Influence of manufacturing technology on cold formed structural members

George T. Halmos
INFLUENCE OF MANUFACTURING TECHNOLOGY ON COLD FORMED STRUCTURAL MEMBERS

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INTRODUCTION

It is estimated that 35-45% of all coils under 3 mm (.118") thickness, produced by the North American steel and aluminum mills, are processed through roll formers. A large portion of the roll formed products is used by the construction/building, transportation, furniture/office equipment and appliance industry. Typical products include:

a) Structural elements: rectangular or round tubings, purlins, channels, load bearing studs, joist.

b) Cladding and sheeting: industrial, commercial, residential, agricultural siding, roofing, floor decks, equipment cover.

c) Interior/Exterior Building Applications: studs, ceiling channels, door and door frames, toilet partitions and doors.

d) Structural elements of automotive, airplane, appliance, furniture and other industries.

e) Miscellaneous Products: storage racks, grain storage bins, conveyor covers, fences, bridge decks, tunnel liners, culverts.

From an engineering point of view, the design is good if, by using the right approach, judgement and experience, the calculations and drawings made by the designer meet all strength, safety, appearance and other requirements. The product however, will become commercially successful only if it can be fabricated at a competitive price, and can be easily erected or assembled.

COST OF PRODUCT

The cost of the manufactured product, in simplified terms is the sum of:

Material Cost
Labour Cost
Overhead

The material and labour costs are influenced more by the designer than by the manufacturing plant. The designers also have a secondary effect on the overhead; the size, shape and nestability of the product has a bearing on the material handling and storage cost, storage area and inventory, which usually are components of the overhead cost.
COST OF MATERIAL

The "base" prices of steel and other metal coils are usually established by the mills on popular product types which are usually the simplest to produce.

In the case of hot rolled steel, the "base" price may be based on the purchase of a minimum of about 20 tons commercial quality steel, approx. 9.5-12.7 mm (.375 -.500") thick and 750 - 1,520 mm (29.5 - 60.0") wide. The lowest priced width and thickness ranges depend on the type of steel, (HR, CR, galvanized etc.) and on the manufacturing equipment and policy of the steel mill.

In addition to the "base" price, separate "extras" are charged for different:

- width ranges
- thickness ranges
- specified surface conditions
- edge conditioning
- width tolerances
- thickness tolerances
- drawing quality
- lock forming quality
- structural quality
- strength or other specifications
- chemical composition specifications
- flatness tolerances
- temper rolling
- specific usage
- electrical and magnetic properties
- zinc coating thickness
- types of coating
- coating on both or only on one side
- appearance of coating
- other coating specifications
- as well as for:
  - pickling
  - oiling
  - killed condition
  - test reporting
  - etc.

Some of the "extra" costs are shown in Table 1, as percentage of the HRS base price.

The designer of the product usually specifies the physical characteristics and other properties of the material, based on a combination of strength, thickness, width requirement, accepted trade practice, and availability. The "extras" are not uniform. The designer can frequently, with minor alteration in material specifications, reduce the price of the product and still meet the requirements.

a) Physical Characteristics

Material with the same minimum yield or other physical characteristics may be purchased at different prices if either strength or chemical composition or additional cold work is specified or reference made to ASTM or other standards.

b) Width

For each type of material, the base price is applied to a certain width range. Sometimes a small increase or decrease in the width puts the same material into a different price range.
### TABLE 1

**PRICE OF DIFFERENT CARBON STEEL STRIPS COMPARED WITH HRS BASE PRICE**

**BASE PRICE**

1.1 **HOT ROLLED STEEL**
- **thickness:** 4.6-5.8 mm (0.180-.229")
- **width:** 610-1220 mm (24-48")
- **type:** CQ and STRUCTURAL

1.2 **COLD ROLLED STEEL**
- **thickness:** 0.7-1.6 mm (.028-.063")
- **width:** 1145-1525 mm (45-60")
- **type:** CQ ASTM A 366

