3.8 DESIGN FOR ROLL FORMING

Roll forming offers an alternative to stamping for some body components. The process entails very low costs for tools and equipment and it offers very high production rates. Section 4.2 contains a discussion of the roll forming process, which is helpful in understanding design for roll forming. This section outlines techniques for utilizing the economic advantages of the roll forming process.

The design principles for components made by stamping and roll forming are distinctly different due to the differences in the mechanics of manufacturing operations. The optimum design practice and the tolerances that can be maintained with either process must ultimately be verified by consulting with manufacturing personnel. The following discussion will acquaint the designer with the fundamental principles of designing for roll forming and will facilitate interaction with the roll former's manufacturing personnel.

3.8.1 DIMENSIONING PRINCIPLES

3.8.1.1 Design to Inside Surfaces

During roll forming, the sheet steel is usually wrapped around the male die. It is therefore generally preferable to dimension cross sections to inside surfaces as illustrated Figure 3.8.1.1-1. Exceptions sometimes occur due to the method of forming, industrial standards or application. For example tubular products, which are not completely formed around a male die, are frequently defined by the outside diameter.

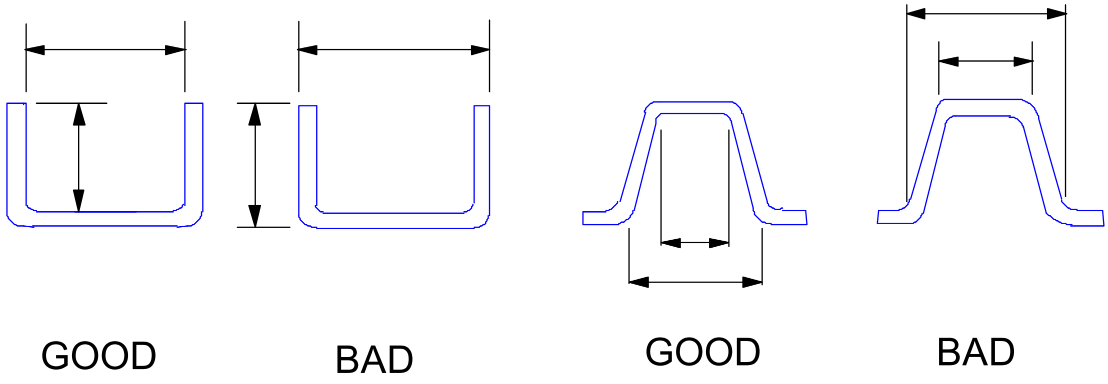


Figure 3.8.1.1-1 Dimension to inside surfaces

3.8.1.2 Establish Dimensions from the Same Surface

It is preferable to establish both reference points of a dimension from the same surface as illustrated in Figure 3.8.1.2-1. Otherwise the specified tolerance must include variations in the thickness of the sheet steel as well as the variations produced by the roll forming operation.

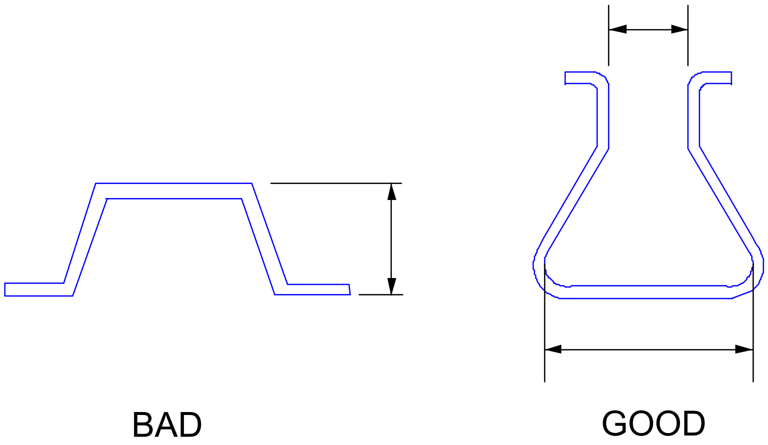
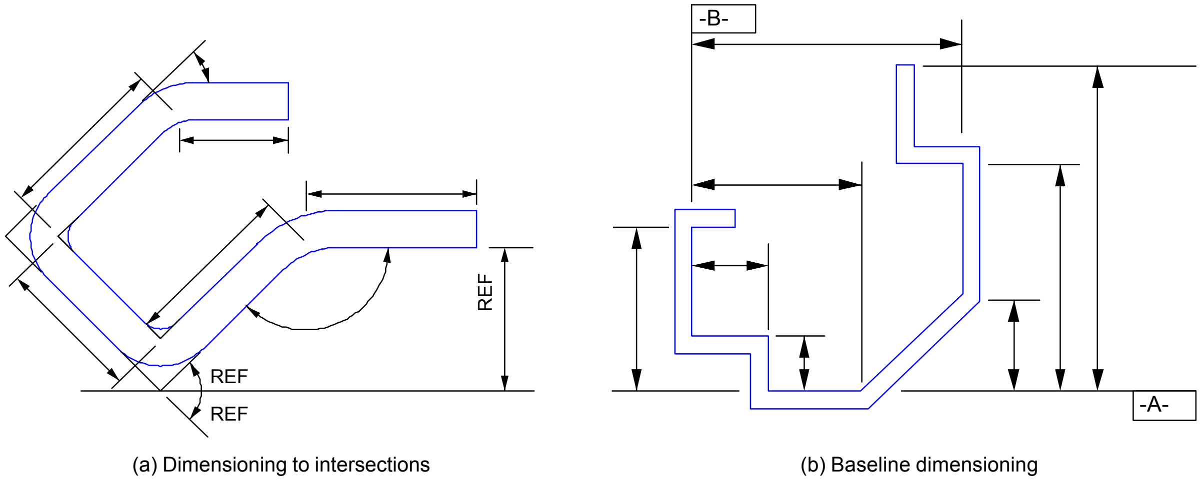


Figure 3.8.1.2-1 Establish both reference points of a dimension from the same surface

3.8.1.3 Dimension to Critical Features

Tool makers generally prefer that the section be dimensioned to the construction points formed at the intersections of the elements rather than to the centers of radii and tangent points, as shown in Figure 3.8.1.3-1(a). This system best reflects the progression of roll forming operations. However, the stackup caused by this system may generate unacceptable tolerances on critical dimensions, such as the opening. Base line dimensioning shown in Figure 3.8.1.3-1(b), which is commonly used in the automotive industry, will give closer control by relating dimensions and tolerances to component functions. The difference in preferred systems of dimensioning are best resolved by direct discussions between design and tooling engineers early in the design process.



