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BUCKLING RESTRAINED BRACES – STANDARDS DEVELOPMENTS AND INNOVATIVE APPLICATIONS

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The Buckling Restrained Braced Frame (BRBF) represents the state-of-the-art in braced frame design. A technology introduced in the late 1990's, it has been codified in just over 5 years and has been incorporated into over 500 buildings to date. The system's critical element, the Buckling Restrained Brace (BRB), is a brace that does not buckle and harnesses the inherent ductility of steel to provide stable, predictable dissipation of seismic energy. Although the brace can be used wherever buckling of the brace is undesirable or where higher ductility and energy dissipation is desired (such as bridge, outrigger, or blast designs), they are typically incorporated as part of the BRBF concentrically braced frame system.

Typical BRB Design Process

The design approach of applications using BRB's typically incorporates the coordination of a BRB manufacturer. This is because some of the factors needed for design with BRB's are dependent on the design of the brace itself and may differ from manufacturer to manufacturer and even from brace connection type provided by an individual manufacturer. It is essential for the design engineer to incorporate design attributes of a BRB brace into their design for a brace that is possible to manufacture. Otherwise, an uncomfortable discussion awaits the design team during the bidding process or after the project has been awarded, when redesign to achievable brace design parameters may be necessary.

Figure 1 shows the typical design process for a BRBF project, demonstrating the flow of information back and forth between the design engineer and the BRB manufacturer. The domestic brace manufacturers do not charge for this service, nor do they need to be under contract or obligation to provide it. Though the input from the brace manufacturer may include a variety of important contributions to the design, there are three critical design items that are contributed by the BRB manufacturer: brace stiffnesses, brace overstrength factors, and verification of testing coverage for the proposed project braces.

Brace Stiffness and Modeling

For an Ordinary or Special Concentric Braced Frame, brace stiffness is tied to the brace area and is determined using the simple equation below.

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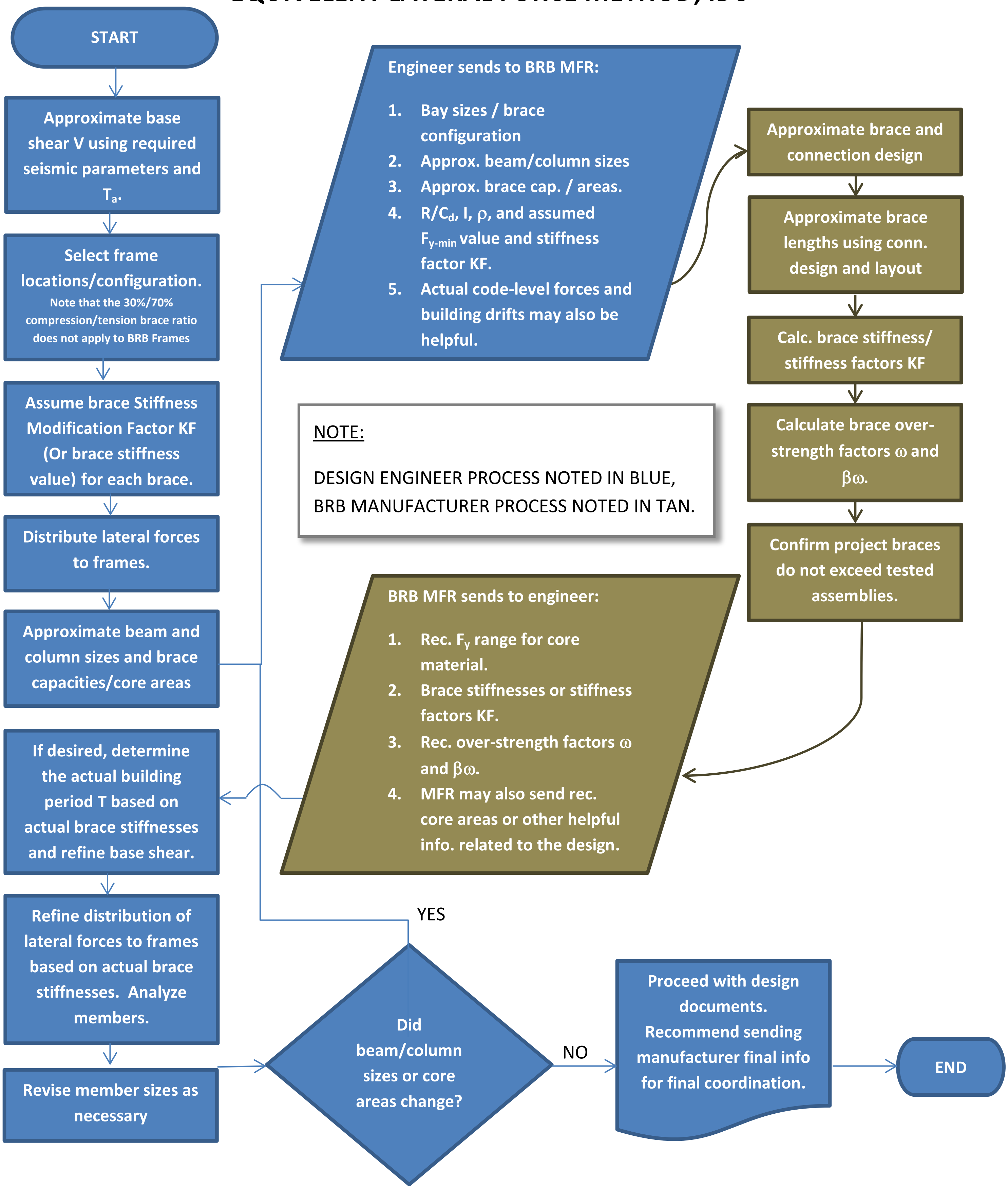
FIGURE 1: TYPICAL BRB DESIGN PROCESS FLOWCHART FOR EQUIVELENT LATERAL FORCE METHOD, IBC



