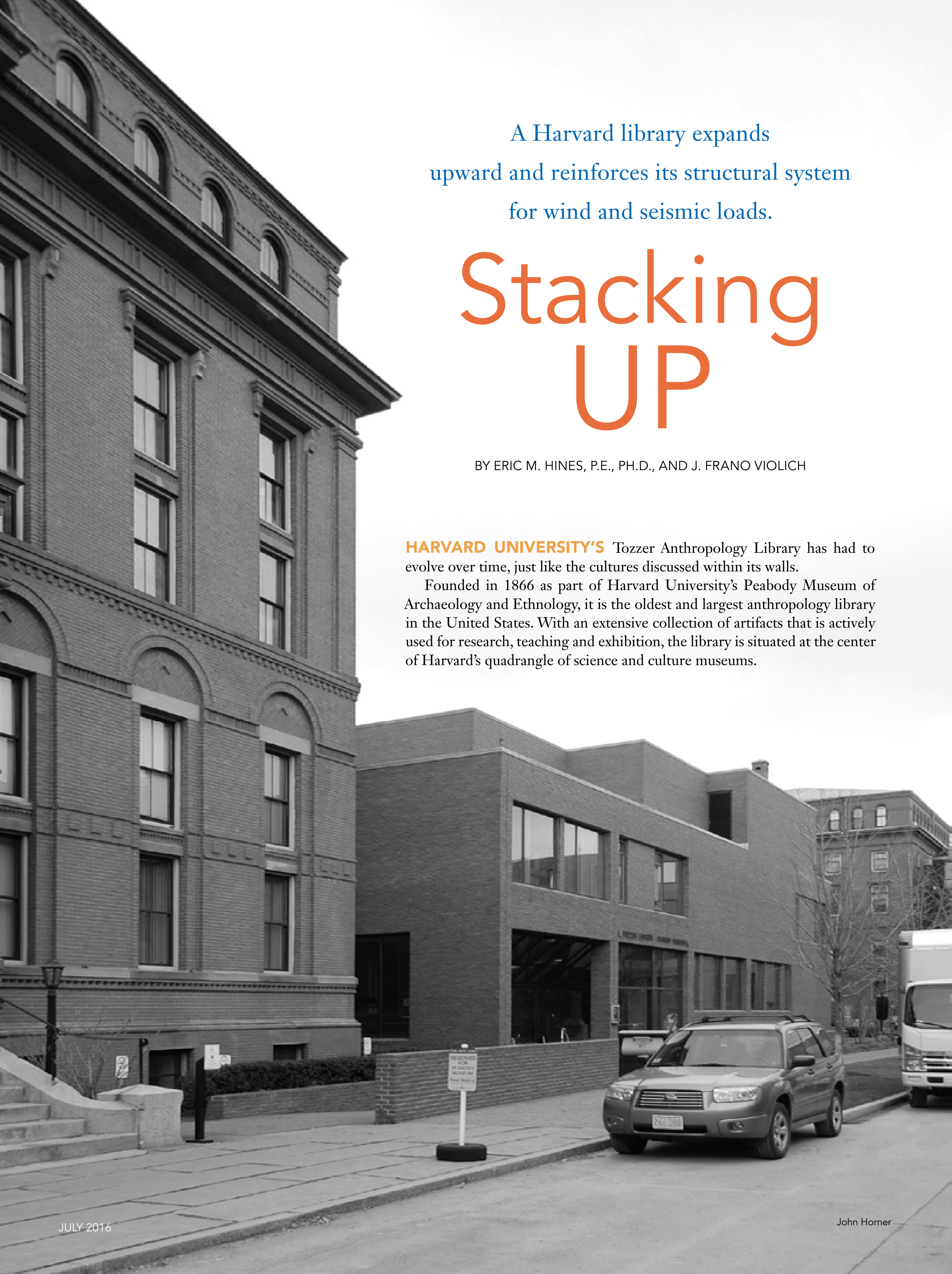
A Harvard library expands upward and reinforces its structural system for wind and seismic loads.

Stacking UP

BY ERIC M. HINES, P.E., PH.D., AND J. FRANO VIOLICH

HARVARD UNIVERSITY'S Tozzer Anthropology Library has had to evolve over time, just like the cultures discussed within its walls.