(a) Dimensioning to intersections

(b) Baseline dimensioning

Figure 3.8.1.3-1 Dimensioning systems

3.8.2 TOLERANCES

Five types of tolerances are applicable to roll formed components:

1. Length and related factors
2. Section dimensions, linear and angular
3. Straightness and flatness deviations
4. Features such as holes, notches and dimples
5. Others such as burr and appearance

3.8.2.1 Length, Width and Related Tolerances

The length of a roll formed component is generated in the cut-off operation, which produces three types of variation: length, squareness and burr. Length tolerance is affected by variations in cut-off operations, which are largely influenced by the type and condition of the machines, controls and tools. Squareness is not generally specified because roll forming mills can usually hold the deviation from perpendicular closer than required. This is especially true for the relatively narrow strips used for automotive body components. Where off-square ends are required, the angle and tolerance should be specified. Burrs may also be generated in cut-off operations; they are addressed later in this section.

Variations in the width of the strip affect certain dimensions of the section. For example, the opening shown in Figure 3.8.2.1-1 (dimension "g") is formed by return lips whose length is directly affected by strip width. The figure shows two design alternatives, both of which concentrate strip width variations on elements that do not affect the opening dimension.

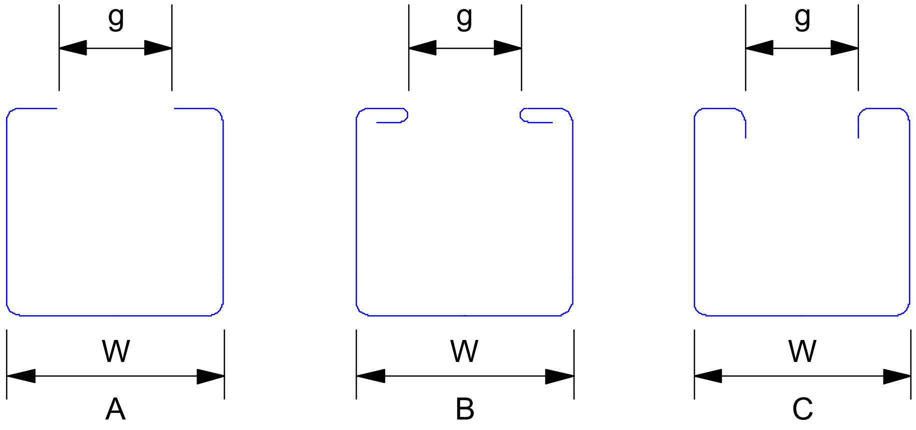


Figure 3.8.2.1-1 The gap width g is affected by variations in strip width in A. Methods for eliminating the effects are illustrated in B and C.

3.8.2.2 Section Tolerances

Guidelines for tolerancing roll formed components are found in documents such as ANSI Y14.5M, the Canadian CSA B78.2 and Delta Standard of Tolerancing Roll Formed Products. Figure 3.8.2.2-1 illustrates the interpretation of tolerances on several common roll formed sections.