$$K_{\text{model}} = \frac{AE}{L_{wp-wp}}$$

Where L_{wp-wp} is the workpoint-to-workpoint distance along the axis of the brace. This analysis is automatically done as part of most structural design software packages. However, a buckling restrained brace is non-prismatic and consists of the yielding core segment, with the minimum cross-sectional area of the brace, and the outer portions of the brace that are designed to stay elastic and therefore include a greater cross-sectional area. Brace strength is controlled by brace core area, but the use of this core area in the structural model without any adjustment will not correctly capture the stiffness of the brace. This stiffness is usually captured in the model through the use of a stiffness modification factor (KF). The modeled brace stiffness would then be represented by the equation below.

$$K_{\text{model}} = \frac{KF(A_{sc})E}{L_{wp-wp}}$$

Where A_{sc} is the steel core area and. The modeled brace stiffness can also be represented as a spring with a defined stiffness K_{model}.

The stiffness factor or modeled brace stiffness is unique to each brace manufacturers' design, although it may be similar between manufacturers. It is also dependent on brace capacity, bay geometry and connection details. The design engineer will need to assume an initial value for this factor for early estimation of required brace capacity and preliminary beam, and column sizes and send this information to a brace manufacturer for early coordination to obtain the recommended stiffness factors for the braces. If brace capacities are adjusted, final values should also be confirmed with the manufacturer prior to finalizing contract documents.

Brace Overstrength Factors

For the BRBF system, the brace is designated as the "fuse" element and all other parts of the frame and connections are designed to remain elastic. As the BRB brace engages in a seismic event, the steel core is designed to yield and then to strain harden. This process will require the beams, columns, and connections to be designed for these higher, strain-hardened brace forces. The increase in the brace force in tension is represented by the factor ω, while the increase in compression is represented by the factor $\beta\omega$. These factors are determined from the results of the AISC 341 required testing. Again, these factors vary by brace manufacturers and even by brace connection type.

Standard and Innovative Uses for BRBs

BRBs have been used on many types of structures as part of a standard BRBF Frame. They are enjoying widespread usage in building structures such as office buildings, hospitals, retail, car parks, multi-story residential, schools, religious, stadiums

Plum Point Energy Station, Osceola, AR

JWA Parking Str C, Orange, CA

and arenas, as well as non-building and industrial structures. However, many projects use the Buckling Restrained Brace in unique ways that differ from the standard BRBF concentrically braced frame. The braces have been used in or proposed for a variety of applications, including bridges, civil structures, horizontal diaphragm elements, highrise outrigger frames, externally anchored braces, wind towers and many other unique applications. The following projects show a sampling of some of the most innovative applications.

Metal Buildings

The Seahawks Practice Facility is a large facility where the Seattle Seahawks NFL Football team practices, outside of the frequent rain and inclement weather that is a frequent companion of the city of Seattle. The project was high profile, and many teams offered numerous methods for building the structure, including several metal building approaches. The winning bid incorporated the team from HCI Steel Building Systems, whose design incorporated BRBFs instead of the SCBF options proposed by the other teams. Since that structure was built in 2007, numerous metal buildings from a variety of manufacturers have incorporated the technology.

Single Brace Retrofit

Rutherford & Chekene, a structural engineering consulting firm in San Francisco, was presented with a unique challenge in the seismic evaluation and retrofitting of a historic steel and concrete structure. This two-story electrical substation was built in the early 1920’s and remains an important link in the region’s electrical power network. Renovations performed over the years had removed the lower portion of one of the concrete walls. The resulting structure was not adequate to meet the owner’s seismic performance