1.3 **GALVANIZED STEEL**
- **thickness:** 3.3-4.4 mm (.130-.175")
- **width:** 610-1220 mm (24-48")
- **type:** CQ and FULL HARD

**H.R.S. EXTRAS (Typical)**

- Grade 50 (50,000 psi min. yield)
- X 65 (65,000 psi min. yield)
- COR-TEN-A
- H.R. Pickled and Oiled
- Drawing quality ASTM 621

**C.R.S. EXTRAS (Typical)**

- .015" thick (base width)
- 36" wide (base thickness)
- .015" thick,36" wide
  - STRUCTURAL ASTM 61 Grade A
  - B
  - C
  - D
  - E
  - Thickness tolerance tighter
  - Width tolerance tighter
  - (50,000 psi) min. yield
  - Electrical

**GALV. STEEL EXTRAS (Typical)**

- .015" thick 42" - 48" wide
- ASTM A446 Grade A
- B
- C
- D
- E

(This guideline is based on the 1981 price book of Republic Steel; Some data was taken from Dofasco's price list. Other producers may have different ranges and extras.)
The width tolerance is also a matter of cost. The base price provides relatively loose mill tolerances. Slitting provides an average +0.13 mm (+.005") width tolerance at increased price. Tighter width tolerance can be obtained at a higher price.

c) Thickness

Rules similar to those of the width also apply to the thickness. Different thickness groups have different extra charges for material supplied at standard mill thickness tolerance. If tighter thickness tolerances are specified, extra charges must be paid.

d) Quantity and Inventory

The lowest, so called base price is charged on the "minimum mill order quantity", which can be 18 150 kilogram (40,000 lb.). Smaller quantities can be purchased at higher prices from the mills, steel centres or warehouses. When designing a product which requires a large variety of thicknesses in small quantities such as: base plates, door components of pre-engineered buildings, grain bins, arched buildings etc., it is frequently more economical to specify the heaviest thickness for all small pieces instead of a variety of thicknesses. The extra cost paid for the heavier weight will be offset by all the material handling and the set-up and administration cost of handling one coil or sheet instead of many.

In the case of building panels and most other products, it is advantageous if the designer is familiar with inventory kept in the plant. Selecting identical blank sizes for different profiles can significantly reduce the inventory carrying charges. It costs a company about $350,000.00 for $1,000,000.00 inventory carried for one year. Doubling the usage of a stock material will not double the inventory, but may increase it by only 15-30%.

e) Surface Coating and Corrosion in Manufacturing and Storage

Corrosion protection of the material is dictated by its end use and cost of the product but the designer must know the effect the material surface, coating and corrosion resistance has on manufacturing storage and transportation.

Hot rolled steel is in the lowest price range, but the oxide layer on the HRS is very abrasive, therefore it should be roll formed only with rolls made from the proper tooling material (usually D2). The oxide scale breaking off the steel can also be "messy" and it is not recommended to fabricate HRS material with machines and tools used for pre-painted or other, more surface sensitive materials.

Pickled and oiled material will eliminate most of the problems with the scale, but again, only at extra cost. An oiled surface on coil will greatly reduce the friction, thus tool wear, pick-up and energy required to roll form the profile. Too much oil however, may create a slippage in certain profiles formed by air bending in the mill. The slippage may make rolling difficult or worsen length tolerance.

Oil also retards rusting during storage. Oil must be compatible however with subsequent operations, such as painting or welding and should be
avoided where slipperiness of end product may cause accidents, as in the case of sloped roof sheets and similar applications.

Very little extra precaution is required when fabricating galvanized material. Zinc pick-up on forming rolls can be a problem, but it can be reduced by using the proper lubricant/coolant in the roll forming mill. Tightly nested galvanized sheets and profiles may develop white rust under humid storage conditions. The development of white rust can be eliminated or retarded by using specific oils and/or proper storage conditions. The surface of pre-painted material is more sensitive to scratches and damages than uncoated steel. Therefore, the quality and surface of forming tools must be good. The minimum bending radius of pre-painted material may be larger than the radius of the parent material. Too sharp a radius may crack the paint and white or brown rust may appear along formed edges.