Founded in 1866 as part of Harvard University's Peabody Museum of Archaeology and Ethnology, it is the oldest and largest anthropology library in the United States. With an extensive collection of artifacts that is actively used for research, teaching and exhibition, the library is situated at the center of Harvard's quadrangle of science and culture museums.



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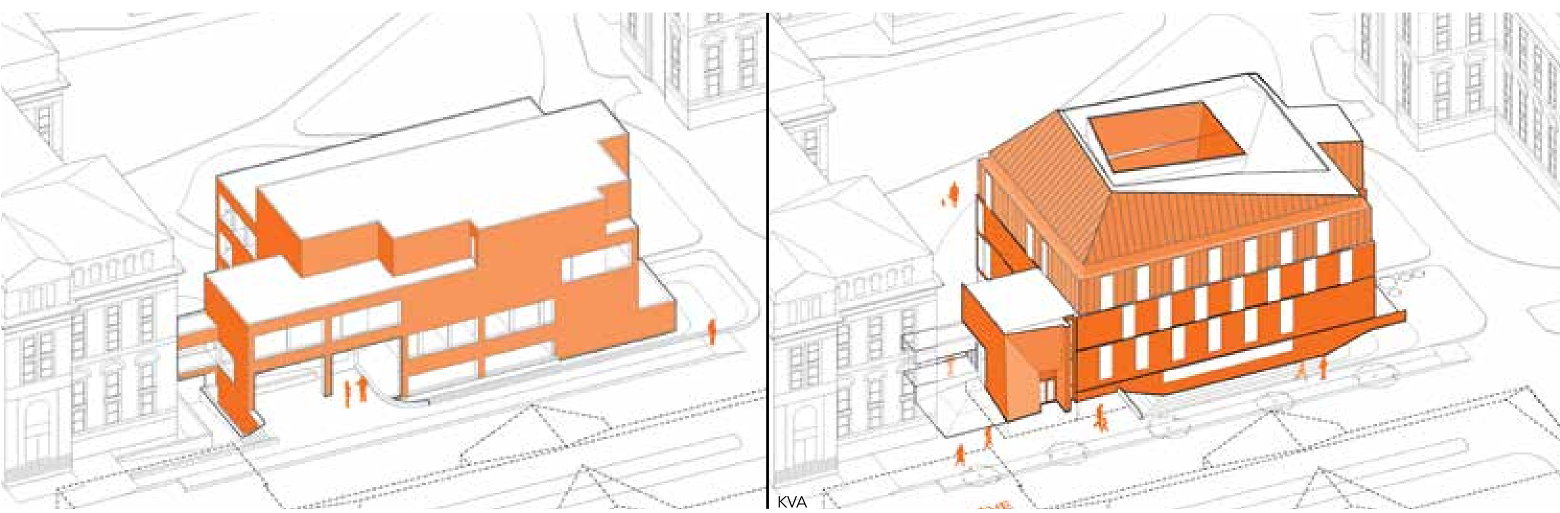
The university decided to expand Tozzer Library into a comprehensive departmental facility by adding faculty offices, graduate student spaces, seminar rooms and public spaces to the existing resources. The university's vision for an updated facility challenged the design team to create more space for departmental research activities while maintaining the character of the existing building. The new design needed to reinvigorate an austere contemporary structure, where the library has existed since 1973, with a warm materiality and an openness emblematic of the department's mission.

In order to accommodate library stack loading, the 1973 building was designed for a live load of 150 psf. The renovation and expansion project planned to move most of the stacks to the at-grade lower level. Planned live loads of 50 psf for new office space made it possible to add two additional floors to the existing two-story structure without overloading the building columns and foundations. The new third floor replaced a previous mechanical penthouse, and the new fourth floor was topped by a hipped roof cut at an angle to create a light well throughout the top three stories of the building. The new structure is 72 ft tall at the highest point of the angled roof and extends 1.5 times higher than the original penthouse roof. The new roof required the existing building's steel moment frame structure to be braced in both directions to satisfy wind load serviceability requirements.