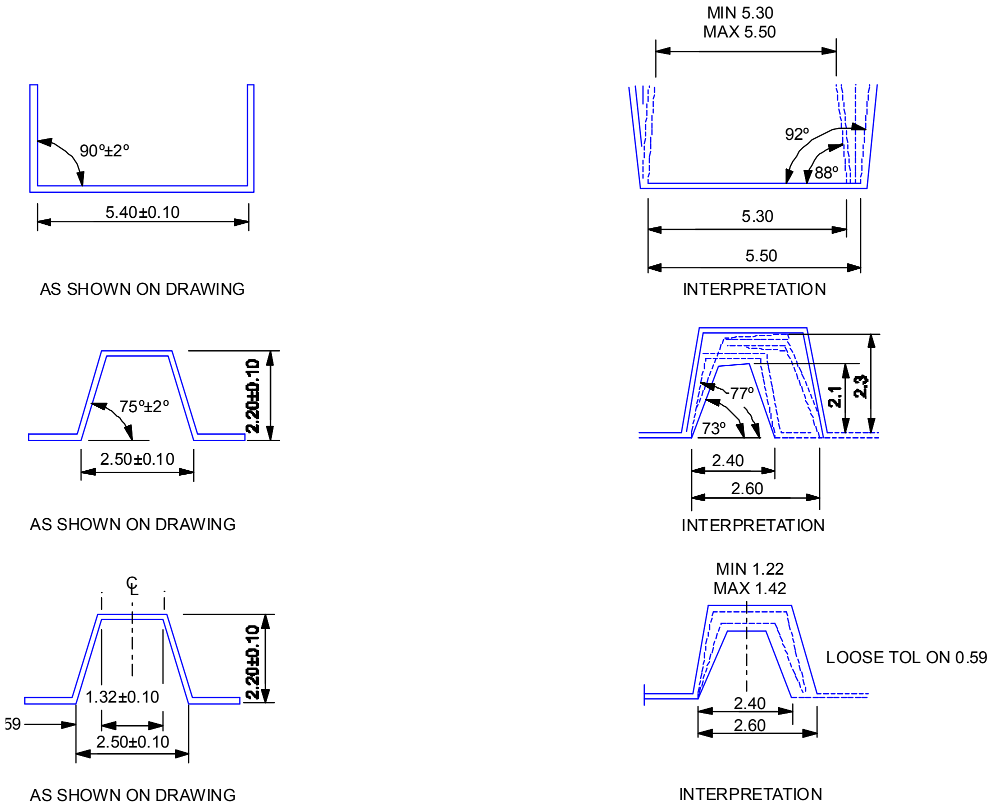


Figure 3.8.2.2-1 Interpretation of tolerances on roll formed sections

3.8.2.3 Straightness Deviations

Straightness deviations of roll formed components are best understood from the mechanics of the roll forming operation (See Section 4.2). As the strip progresses from flat to final form, residual stresses are induced. These stresses, combined with variations in material properties and dimensions, cause distortions in the finished component. The distortions may be aggravated by manufacturing variables such as improper tool design, incorrect roll alignment and insufficient maintenance of equipment.

Residual stresses and material variations may cause variations due to springback; they can also cause bow, camber, twist, flare, wavy edges, wavy center and herringbone effect. Prepierced features, such as holes, notches and embossments usually increase these deviations. The conditions are defined in Figure 3.8.2.3.2-1 to Figure 3.8.2.3.6-1.

3.8.2.3.1 Springback

Springback in roll formed products is similar to that in stampings. It is caused by the elastic component of deformation in the metal, which deflects the section when the tool forces are released. The amount of springback is primarily a function of metal thickness, material strength, forming radius and gap between the rolls.

3.8.2.3.2 Bow and Camber

Bow is the deviation in the longitudinal direction perpendicular to the plane of the roll forming shafts, which are normally horizontal (Figure 3.8.2.3.2-1). It is usually specified as a function of length, such as X in. bow per Y in. length (or mm per mm). For short lengths, the maximum bow is usually specified. Camber or sweep is deviation in the plane parallel to the roll forming shafts, and is normally specified in the same terms as bow (Figure 3.8.2.3.2-1). The final decision about component orientation is determined by manufacturing personnel and may not be as anticipated by the designer. It is therefore advisable to specify the direction of bow and camber tolerances on the drawing.

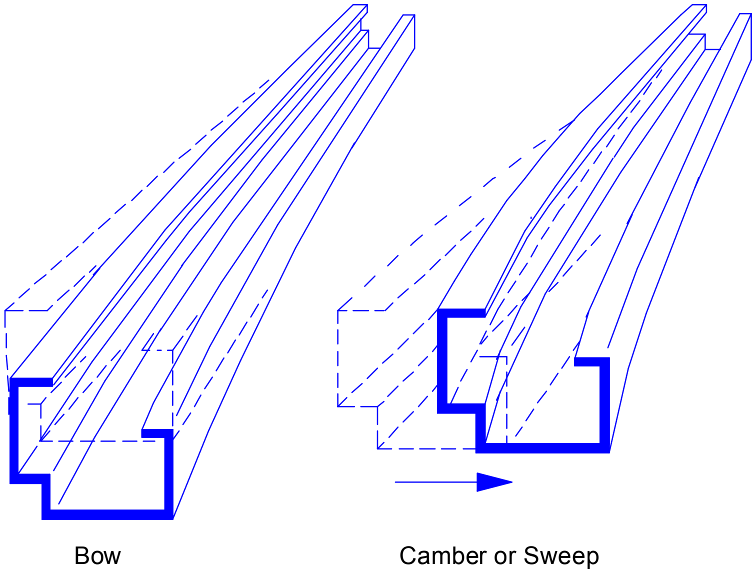


Figure 3.8.2.3.2-1 Bow and camber straightness deviation

3.8.2.3.3 Twist

Twist is the angular variation of a flat surface over the length of a component (Figure 3.8.2.3.3-1). It is measured by clamping one end of the component on a flat surface and measuring the deviation at the other. Twist is frequently specified as a function of component length, such as X° per Y mm (in.).

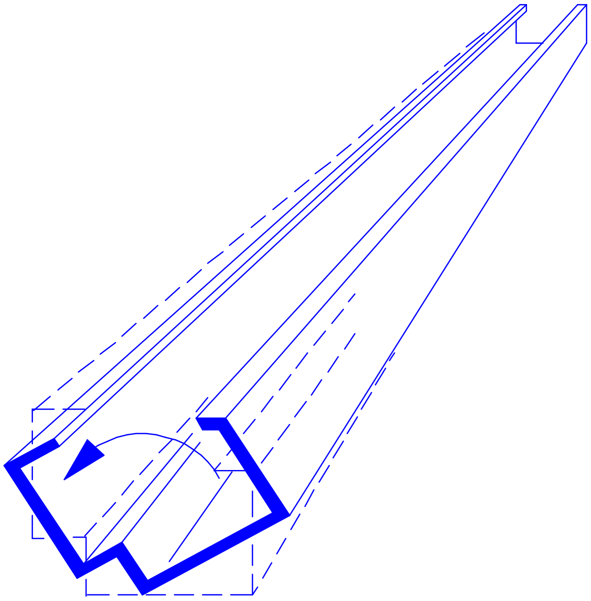


Figure 3.8.2.3.3-1 Twist straightness deviation

3.8.2.3.4 Flare

Flare, which is typical of roll forming, is a measure of the amount that the edges of the strip turn inward or outward adjacent to the cut end (Figure 3.8.2.3.4-1). Tolerances specified for flare override, and do not add to, dimensional and angular tolerances.

