD’s Omotesando

Toyo Ito soon followed Mediatheque with two more base-isolated buildings: TOD’S Omotesando completed in 2004, and the Tama Art University Library in 2007. As figure 5 shows, the TOD’S building has a visually striking structural skin: a concrete framework whose form is derived from the nearby Zelkova trees which line the broad boulevard that the building fronts. Like the Prada Aoyama building discussed above, the TOD’S building houses an expensive boutique, and is located in the same district of Tokyo. The two buildings are also similar in the relationship between structure and architecture.

In both Prada Aoyama and TOD’s, the visual pattern of the façade elements strongly defines the architecture, and in both buildings these elements are the sole seismic-resisting system. In TOD’S, that façade is an 30-centimeter-thick reinforced concrete frame with irregular openings. All steps were taken to minimize the frame thickness. At the connection of the floor slab to the exterior frame, the slab depth is reduced from 50 to 25 centimetres in order to reduce the out-of-plane moment transferred from the slab to the wall [5]. Similarly, the base isolation system reduced the seismic forces to allow a more open frame, and to reduce drift for a glazing system that demanded tight tolerances. Nakai [5] explains “For this building, the base-isolation system is an indispensable element for the integration of façade and structure”.

An important difference between TOD’S and Prada Aoyama is the architectural treatment of base isolation itself. At Prada Aoyama, the only visual evidence of base isolation is a thin metal-edged seam in the pavement of the plaza that surrounds the building. It is clear that the architect’s intent is to visually suppress the base isolation mechanism. At TOD’S, in contrast, the characteristic moat around the building is covered by an open grate, making the moat clearly visible (figure 6). In the evening, the presence of the moat is underscored by lights in the moat that wash illumination up the walls of the building.

4.2 Tama Art University Library

Ito’s Tama Art Museum Library (figure 7) uses base isolation in a similar manner. As with the buildings discussed above, this building’s program provides no impetus for higher-than-normal seismic performance. It is a small library, which does not house a rare collection. The motivation for base isolation is clearly enabling the lightness of the thin frame-arch structures which compose the façade of the building, and define its interior spaces. These frames are steel plate girders encased in concrete, and are only 20 cm thick. This light and open structural system defines the visual impact of the building, both inside and out. In addition, the building repeats the detail
of covering the dry moat around the building with an open grate, making it plainly visible (figure 8).

4.3 Other notable buildings

There are three other buildings of note in this discussion: Raphael Moneo’s Cathedral of Our Lady of Angels, completed in Los Angeles in 2002; Skidmore Owings and Merrill’s Cathedral of Christ the Light, completed in Oakland, California in 2008; and Herzog and de Meuron’s de Young museum, completed in San Francisco in 2005. As with the preceding examples, these are influential pieces of architecture which employ base isolation. These buildings are different in that aesthetics was not the sole motivation for using base isolation, they also had programmatic pressures to achieve high seismic performance.

Concerning Moneo’s Cathedral of Our Lady of Angels, planning for the building began shortly after the 1994 Northridge earthquake severely damaged Saint Vibiana’s, a late 19th-century masonry structure. Cardinal Roger Mahoney decided to build a new, much larger cathedral and stipulated that the new building should be able to survive unscathed from a magnitude 8 earthquake, be able to serve as a place of refuge in a time of disaster, and have a service life of 500 years [8]. This performance demand provided much of the motivation for base isolation, although the building had additional aesthetic demands where base isolation undoubtedly helped with structural aspects of the building. In particular, the 2-story 150 tall building had severe deflection limits to prevent cracking in exposed concrete, and damage to fragile finish materials [8]. This building was completed in 2002, and its design and construction are nearly contemporary with that of Sendai Mediatheque. The key difference is that for Mediatheque, base isolation was employed purely for visual-architectural reasons, while the Cathedral of Our Lady of Angels also had a mandate from the owner for excellent seismic performance.

In Oakland, California, the Cathedral of Christ the Light, completed in 2008, shares many characteristics with its counterpart in Los Angeles. Its construction was planned after an earthquake—1989 Loma Prieta—damaged the previous home of the Catholic diocese, and the owners specified that the building have a lifespan of 300 years [9]. Instead of the normal 475-year return period specified by the California Building Code, the Cathedral’s 36.5 meter tall main sanctuary was designed to remain undamaged when subjected that code’s Maximum Considered Earthquake (MCE), with a return period of 1000 years. The main sanctuary includes a great deal of exposed structure, particularly tension-only steel braces that required special consideration in design [9]. Like the Cathedral in Los Angeles, base isolation surely facilitated the visual impact of the structure, but the choice of base isolation was also strongly driven by the owner’s desire for high seismic performance.

In nearby San Francisco, Herzog and de Meuron’s de Young Museum is yet another high-profile work of architecture that employs base isolation. Like the Cathedral of Christ the Light, the new building replaced a predecessor damaged in the 1989 Loma Prieta earthquake. The primary motivation for base isolation in this building was to protect the art collection. Like the Cathedral of Christ the Light, the new building had severe deflection limits to prevent cracking in exposed concrete, and damage to fragile finish materials [8]. This building was completed in 2002, and its design and construction are nearly contemporary with that of Sendai Mediatheque. The key difference is that for Mediatheque, base isolation was employed purely for visual-architectural reasons, while the Cathedral of Our Lady of Angels also had a mandate from the owner for excellent seismic performance.

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5. Conclusions

After limited implementations in the 1960s and 70s, the 1980s and 1990s saw the use of base isolation expand to wide application, particularly in cases that demanded extremely high seismic performance, and in historic preservation retrofits. The early 2000s saw the initial use of base isolation purely for aesthetic purposes in architecturally significant buildings. This paper argues that the first such building was the Sendai Mediatheque, even though its base isolation system is composed of steel frames, rather than conventional base-isolation devices. Those frames serve as a
flexible and ductile layer between the main structure and the foundation, and serve the same function as base isolators. Prada Aoyama, TOD’s Omotesando, and the Tama Art University Library soon continued this strategy, employing base isolation solely for aesthetic reasons. Other notable works of architecture also employ base isolation, including the Cathedral of Our Lady of Angels, the Cathedral of Christ the Light, and the de Young Museum. These buildings, however, had additional motivations for the high seismic performance that base isolation provides.

Toyo Ito’s contributions are particularly notable. In addition to pioneering the aesthetic application of base isolation with Mediatheque, Ito’s detailing on the TOD’s building and the Tama Library building is also innovative. These buildings expose the isolation moat by covering it with an open grate, rather than concealing it with a more conventional opaque cover. In addition to using the isolation system to achieve visual lightness in the building frame, Ito integrates the isolation system itself into the architecture.

6. References