Existing System

The original 1973 structure was framed with wide-flange members on a grid of four bays at 22 ft, 8 in. each in the long direction and three bays of 26 ft, 16 ft and 26 ft in the short direction. Two existing open bays at the center of the original penthouse floor/low roof formed the basis for the light well, which was designed to extend up through the new fourth floor and roof. Existing floor construction was 4½ in. lightweight concrete on 1½ in. 20-ga. steel deck. In the long direction, W24×84 interior girders and S20×75 exterior girders framed into the weak axes of W12 columns to form a moment frame. In the short direction, W16×26 beams at 4 ft, 6 in. spanned between the girders, bearing on the girder top flanges and elevating the bottom of the floor and roof slabs 16 in. above the girders' top to allow openings within the framing system for ductwork. On the column lines, W16×31 beams framed into the column strong axes to form a moment frame lateral system in the short direction. Analysis showed that the beams plus strong-axis columns created short-direction moment frames with similar stiffness characteristics—story drift of approximately h/400—to the long direction moment frames consisting of girders plus weak-axis columns.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▲ Tozzer Library before and after renovation.

◄ The existing facility was built in 1973.

▼ The new structure is 72 ft tall at the highest point of the angled roof and extends 1.5 times higher than the original penthouse roof.


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LeMessurier

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Lateral Upgrade

Considering the increase in building height from 48 ft to 72 ft, plus the increase in design wind pressures at higher elevations, the wind loads in both directions increased by a factor of approximately 67%. In the short direction, the original lateral force resisting system (LFRS) had been designed assuming an additional line of framing that was not constructed, resulting in an effective increase of 100% to the short direction wind loads. To stiffen the building against wind loads in both directions, the design team developed two special bracing systems that responded to both the new architecture and the existing framing. In the short direction, eccentric braces were used to stiffen two lines of framing while keeping the public area surrounding the light well clear. In the long direction, a single bay of concentric bracing was designed for the one bay in the building where space for new bracing was available.

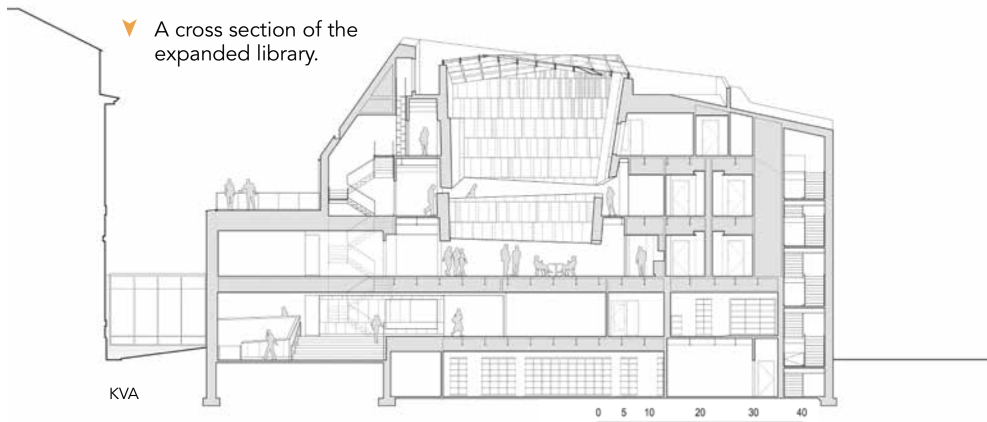
While stiffening the building with bracing solved the problem of wind loads, it also caused the seismic loads to increase to a level on par with the wind loads. Recognizing Harvard's long-term interest in the building, the design team discussed with the owner the concept of developing the seismic design according to an approach that went beyond prescriptive requirements but without incurring substantial cost. Formally, the building seismic system was designed assuming an *R* factor of 3, which meant that wind loads would continue to govern in the short direction but seismic loads would govern in the long direction.

In going beyond prescriptive code requirements, the design team elected to consider the existing moment frame structure as a reserve system, which was analyzed independently according to an array of damage scenarios. A typical damage scenario consisted of removing the bracing from a given story, calculating the resulting building period and ensuring that the damaged structure would satisfy the code, assuming $R = 3$ for the reserve system. This approach was considered to be conservative in light of research that has shown that *R* factors higher than 3 are satisfactory in the presence of a reserve system that can resist collapse. This "belt and suspenders" approach to collapse resistance takes advantage of the fact that once bracing capacity is lost in a system, the building period increases and results in a reduced seismic force level. Such a system can be thought of as a primary braced frame with a moment frame reserve system. But in the case of Tozzer Library, where the original LFRS was a moment frame that required stiffening rather than strengthening, this moderately ductile dual system was conceived as a moment frame, stiffened for wind loads with lateral bracing.