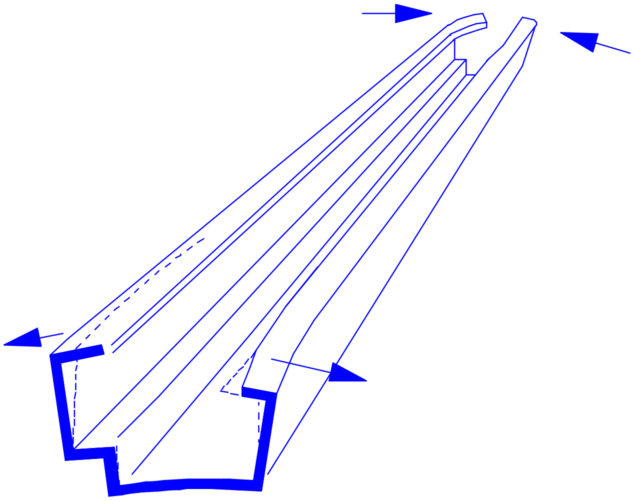


Figure 3.8.2.3.4-1 Flare straightness deviation

The direction of flare is usually inward at the front end (first through the rolls) and outward at the tail. With high strength material or deep sections, both ends may flare outward. The length to which the flare tolerance is applied is sometimes specified, typically 50 to 150 mm (2 to 6 in.). Components formed from pre-cut blanks usually exhibit more flare than those made from continuous strip. The amount of flare in components made from continuous strip is not influenced by the method of cutting.

3.8.2.3.5 Cross Bow

Cross bow is the deviation of a surface from flat, measured from the starting and ending points of the flat surface or full section, parallel with the roll forming shafts (Figure 3.8.2.3.5-1).

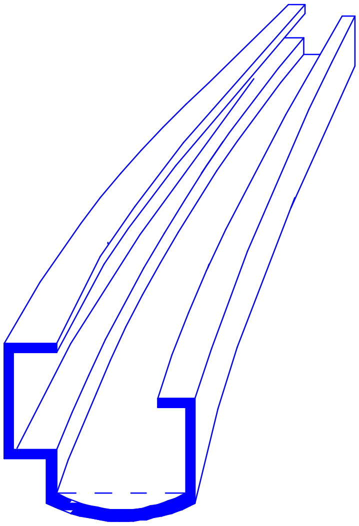


Figure 3.8.2.3.5-1 Cross bow straightness deviation

3.8.2.3.6 Waviness and Herringbone

Wavy edges, wavy center (oil canning), and herringbone effects are typical of wide flat sections formed from thin material. These deviations are seldom measured and can not be well defined (Figure 3.8.2.3.6-1). Acceptance limits are sometimes established by visual inspection, usually employing light reflected at a shallow angle.

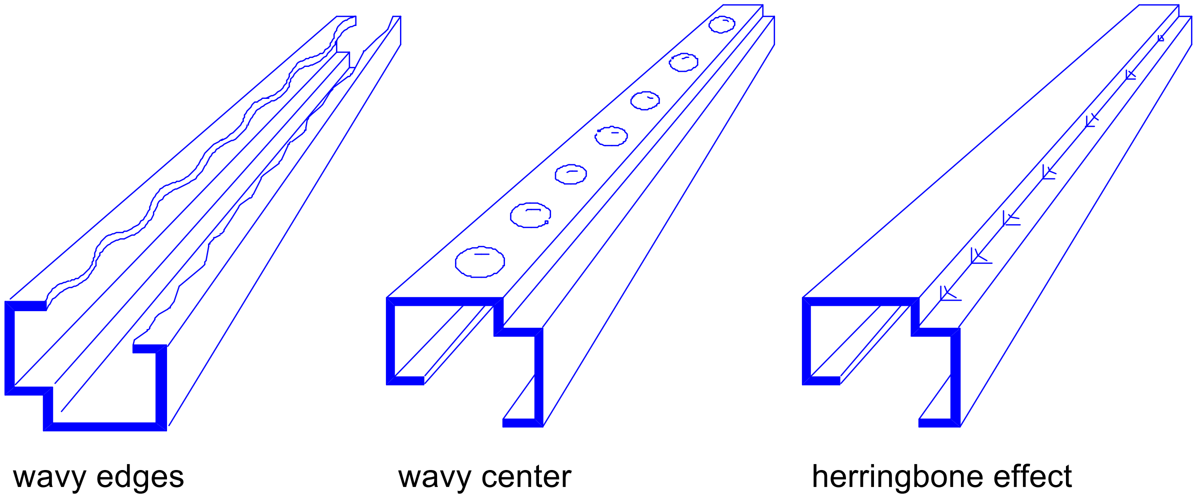


Figure 3.8.2.3.6-1 Defects that are not readily measured

3.8.2.4 Holes, Notches and Dimples

Dimensioning and tolerancing other features such as holes, notches and dimples should follow ANSI Standard 514.5. The implications of the various manners of applying the dimensions and tolerances are demonstrated in the U-channel shown in Figure 3.8.2.4-1. The channel can be formed from pre-cut blanks or formed from continuous strip and cut after forming. The holes can be pierced individually, by twos, by threes, or by sixes. The piercing operations can occur before, during or after forming. These variables generate sixteen different ways to produce the simple component by roll forming. (Theoretically there are twenty-four combinations; in this case, eight are not practical.) Each way uniquely affects tolerances. Where these types of variations exist, tolerances should be determined in consultation with manufacturing engineers to achieve the required tolerances at maximum economy.

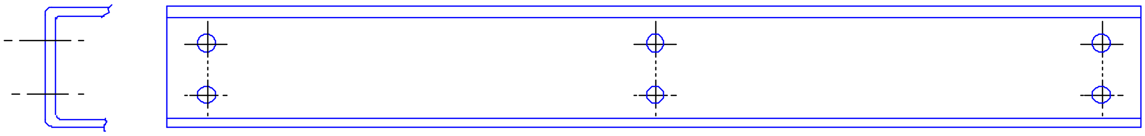


Figure 3.8.2.4-1 There are 16 different ways of manufacturing this simple U-channel by roll forming. Each of the ways has a unique effect on tolerances.