It is impractical and incorrect to specify certain operations, such as spot welding and stud welding, to pre-painted surfaces. Similarly the oxide scale on the hot rolled steel or the zinc on galvanized steel may create problems in case of resistance welding. Plants welding galvanized steel must have proper ventilation to exhaust toxic zinc fumes.

f) Other Material Characteristics

In addition to the yield, tensile and elongation, other characteristics, such as formability, aging, work hardening, weldability, heat resistance, chemical or corrosion resistance and thermal expansion should be checked to avoid unpleasant surprises.

g) Changing Material Specifications

The cost of steel, aluminum and other metals is traditionally based by the mills on their own manufacturing costs, demand, and market conditions. Fluctuation in raw material, energy and labour costs, general economic conditions and inflation, changes in technology and demand, force the mills to change prices time to time. Therefore, in a progressive metal fabricating company, the material specifications and inventory must be constantly reviewed, not only by the purchasing, inventory control and plant personnel, but also by the designer.

Cooperation between these groups will assure that the products are always manufactured from the most competitive, lowest priced starting material.

LABOUR CONTENT OF THE PRODUCT

When a product is designed, the conversion or labour cost of the goods is frequently overlooked. This may stem from the fact that material weight and cost can be easily calculated but it requires considerable experience and shop knowledge to estimate the man hour/piece, unit length or unit area.

The ratio of labour to material costs depends on the type of product and the manufacturing method. Typical examples of labour content are shown in Table II.
TABLE II

<table>
<thead>
<tr>
<th>Section</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;C&quot;, &quot;Z&quot; Sections Culverts</td>
<td>5-7%</td>
</tr>
<tr>
<td>Roofing, Siding</td>
<td>9-12%</td>
</tr>
<tr>
<td>Grain Bins</td>
<td>14-16%</td>
</tr>
<tr>
<td>Storage Racks, Shelving</td>
<td>25-40%</td>
</tr>
<tr>
<td>Lockers, Office Furniture</td>
<td>40-50%</td>
</tr>
</tbody>
</table>

The figures shown on Table II are rough estimates only and may be increased or decreased depending on conditions. Some minor factors, such as the "nestability" of the product have such an impact on cost that they can influence the designer when section is finalized. Nestable panels and decks can be manufactured at full roll forming mill speed, while non-nestable profiles (where every second piece must be turned $180^\circ$ at the run-out table) may run at 60% of full speed. If separating blocks are placed manually between panels then the production speed may be reduced to 25% and the labour cost increased accordingly. Since material is available for more or less the same price from competitors, the saving in labour can be very significant. The early design stage is the best time to consider all manufacturing cost elements, including set-up times, rolling speed, maximum and minimum lengths, widths, method of handling, maximum weight, and others. Some minor items, such as piercing additional holes for drainage or hanging on the paint line, or adding dimples to separate painted sections during drying may not require any extra labour or material but can save considerable labour in the subsequent operations. Therefore, it is highly recommended that the designer consult personnel involved in purchasing, manufacturing, handling and assembling of the product at the early stage of the design. It is easy to modify, add or eliminate certain things on paper, but it can be costly or impractical after tools are made, equipment is purchased, and production is started. A careful approach results in lower manufacturing cost, thus the success of a product frequently hinges on these minor modifications which have nothing to do with the basic design requirements.

DESIGN OF PRODUCT

The primary objective of a designer, especially a structural designer, is to meet with structural load and safety requirements, and regulations at the lowest possible cost. The design will be influenced by appearance and quantity requirements and restricted by the availability of material, manufacturing technology, equipment, tooling, manufacturing and storage space, skill of manpower, means of transportation, and other local requirements. The approach to the product and the appearance is frequently influenced - for better or worse - by marketing/sales personnel or by the supervisor of the designer and other people in the company.