In the short direction, existing beam-column connections of the new eccentrically braced frames were strengthened to carry the beam plastic moment capacity and resulting shear. By staggering the braced bays on each framing line, it was possible to distribute overturning forces to an extent that no column reinforcement was required. The existing moment frames were able to deliver horizontal pass-through forces between staggered bays without additional reinforcement. In the long direction, it was preferable to develop the entire bracing scheme in a single bay because the floor slab, acting as the building diaphragm, was elevated above the girders by the height of the W16 beams. Within the braced bay, special inter-story shear transfer details were developed to create a continuous load path between stories.

Hipped Roof and Light Well

Central to the new library's architecture is the angled, hipped roof, which was designed to fold in on itself and create a dynamic relationship between the building's exterior and interior. This new roof relates more intimately than its predecessor to the surrounding courtyard of 19th century museum structures, and it also gives the library a distinctive form whose feeling changes depending on an observer's point of view. On the exterior of the building, the roofing extends



A cross section of the expanded library.

The brick masonry facade is detailed down to the individual brick.

to the bottom of the third floor, balancing the massing of the first two brick masonry stories and moderating the new building's scale. From its function as cladding on the third floor, the copper standing seam roof transitions seamlessly into the four side slopes that governed the addition's geometry. Slight twists of the light well create a dynamic interplay of the roof ridges and their descent into the building. An algorithmic model was developed for the "twisted hip-roof" condition to allow continuous standing seam panel ribs to cross the roof's four hipped conditions without interruption, and interior views into the light well are framed with sensitivity to this feeling of movement. Existing columns near the light well were transferred back into the office spaces, and new bracing was coordinated so as not to interfere with the ambulatory space around the light well at each level, giving the roof and light well a sense of fluidity and wholeness.

Windows

The architectural experience of the building as a whole required integrating interior and exterior while expanding the building's square footage and maintaining a sense of human scale within the constraints of the intimate site. In order to respect and preserve this concept, the design team worked to locate horizontal and vertical joints in the brick masonry facade with discretion. Windows were designed to span from floor to floor, staggered in elevation and designed to project a few inches proud of the brick in order to minimize the visual presence of joints. These architectural

Looking up at the brickwork of the building's front entrance.

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moves required subtle detailing of relieving angles that varied on a floor-by-floor and wall-by-wall basis due to the stacked framing configuration.

The brick masonry facade is detailed down to the individual brick dimension, and special attention was given to the development of a detailed field survey during construction prior to the development of structural steel shop drawings. The results of this survey, which was designed to detect framing differences to within ⅛ in., revealed that certain slab edges were off by several inches. Having planned to respond to the survey results prior to steel fabrication, the design team was able to redesign the facade to incorporate the exact as-built dimensions and maintain a deliberate placement of every brick. The vertical realignment of elements within the new building envelope also met two critical aspects of high-performance building enclosures—air/water tightness and thermal performance—while meeting NFPA 285 requirements, which limit the extent of combustible materials on non-bearing wall assemblies.

Integrated Design Process

Critical to the transformation of Tozzer Library and the consolidation of Harvard's Department of Anthropology was the ability to iterate through multiple design ideas at the correct moment in the design process. The roof and light well were established early in schematic design, with transfers and lateral system reinforcement budgeted at a sufficient level of detail to anticipate eventual construction costs. Establishing these parameters early on allowed for intense focus on facade support and the integration of windows and masonry patterns during the development of construction documents. Structural details for the facade and window support were developed over multiple iterations that were as extensive as those for the entire lateral system and its complex details. A willingness to integrate structural and architectural thinking about the facade was critical not only for the building facade as a whole, but also for the front entrance specifically, which required masonry facade elements to function in a structural capacity. In certain cases, the conditions of the building demanded this integration to be so precise that full-scale mock-ups were required to make sure that unique elements could be assembled with the requisite precision. The result is a building that conveys the importance of firsthand experience with physical cultural objects, not only in scholarly research but also for the greater public.

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