3.8.2.5 Burrs and Appearance Factors

Burrs are formed by cutting and piercing operations such as cut-off and notching dies. The burr height can be appreciable if the die is dull, damaged or incorrectly set up. It can also be diminished by subsequent operations that "iron off" the burr. Tolerances for burrs and acceptance standards for appearance factors are usually covered by separate specifications. In critical cases, such as where a burr may cause assembly problems, the drawing should indicate the permitted direction of the burr or clarify that the plus tolerance includes burr.

3.8.3 MATERIAL FACTORS

3.8.3.1 Mechanical Properties

The mechanical properties of sheet steel in strengths up to 275 MPa (40 ksi) yield and with normal ductility have little effect on dimensional tolerances. As strength increases further and ductility decreases, larger bending radii are required and springback increases. Ultra-high strength steels may require 15° to 20° overbend to achieve a 90° bend. The increased springback makes it necessary to increase overbend, and it aggravates the dimensional variations caused by variations in material thickness and yield strength.

Springback variations are worse with ultra high strength steel because specifications usually define the minimum strength in the direction of rolling, but do not limit maximum strength. Neither strength nor elongation is specified across the direction of rolling, and they may fluctuate within one coil. Since the main bending stresses created during forming are oriented across the direction of rolling, allowable yield strength variations can contribute to substantial springback variations.

3.8.3.2 Coatings

Sheet steel that is coated with aluminum, zinc or paint, and plastic laminated sheet steels can be roll formed. The coatings do not affect tolerances but may impose limits on forming operations. For example, roll pressures that are needed in some cases to form the section can cause shiny streaks on the surface. Proper design of the rolls and use of the correct lubricants are necessary to prevent the rolls from picking up pieces of the coatings. Polishing and other surface treatments on the rolls also help to minimize the amount of coating pickup.

3.8.4 CURVED COMPONENTS

Roll forming offers the latitude to sweep or curve the component in the longitudinal direction. This capability allows for curved components to be economically fabricated by roll forming. Components can be curved after they are cut to length, but it is usually more economical to curve continuously, then cut to length. Curving is a well developed science, but it has not yet been documented. Therefore, in most cases the development of tools and techniques are based on the experience of the tool designer and on trial and error.

3.8.4.1 Effects of Curving

Curving produces different effects on the component cross section than do normal service loads. Normal service loads induce stresses only within the elastic range of the material, whereas curving operations force the material well into the plastic deformation range. The bending loads applied in curving operations induce plastic tensile strain on the outside of the section and compressive on the inside. Since the material volume does not change, the outer surfaces become thinner and the inner surfaces thicker as shown exaggerated in Figure 3.8.4.1-1.

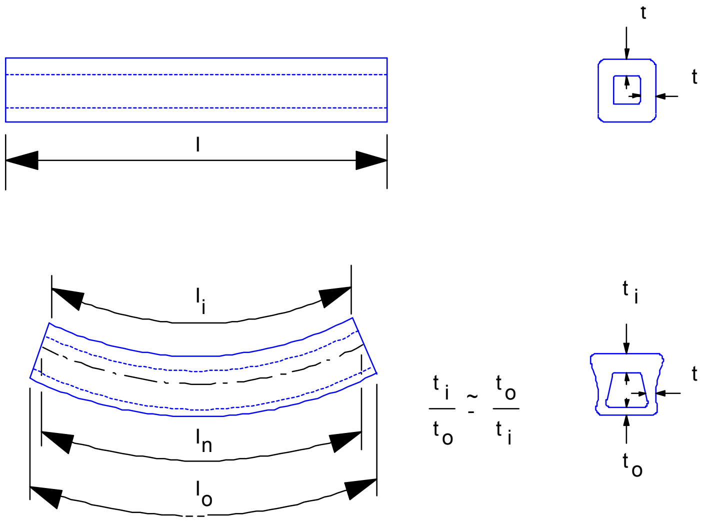


Figure 3.8.4.1-1 Curving induces plastic strain that changes section properties

The redistribution of material shifts the neutral axis toward the inside surface. Other factors associated with manufacturing processes and material characteristics also contribute to the shift of the neutral axis. Curving produces effects that may cause changes in the shape of the cross section. This behavior is discussed for curved members in Section 3.2.2. Elements that are subject to tensile strain tend to move toward the center of curvature, and elements subject to compressive deformation tend to move away. These tendencies produce the effects shown in Figure 3.8.4.1-2. Note that the asymmetrical angle section tends to twist.

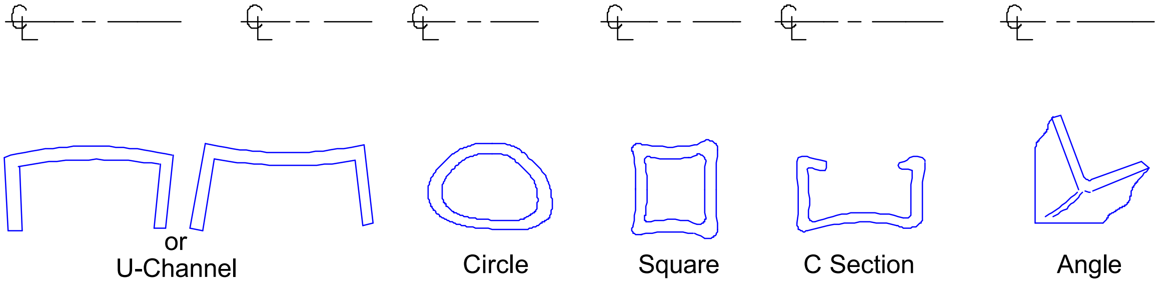


Figure 3.8.4.1-2 Distortions in common sections caused by the tendency for material in tension to move toward the center of curvature

The tensile side of the section usually experiences less trouble than the compressive side in continuous curving because the material is pushed through the curving rolls. The compressive forces subtract from the tensile stresses on the outside, and stresses rarely exceed ultimate tensile. However, the compressive forces add to the compressive stresses on the inside, increasing the possibility of buckling in wide, thin elements of the section.