In the following paragraphs however, only the influence of manufacturing technology, tooling and equipment will be described in detail.

FORMING

Products made out of sheet metal are usually formed during the manufacturing process. Forming can be achieved in many different ways but in practice cold forming is usually done in presses, brakes and roll formers.
The differences in the equipment and tooling and the stresses created in the metal during forming provides advantages and creates limitations for each process. To achieve the best result, it is frequently advisable to design the product for a specific process and/or equipment and tooling. Changing the technology for a given product, say, changing from brake forming to roll forming, usually does not create a problem. In many cases, however, it is advisable to make some modifications to minimize difficulties during manufacturing and/or utilize all the advantages provided by the roll forming method.

It is not within the scope of this presentation to describe all effects the forming has on design, but examples cited below will highlight a few important but frequently overlooked points when products are roll formed.

1. **Bending Radius**

The minimum bending radii for different combinations of material thicknesses and qualities are available in numerous tables. The corner radii of the inner forming rolls usually are made to match the specified minimum radii.

Rolls designed for a specific profile usually must serve for more than one thickness of material. The roll design is based on the thickest material, to provide adequate space between top and bottom rolls. The mill operator compensates for the thickness difference by adjusting the top shaft up or down, thus the varying gap between top and bottom rolls (see Figure 1).

Gaps between the rolls which are not horizontal can also be changed by placing or removing shims between the split rolls. However, this procedure takes a considerable amount of time and, therefore, in most cases it is either not practiced or it is restricted to minimum usage.

For siding, roofing and structural components it is preferred to leave the shims unchanged or, if dimensions are critical, they may be changed in the final two - three passes. Shimming in the last passes may also be required for spring-back adjustment when materials with a wide spread in their physical characteristics are formed.

Proper dimensioning of the profile drawings is a great help to the tool designer. The dimensioning and tolerances should take into consideration the forming method, need for thickness compensation by adjusting upper shafts and/or axial shimming. Figure 2 gives the recommended method for dimensioning a flute or cell and Figure 2b shows why the thinnest material will have practically the same inside radius as the thickest one. For designing light gauge sheet metal products the bending radius required for the thickest material shall be specified for all thicknesses. A typical example is shown below for material where the minimum inside bending radius is restricted to two times the thickness of material.

Max. Panel Thickness .075" (1.9 mm) R= .15" (3.8 mm) or R= 2 t

Min. Panel Thickness .020" (0.5 mm) R= .15" (3.8 mm) or R= 7.5 t
TOP ROLLS

Gap Between Rolls is Designed for the Thickest Material to be Rolled

FIGURE 1a

Top Rolls are Moved Down for Thin Material (This Action Takes Little Time)

FIGURE 1b

Top Rolls are Moved Down and Shifted Sideways by Changing Shimms (Adjustment Takes Considerable Amount of Time)

FIGURE 1c

Adjusting Top Rolls to Suit Various Material Thicknesses

FIGURE 1

Effect of Top Roll Adjustment on Formed Shape

FIGURE 2

Effect of Top Roll Adjustment on Formed Shape
This data can be critical when strength, web crippling or other characteristics are calculated. When forming high strength-low elongation material, such as ASTM A466 Grade E, or unannealed, the minimum bending radius should be larger. Following the above example the .020" (0.5 mm) thick Grade E material will have a bending radius of 15t or .30" (7.5 mm).

The tool designer should be informed of the physical characteristics of all possible materials to be formed. It is more important to know the anticipated actual maximum yield and other characteristics than the specified minimum in the standards. The formability of the material is related to its physical properties and influences the number of passes required for proper forming.

Unannealed steel with approx. 80,000 psi (550 MPa) and 2% - 4% elongation (ASTM A446 Grade E) usually cannot be formed with tooling designed for material with maximum 45,000 psi (310 MPa) yield and 20% elongation. If rolled, the material may exit the mill slit at each bending line. On the other hand, all lower yield, higher elongation materials can be formed with rolls designed for high strength material.