Power Station, CA

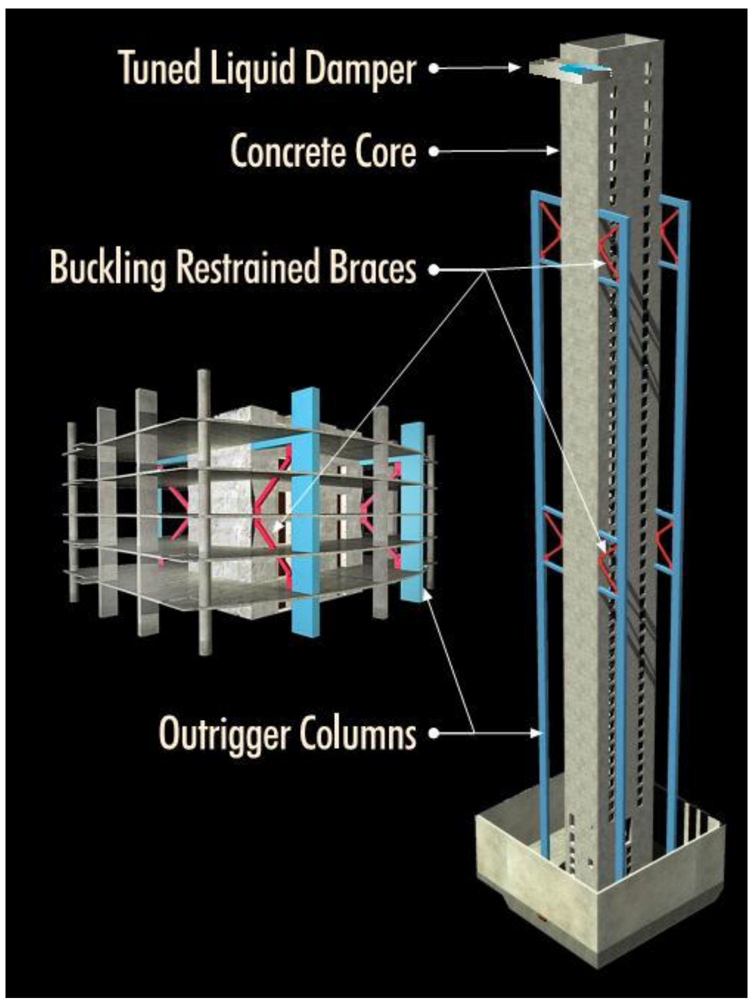
objectives.

Retrofit options were limited. Replacement of the concrete wall that had been removed was not an option, as critical communications equipment that could not be moved had been placed in that area. Bracing on the exterior of the structure was not possible because of the historic character of the building and the presence of high-voltage buried conduits. A single brace could be allowed in the high-bay room adjacent to the area where the wall had been removed. A buckling restrained brace was selected as it was able to support both tension and compression loads while maintaining the required strength and ductility (see Figure 1). In addition, the brace strength could be “tuned” to avoid overloading collectors and floor diaphragms, and to match the strength of the remaining walls and reduce the possible plan-torsion of the structure under strong earthquake shaking. A new collector and foundation was provided to complete this portion of the retrofit.

Highrise Outrigger System

The One Rincon Hill South Tower is a 56 story, 578’-4 feet tall residential structure. It is located next to the western approach of the San Francisco – Oakland Bay Bridge. While being in the heart of one of the most seismically active regions in the US, the design was also governed by design considerations from powerful Pacific winds due to its prominent location on the skyline.

The design of the structure includes a rectangular concrete core for the seismic and wind forces. The length of the core in one direction was sufficient to resist overturning demands but the other was too narrow to adequately control building sway. The design team at Seattle based Magnusson Klemencic Associates decided to incorporate an outrigger system into the structure to bolster the stiffness in the



One Rincon Hill Tower, San Francisco, CA

core's narrow dimension, much the same as the use of ski poles can stabilize a skier. The outrigger system served to reach out to the large concrete outrigger columns to engage them for resistance to overturning at four levels of the structure (see Figure 2). Buckling restrained braces allowed the design team to limit the amount of load that would be delivered to the outrigger columns while controlling the stiffness and response of the building. In addition, a large tank at the top of the building holding up to 50,000 gallons of water is used for two purposes: As a tuned liquid damper to counter the sway from wind forces and as a reservoir for firefighting purposes.

Civil Structure

Casad Dam is a concrete gravity arch dam built in the 1950's that includes an integral intake tower located on the upstream face at the center of the dam. The intake tower was not adequate to support the anticipated seismic demands, where the peak ground acceleration was increased due to the proximity of the Seattle fault and new research into the magnitude of potential events. A retrofit scheme was needed for the intake tower that would have minimal impact on the normal operation of the dam, would have minimal underwater work, and could be done with minimal expense.

The design team at Hatch Associates Consultants, Inc. in Seattle, WA investigated several options and found that bracing the tower back to the dam best met their key objectives for the retrofit, rather than strengthening the tower at its base. However, the arch dam required protection by limiting the brace forces. Viscous dampers and buckling restrained braces were considered and, after detailed simulations, stainless steel buckling restrained braces with a yielding steel core were selected (see Figure 4).

Casad Dam, Bremerton, WA

The project successfully met diverse functional objectives that included preventing tower collapse under a maximum credible earthquake with a 0.78g peak ground acceleration, meeting low maintenance requirements while providing high reliability, and ensuring that there were no environmental or water quality impacts.

The projects listed above provide only a small sampling of unique uses for buckling restrained braces. As the brace usage expands, functions requiring symmetrical capacity between tension and compression, calibrated stiffness of elements, limiting of force transfer through an element, the incorporation of ductility and energy absorption and other features of the brace will continue to be found. The applications found truly demonstrate the abundant creativity of the engineering designers using the technology.