740 Heinz Avenue

INHERENT REDUNDANCY OF BRB MAST-FRAME SYSTEM SOLVES CODE CONUNDRUM AND DELIVERS COST-EFFICIENT HIGH PERFORMANCE

STRUCTURAL: TIPPING STRUCTURAL ENGINEERS
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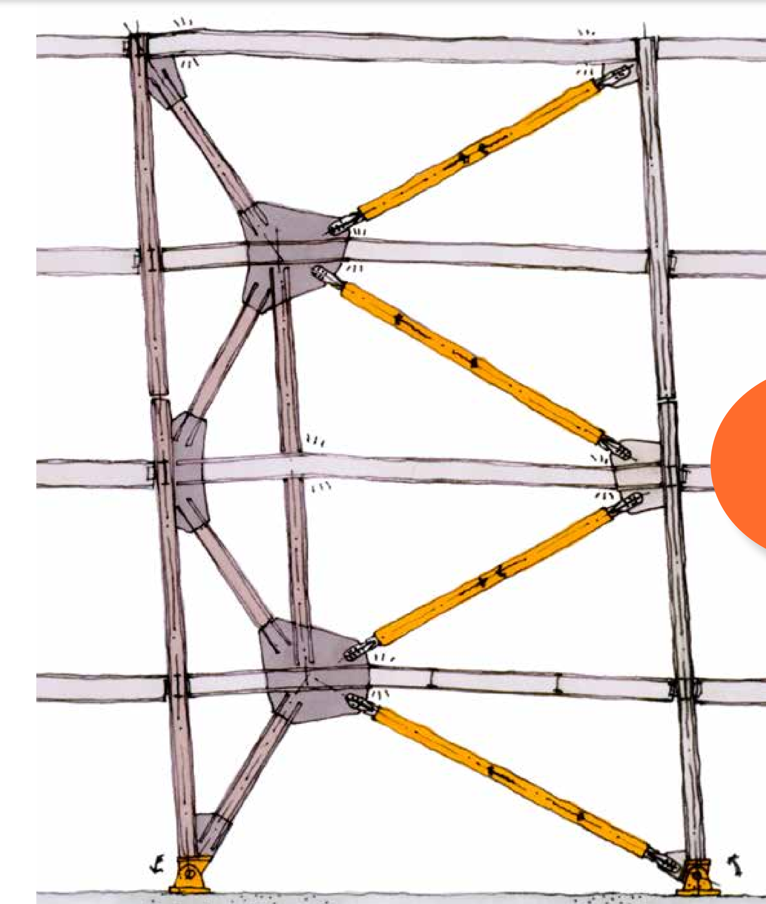
CONTRACTOR/BUILDER: BNBT BUILDERS

