STRENGTH, STABILITY AND STIFFNESS are, of course, all factored into the design of a structural framing system. But as buildings age, take on new uses or are expanded, sometimes they a need a structural boost.

There are several ways to incorporate structural reinforce-

In determining the reinforcement scheme, an important practical consideration is the types of obstructions that will be encountered. For example, the bottom ange reinforcement in Figure 2a must be stopped short of the end of the beam. If the reinforcement must extend to the end of the beam, another type of reinforcement may be more economical. A similar case is shown in Figure 2b for web plate reinforcement obstructed by a secondary beam framing to the web of the reinforced beam.

Due to obstructions and economic considerations, reinforcement is often placed on only part of the member length.

Obstructions requiring partial-length column reinforcement are shown in Figure 5. Under most conditions, the reinforcement can be discontinuous at lateral brace locations. In these cases, the column should be designed as a stepped member. Additionally, the non-reinforced part of the column must be checked for yielding.

In the rare case where the non-reinforced part of the column is overstressed, cross-sectional area can be added with wing

Various parts of the AISC *Speci cation* limit the longitudinal distance between welds. The provisions in Section J3.6 are intended to ensure close t-up over the entire faying surface and to prevent corrosion between the connected elements. The dimensional limitations in Section J2.2b are to ensure proper welding techniques. For members loaded in axial compression, the limits in Section E6.2 are to prevent longitudinal buckling between the welds.

W dabi i. To minimize the risk of cracking of the weld and base metal, the weldability of the existing steel must be analyzed. As discussed in AWS D1.7 *Guide for Strengthening and Repairing Existing Structures*, several different carbon equivalent (CE) equations have been developed to estimate weldability based on the chemical composition of a steel. The CE value indicates the level of brittleness of the heat affected zone upon weld cooling; therefore, as the CE value increases, weldability decreases.

The chemical content of the steel can be found in mill test reports or chemical tests of samples cut from redundant parts of existing structures. Weldability can also be ensured if the structure has been successfully welded in the past. A bend test to determine weldability is also described by D. Ricker in a 1988 *Engineering Journal* article, "Field Welding to Existing Structures."

W di ad d m mb . In addition to the nal as-built design, member strength during erection must be considered. Welding has a detrimental effect on loaded members due to a reduction in material properties at high temperatures near the arc. In some cases, the load can be removed from the reinforced member until welding is complete; however, this can be impractical and is usually not required because the effect of welding heat is highly localized.

Member strength can be evaluated based on a reduced cross section, where the high-temperature area near the arc is inactive in resisting load. The width of inactive material is proportional to the heat input, which is dependent on the current, voltage and arc travel speed. For welds with low heat input, the inactive width is less than 3 in. parallel to arc travel and 2 in. perpendicular to arc travel. However, the inactive width can be much larger for high heat input processes, such as ux-cored arc welding (FCAW). The welding procedure speci cation (WPS) provided by the erector will include the required information for heat input calculations.

General guidelines for low heat input are:

- Low welding current
- Small diameter electrodes
- Allow time for welds to cool between successive passes
- Use stringer beads only (in lieu of optional stringer or weave beads)
- Intermittent welding in short lengths
- Temperature crayons or other suitable means should be used to monitor the temperature of the base metal near the weld

Member Tolerances

All members have initial imperfections. The initial out-of-straightness has a critical effect on the lateral buckling strength of columns. Figure 8 shows this effect using three magnitudes of initial out-of-straightness. The column that is in tolerance, represented by the solid line, has typical column behavior where the P-δ curve is almost linear until the maximum load is approached. The middle curve, representing the column with δ_0 = 0.48 in., is out of tolerance by a factor of three. This column behavior is characterized by a more nonlinear P-δ curve, which results in a higher second order moment and lower strength. The bottom curve represents a damaged column.

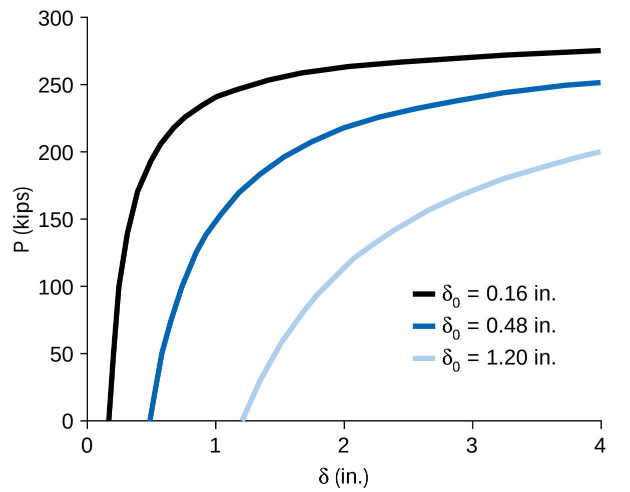

Fig. 8. Load versus lateral deformation for columns with various initial out-of-straightness.

For reinforced members, geometric imperfections are caused by a combination of:

- Imperfections of the non-reinforced member resulting from rolling, fabrication and erection
- P-δ deformations from the initial load in the member
- Shrinkage deformation from welding of reinforcement (see Figure 9, next page)

All imperfections except weld shrinkage deformation can be measured prior to member design. Weld shrinkage deformation for non-loaded members can be estimated using empirical equations (for example, see Blodgett, 1966). The values should be adjusted to account for any load in the member at the time of welding.

According to Section 6.4.2 in the AISC *Code of Standard Practice*, the maximum variation in straightness for a built-up shape is $^1/_{1000}$ of the length between points of lateral support. The total post-weld out-of-straightness for members with signi cant initial load is likely to exceed this value—especially where singly symmetric reinforcement is used. Because the column curve in the AISC *Speci cation* is based on the maximum variation in straightness allowed by the AISC *Code of Standard Practice*, any out-of-straightness in excess of 1/1000 of the length of the member must be accounted for in member design. This can be accomplished using any of the methods in Chapter C of the *Speci cation*.

Contract documents must convey the importance of minimizing weld distortion. As a minimum, a simple drawing note should be provided, stating, "Reinforcement shall be welded by qualified welders using techniques and sequences that minimize post-weld distortion of the member. Welding procedure specifications and welding sequences shall be submitted to the engineer of record for review." In the design stage, distortion can be minimized by selecting intermittent welds and other welds with low heat input. Post-weld member tolerances should also be included in the contract documents. ■