Another effect of curving is web crippling; several types are shown in Figure 3.8.4.1-3. Crippling is aggravated by cutouts in the web such as holes, slots and notches. The section distortions illustrated in Figure 3.8.4.1-2 and Figure 3.8.4.1-3 can be minimized or eliminated by using tools that support the section during curving, such as forming shoes. Distortions can also be minimized through good component design practice, such as the use of stiffeners. (See Section 3.1.2.1.)

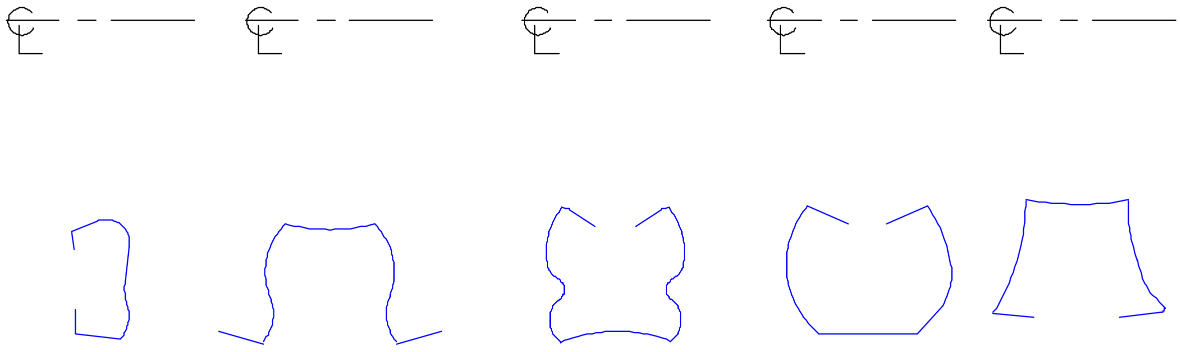


Figure 3.8.4.1-3 Distortions in common sections caused by web crippling

3.8.4.2 Design of Curved Components

Several design factors influence the minimum radius of curvature for a section. Recognizing these factors will help the designer anticipate the amount of curvature that can be attained and recognize the tradeoffs that can be made.

3.8.4.2.1 Material Thickness

The thinner the material, the larger the minimum curving radius because thinner material has more tendency to buckle and is thus more difficult to compress.

3.8.4.2.2 Section Height

The higher the section (in the direction of curving), the larger the minimum curving radius because the amount of strain is proportional to the distance from the neutral axis of the section. The mutual effects of section height, curving radius and material thickness are shown schematically in Figure 3.8.4.2.2-1.

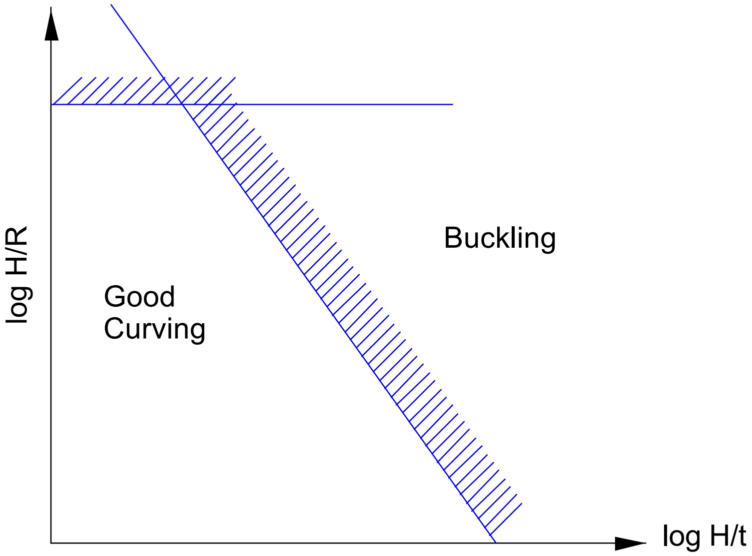


Figure 3.8.4.2.2-1 Mutual effects of section height (H), curving radius (R) and material thickness (t)

3.8.4.2.3 Section Shape

Wider flat compressed elements in a section are more prone to buckling than narrower flat or curved elements. Figure 3.8.4.2.3-1 shows methods for reducing the length of flat elements or replacing them with curved elements. The figure also indicates that it is more helpful to modify elements on the compression side than on the tension side because the compression side experiences more difficulties as noted above.

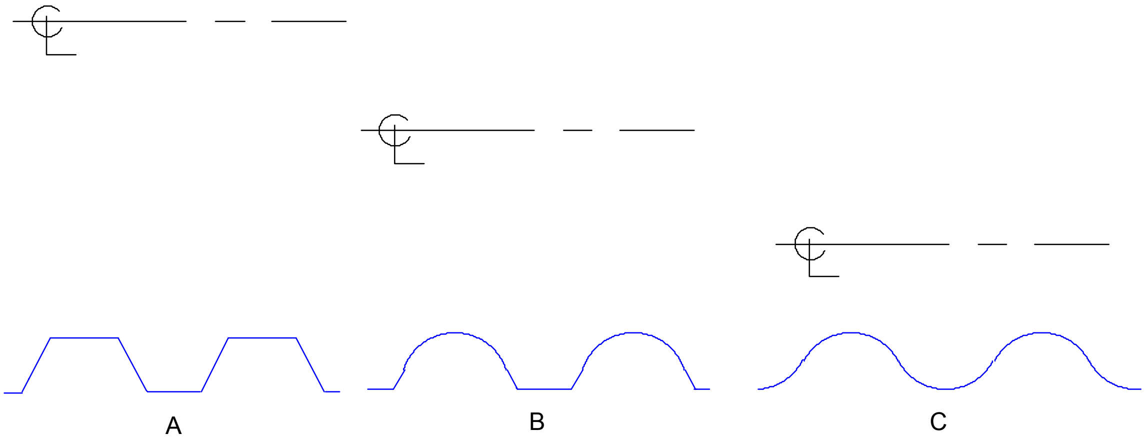


Figure 3.8.4.2.3-1 The relatively large minimum curving radius for Section A can be reduced by substituting curved elements for flat on the compression side. Substituting curved for flat on the tension side also gives a further reduction.