 TIPPING STRUCTURAL ENGINEERS

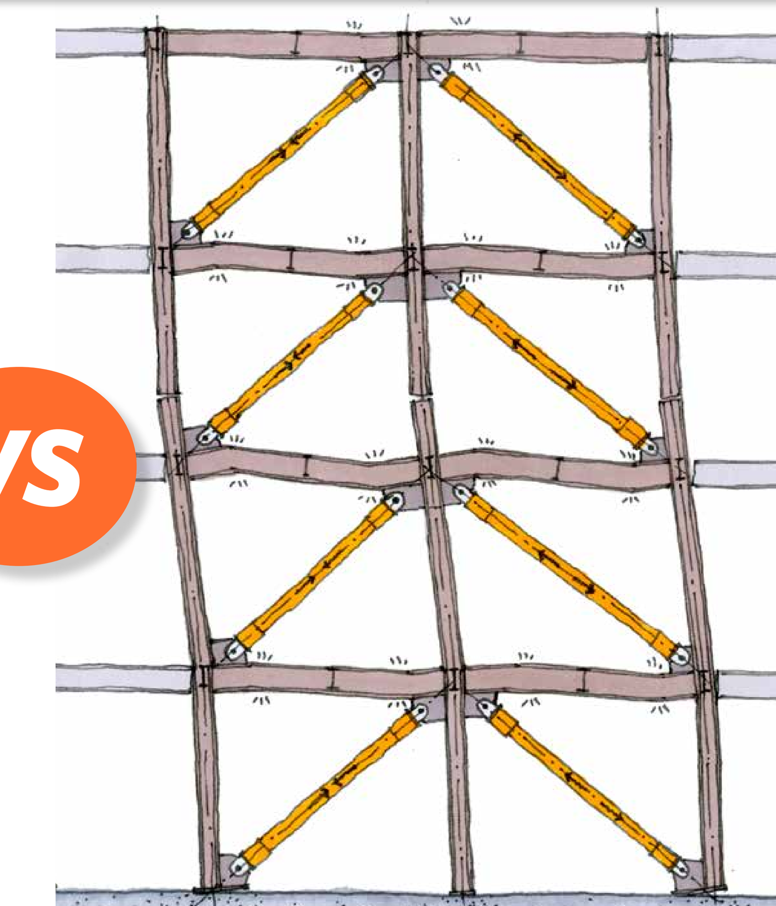
740 HEINZ AVENUE: FIRST MAJOR APPLICATION OF BRB MAST-FRAME SYSTEM

STEEL FRAMING SHOWING THE MAST FRAME ON THE BUILDING'S SOUTH SIDE



TIPPING'S BRB MAST FRAME

VS



CONVENTIONAL BRB FRAME

SINCE THE EARLY 2000s, buckling-restrained braces (BRBs) have been an important addition to the seismic engineering design toolkit and are prevalently used in highly seismic regions throughout the United States. Owing to their highly reliable inelastic response, as well as consistent tension and compression capacities, BRBs were introduced into U.S. construction practice to address some of the shortcomings of traditional bracing members. Additionally, they are custom fabricated to each project's required design force. The current building code offers BRB systems as an option for reduced seismic load design, and they have become the bracing system preferred by seismic engineers.

Recently, engineers have been exploring other bracing configurations to capture the benefits provided by BRBs while improving performance. One such alternative is the **BRB MAST-FRAME SYSTEM.** Devised by Tipping Structural Engineers, *it enhances seismic performance and offers better architectural compatibility at a lower cost than conventional systems.* **740 HEINZ AVENUE,** a new four-story building in Berkeley, CA, is a case study in the efficacy and cost efficiency of BRB mast frames.

THE DESIGN CHALLENGE

While there are economies in designing for lower seismic forces, the redundancy provisions of the building code can still dictate numerous bays of bracing, resulting in a large number of BRBs, which in turn adversely affects architectural programming and cost. Furthermore, BRBs' reduced stiffness leads to larger building deformations, rendering a structure more susceptible to weak-story mechanisms. Ironically, these disadvantages come with a cost premium.

Tipping designed the BRB mast-frame system as a response to the disadvantages posed by conventional steel and BRB-only systems: this new system consists of yielding BRBs in series, with a stiff, elastic vertical frame (the "mast") designed to pivot about its base. The mast redistributes loads between stories, forcing a fundamental change in the kinematics of the system to produce a more uniform distribution of interstory drift. This eliminates the possibility of inelastic weak-story mechanisms. (In parallel development, Jiun-Wei Lai and Professor Stephen Mahin at UC Berkeley studied the efficacy of a similar BRB-mast hybrid, the "strongback system.")

740 HEINZ AVENUE

Also known as "The Garr Building," 740 Heinz represents the first major application of the BRB mast-frame system. It was designed as a flexible, state-of-the-art life sciences R&D building. Clad in precast concrete behind brick veneer, the building has a footprint of approximately 136 feet north–south by 192 feet east–west, for a total of approximately 110,000 gross square feet. The floor framing system consists of steel beams and girders supporting concrete-filled metal deck. Framing is supported by steel columns spaced at approximately 32 feet on center in both directions.

The seismic lateral-force resisting system consists of two BRB mast frames in each direction. In the transverse direction, the frames are located next to the building's stair cores; in the longitudinal direction, the frames are installed at the perimeter façade line. Such placement leaves the architectural space plan undisrupted.

Each BRB mast frame comprises yielding BRBs connected to a vertically oriented truss-like mast; a true pinned-base connection joins the frame and base. The structure was designed according to the provisions of the 2010 CBC; the frames were designed using an R of 7. Seismic analysis relied on a conventional code modal response-spectrum method. The base connection, anchorage, braced-frame pile caps, and piles were designed to resist omega-level forces. The BRB mast frame's vertical-truss configuration is a key aspect of the design, as it is able to redistribute lateral loads between levels, eliminating soft-story mechanisms. The carefully detailed BRB mast-frame system relies on capacity design principles to ensure that inelastic mechanisms will form predictably and reliably.