At first glance this restriction could call for all rolls to be designed for high strength material. However, this would require, in most cases, larger bending radii and more stands resulting in higher tooling costs.

Roll form designers prefer to work with reasonably tight radii which helps to "set" or stabilize the profile. Forming very large radii, as shown in Figure 3, takes only one or very few passes but it does not "set" the material. It results in limited permanent deformation, and, therefore, it is difficult to keep the shape and dimensions.

![Figure 3](image_url)

It is Difficult to Maintain Shape with Large Radius/Thickness Ratio

FIGURE 3
2. **Width of Non-Formed Sections**

Too wide or too narrow unformed elements between the first bend line and the edge of the strip, or unformed sections between two bend lines can create problems. Figure 4 shows the simplified path of the strip edge while roll formed to 90°. During the forming operation the original "L" long edge must stretch by "e" to keep continuity. Once the edge is in the 90° position, it will run parallel to the bend line. To have the same length as the bend line the stretched edge must contract back to its original length. There will be no visible effect if the elongation which occurred during the forming process is within the elastic limit. However, if the "H" is too high and/or the "L" is too short the edge may be permanently elongated. In this latter case the edge will remain longer than the bend line resulting in a "wavy" edge (see Figure 6). The wavy edge can be eliminated or the waviness can be minimized by keeping the leg short, or by introducing an additional bend line close to the strip edge, as shown in Figure 7, and/or utilizing more passes for forming. The additional bend line can also help in the case of coils shipped with a wavy edge by the mills.

![Edge of Strip Elongates During Forming](image-url)
A distance between the edge and the nearest bending line that is too short may create forming problems (see Figure 5). For easy formability the length of the "leg" is preferred to be six times the material thickness (6t) or at least 4t.

It is Tough to Form Short "Leg"

FIGURE 5

Wide Edge Bent Up or Down will be Frequently Wavy

FIGURE 6

Waviness Can Be Avoided by Adding Bend Lines Close to the Edge

FIGURE 7
The width of the "leg" may become too narrow or too wide during the rolling because of a variation in set-up, "wandering" or moving of the coil, or change in strip width.

A panel with six cells or flutes will have 12 segments that are almost vertical. A .010" (0.24 mm) change in the height due to tightness or looseness of upper shafts could result in an approx. .120" (3 mm) change in blank or strip width. This change will influence the width of the "leg".

The coils are usually guided in the roll forming mill by edge guides. Changing the location of the coils or telescoping coils, the position of the guide or camber in the coil will move the centre line of the coil to the left or right thus making one edge wider and the other one narrower.

Slit edge coils usually have a tight width tolerance (+.005" or .13 mm) but mill edge coils may have a wide range of tolerances. Most wider coils are purchased with a mill edge because slitting represents a substantial extra cost. The fluctuation in blank size or change in the relative location of the edges may create other problems. Some examples are shown in Figure 8. A long leg may create problems in the forming process, deformed lock seam or difficulties with erection. A short edge distance can cause other problems or a lack of strength.

![Diagram of coil with "legs" showing good, short, and long configurations.]

Too Short or Too Long "Legs" May Create Assembly or Erection Problems

FIGURE 8
The leg length can be tightly controlled with a special, but more expensive roll design shown on the right hand side of Figure 9. This process requires tight width tolerance and offers less flexibility.

The ratio between the depth and width of the cell as a function of material thickness should always be considered when the profile is designed. Relatively thin, unsupported rolls may break frequently when forming narrow and deep flutes (see Figures 10a and 10d). Forming thicker and/or higher strength materials results in higher pressure and increases the probability of roll breakage.

Production of narrow but shallow grooves or offsets as shown in Figure 10b does not usually create problems. When the stiffener rib is close to the edge of the roll, the slenderness of the roll should be taken into consideration (Figures 10c and 10d).