3.8.4.2.4 Use of Stiffeners

Stiffeners can be added to some sections subject to crippling to increase stiffness of critical elements. The use of these stiffeners is similar to those used for load carrying members subjected to stresses within the elastic range discussed in Section 3.1. The principles developed in that section can be applied qualitatively to curving operations, but not quantitatively because the formulae assume that the stresses are within the elastic limit. Figure 3.8.4.2.4-1 illustrates stiffeners applied to the legs of the U channel to reduce the crippling tendency.

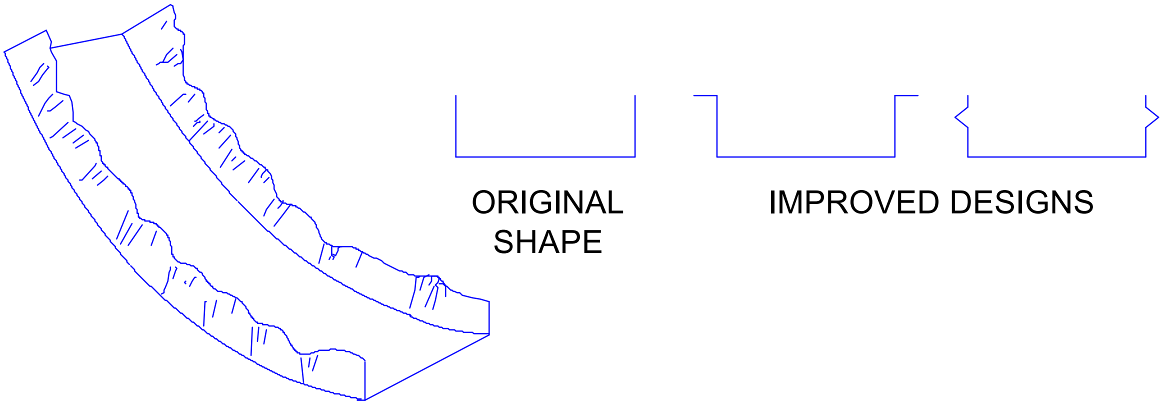


Figure 3.8.4.2.4-1 Stiffeners on the legs of the channel reduce the tendency of the legs to cripple in curving operations

3.8.4.2.5 Hidden Bend Lines

Bends made in the section enhance its strength and rigidity, but they make the component more difficult to curve, particularly when they prohibit roll contact on areas of the section that are critical to the bending operation. It is easier to curve components with rolls if all of the bend lines are accessible to the rolls. For example, the C section and the hat section Figure 3.8.4.2.5-1 have the same blank size, thickness, width, height and section modulus about a horizontal axis.

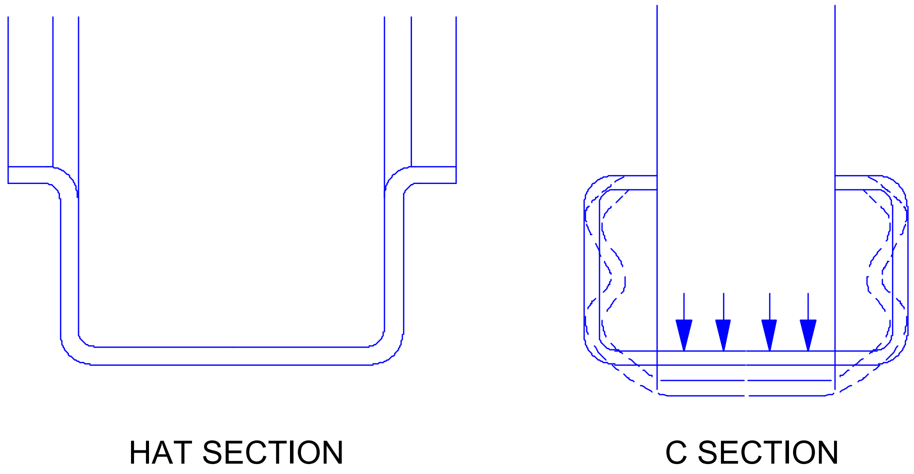


Figure 3.8.4.2.5-1 The curving rolls can reach the bend lines of the hat section but not the C section. Distortion of the C section can occur as illustrated.

All of the bend lines in the hat section are accessible to the rolls. However, the rolls are obstructed from the bend lines at the junction of the web and legs of the C section, so it can distort during curving. Therefore, the hat section can be curved to a smaller radius than the C section. This principle does not apply if the sections are curved with shoes (curved bronze members that are fitted to both surfaces of the metal and do not rotate).

3.8.4.2.6 Cut-Outs and Dimples

The economy of roll forming makes it desirable to form cut-outs of various types and formations such as dimples as a part of the roll forming operation. However, these features complicate curving. The undesirable effects of these features can be minimized by observing the following precautions.

1. Dimples, lances and embossed holes require grooves in the curving tools to prevent the tools from flattening them. These protrusions should therefore be located far enough from the bend lines to allow maximum surface contact between the curving tool and material.
2. Hole-to-hole distances in surfaces subject to tensile strain will increase and the holes will elongate. The opposite will be true of holes in surfaces subjected to compressive strain. These effects should be accounted for in design if they adversely affect product function.

3. Holes too close to the edge of a leg or web in areas subject to compressive strain can cause buckling, as illustrated in Figure 3.8.4.2.6-1.