The BRB mast frame has equal-capacity BRBs at all levels. In contrast, a conventional code-designed braced frame, based on a prescribed triangular lateral-force distribution, typically has the strongest BRBs at the base and the weakest at the top.

THE PROMISE OF BRB MAST FRAMES

The inherent redundancy of the system allows for fewer braced frames. Employing BRB mast frames at 740 Heinz allowed the number of required frames to be cut from 7 conventional BRB frames down to 4 BRB mast frames; the total number of BRB elements was reduced from 56 to 16. Moreover, because the BRB mast frames were easily located next to the building's two stair cores and at the perimeter façade, they did not impinge on the architectural space plan.

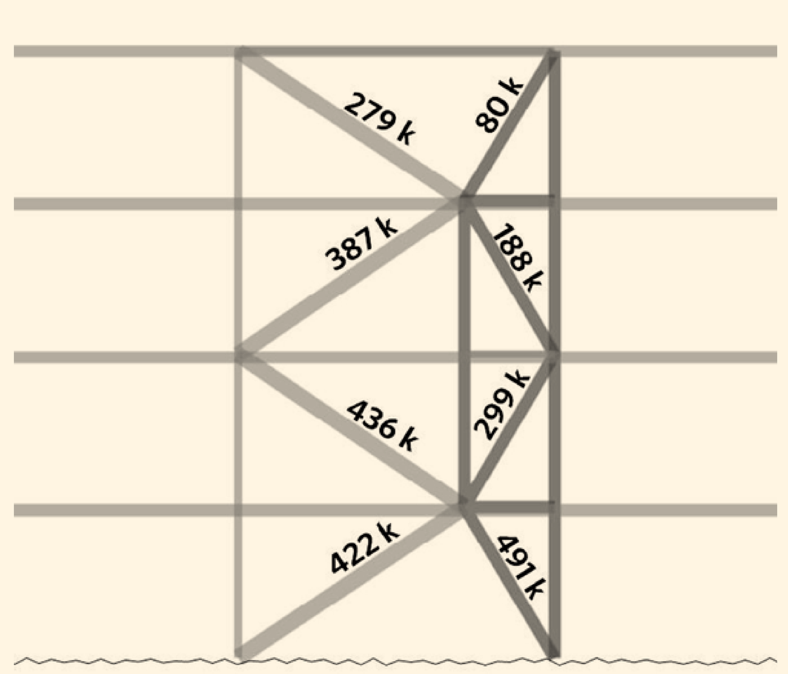
The foregoing illustrates how the BRB mast-frame system not only contributed to a successful project but also holds a great deal of promise for the future: it is a cost-efficient, nonproprietary, and simple high-performance system that can be designed in any number of possible configurations, making it an ideal lateral system for any steel braced-frame building.

CODE CONUNDRUM

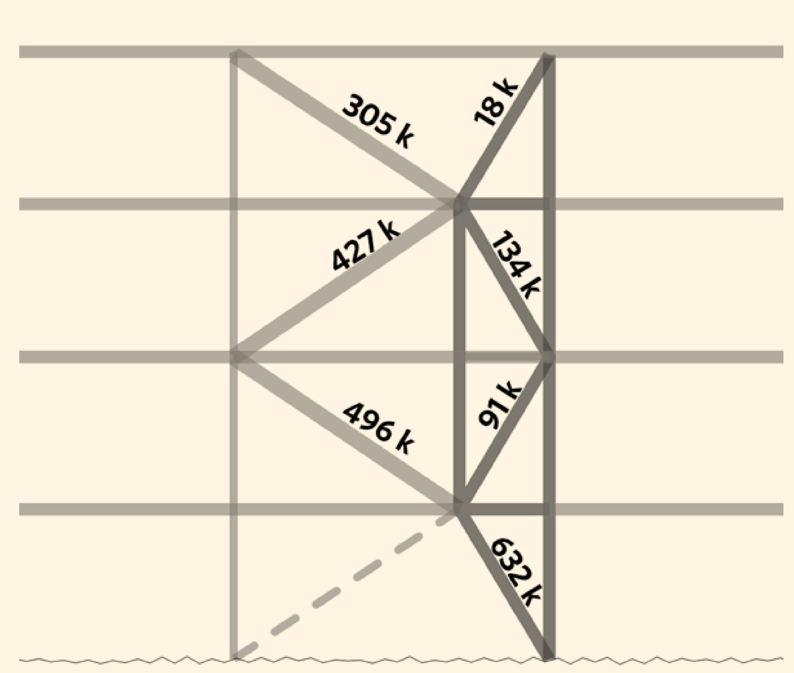
THE REDUNDANCY FACTOR, ρ, was added to the building code to prescriptively compel engineers to consider the number of the lateral bracing elements and their locations. ASCE 7 dictates that a braced-frame system is properly redundant if the number and arrangement of frames is such that the removal of any one brace in the system results in neither more than a 33 percent reduction in story strength nor an extreme torsional irregularity. Otherwise, the nonredundant structure must be designed with a 30 percent increase in the structure's design base shear.

Noting that adding concentric braced frames to eliminate the ρ penalty, with or without BRB diagonals, still results in a weak-story failure of the lateral system, TSE developed the inherently redundant mast-frame configuration to meet prescriptive requirements without the addition of lateral-bracing elements.

BRB MAST FRAME SYSTEM: CODE REDUNDANCY ANALYSIS AND VERIFICATION



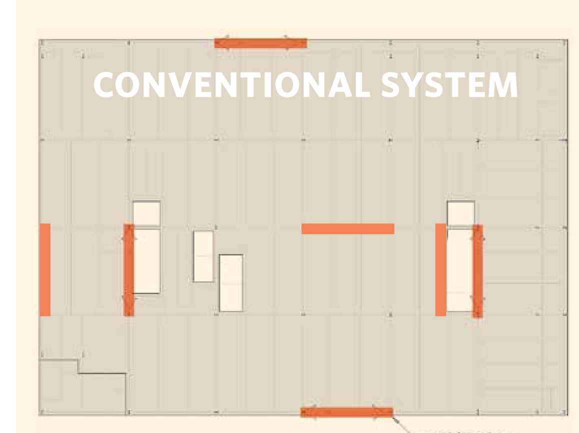
FORCE DISTRIBUTION IN ACCORDANCE TO CODE

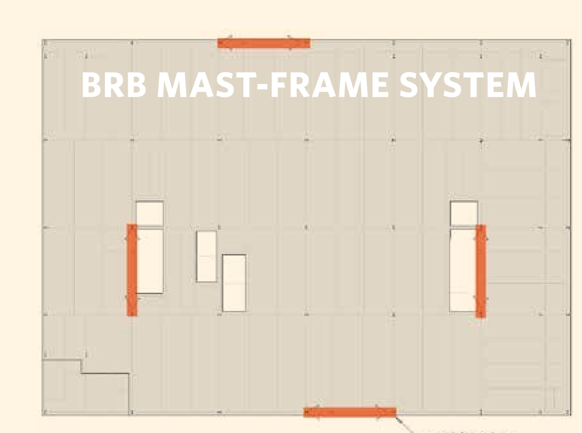


FORCE DISTRIBUTION, ONE BRACE REMOVED

To systematically prove that the BRB mast-frame system met ASCE 7's redundancy prescription, Tipping created a 3D analysis model to directly assess the performance of the frames with brace elements removed: BRBs were removed from each frame at each story to evaluate the redistribution of forces and calculate resulting deformations. The results revealed that the remaining BRBs and diagonal mast members in the modified structure were indeed able to resist redistributed forces: **in the controlling case, story strength was reduced by 21 percent, 12 percent less than the code-allowed 33 percent reduction. Furthermore, the maximum story drift ratios did not exceed the limit of 1.4 times as required by *ASCE 7*.**

CONSTRUCTION COST SAVINGS: COMPARING CONVENTIONAL AND BRB MAST-FRAME SYSTEMS





FRAMING SYSTEM	NO. OF FRAMES	NO. OF BRBS	COSTS: BRB	COSTS: STEEL FRAMING	COSTS: FOUNDATIONS	COSTS: TOTAL
Conventional	7	56	$560,000	$470,000	$280,000	$1,310,000
BRB Mast Frame	4	16	$160,000	$550,000	$240,000	$953,000
Cost Savings			**$400,000**	**−$80,000**	**$40,000**	**$360,000**

A conventional braced-frame system would have required 7 frames (56 BRB elements), intruding significantly on the building's space plan. **Tipping's BRB mast-frame system reduced the number of required frames to 4 and BRB elements to 16, resulting in a construction cost savings of $360,000 for the project.**