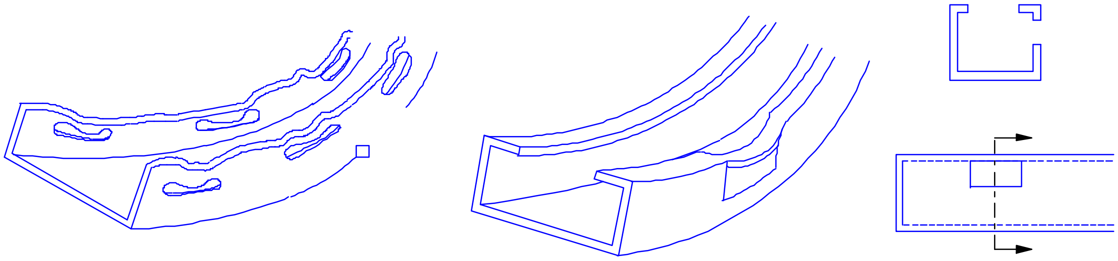


Figure 3.8.4.2.6-1 Holes located too close to the edge of compression element can cause buckling

4. Flare, as noted above, occurs at the beginning and end of sections. Deep cut-outs, such as those shown in Figure 3.8.4.2.6-2, simulate cut-offs and induce flare. Curving with rolls can accentuate flare at cut-outs; the use of curving shoes can minimize or eliminate it.

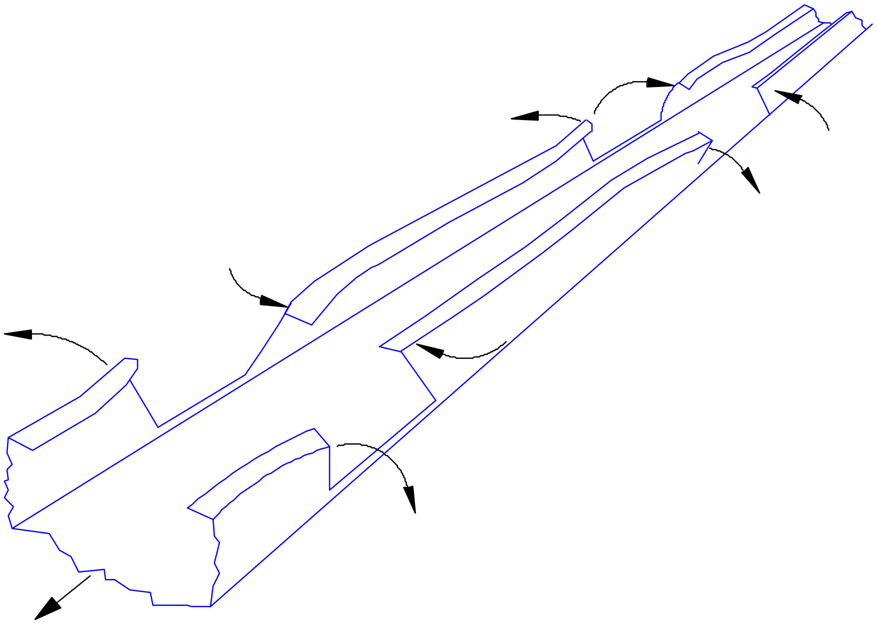


Figure 3.8.4.2.6-2 Deep cut-outs can cause flare

5. Deep cut-outs can also weaken a section and induce buckling during curving as shown in Figure 3.8.4.2.6-3. If the cut-out is on only one side, the component can be expected to twist. These problems can also be minimized or eliminated by using curving shoes.

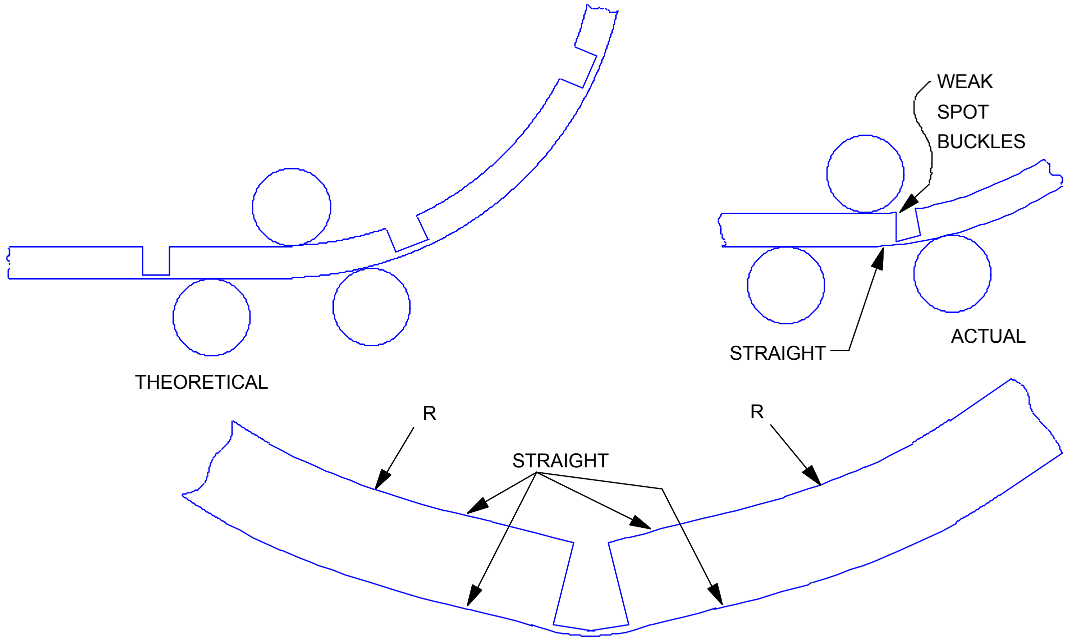


Figure 3.8.4.2.6-3 Deep cut-outs can induce buckling during curving