Not Confined (Left) and Confined (Right) Rolling of "U" Channels

FIGURE 9
Leaving a relatively wide strip between two bend lines does not usually present any problem in roll forming but the appearance of the finished panel can be poor. A large percentage of the commercially available coiled products are not completely flat but have either a wavy edge or a wavy centre, the latter one described as "full centre" or "oil canny appearance". These imperfections are induced during the rolling process at the mill and cannot be removed by straighteners or levellers. Roll forming may minimize the effect by distributing the ripples but there is a good chance that the "oil canny" effect will show up in webs wider than 6" when light gauge material is roll formed. Glossy surface and paint will accentuate this unsightly effect which is shown on the left side of the panel drawn in Figure 11. The right hand side of the same panel shows a typical groove stretched into the material to break the surface into smaller segments and disipate the waviness. Embossing or the occasionally used cross-ribbing also alleviates the effect of the "oil canniness".
3. **Limitations of Section Height**

The distance between the top and bottom shafts is called the vertical centre distance. Most roll forming lines have a limitation on the distance the top shaft can be lifted.

In the case of spur gears or "fixed position" design, the top shaft may not be lifted at all.

If the upper shaft is driven with long addendum gears, depending on the design, the top shaft may be lifted up to $1/8"$ or $3/16"$.

A linkage system in the gears, depending on the make, type and size of the roll forming head, will allow lifting the upper shafts by approx. $3"$ to $6"$.

The largest vertical adjustment is feasible with forming mill stands driven by a separate gear box and shafts with universal joints, or shafts driven by individual motors or when the top shafts are not driven at all.

To explain the significance of the vertical distance let's take an example illustrated in Figure 12.

![Diagram showing vertical centre distance and limitations for section height.](image)
Example:

Max. Vertical Distance: $v = 8''$ (203.0 mm)
Shaft Diameter: $d = 3''$ (76.2 mm)
Spacer Thickness: $T_s = .25''$ (6.3 mm)
Width of Profile: $W = 3''$ (76.2 mm)
Width of Leg: $L = 1''$ (25.4 mm)

Question: Is it possible to fit the 3'' wide "C" channel into the roll former?

Calculation:

- Top Shaft Half Diameter: $1.25''$ (32.0 mm)
- Thickness of Spacer: $0.25''$ (6.3 mm)
- Space Between Profile and Spacer (to allow bending of up leg): $0.162''$ (4.1 mm)
- Profile (out to out max.): $3.0''$ (76.2 mm)
- Bottom Roll Minimum Thickness: $1.0''$ (25.4 mm)
- Bottom Shaft Half Diameter: $1.25''$ (32.0 mm)
- TOTAL (vertical distance required): $6.912''$ (176 mm)

Answer: The vertical distance will not prevent the forming of the specified "C" channel in the mill. However, to form a "Z" section with the same width and length would require a mill with a maximum vertical shaft distance of approx. 9.33'' (237 mm) (calculation now shown), and will not fit in a mill with 8'' max. vertical center distance.

4. Forming Angles

Due to the nature of the roll forming method it is relatively easy to form shapes up to or close to 90°. To form multiple bend lines in a panel over 90° is more complicated and would require additional side stands or other methods (see Figure 13). However, bending over 90° in special shapes made from narrower widths is very common. Some typical examples are shown in Figure 14.

![Effect of Forming Angles on Rolling Wide Panels](image-url)
Complicated Shapes with Variety of Angles and Radii Can Be roll Formed

FIGURE 14
5. **Continuity of Bend Line**

It is accepted by every designer that bend lines increase the strength of a flat sheet but the weakness introduced by the discontinuity of the bend line is frequently forgotten.

Figure 15 illustrates a few examples where, by design or by incorrect forming, the straight bend line is discontinued or damaged.

Figures 15a to 15f represent a panel with longitudinally rolled ribs formed into cross crimped material. The bend lines of the previous cross crimping cannot always be "ironed out" and shows up as a "bump" on the bend line. The design also introduces other problems, such as elongating the panels along the ribs which the centre part remains close to its original length.

A similar problem can occur when a panel "cross-ribbed" in prior operation is roll formed with a longitudinal bend line going over the cross-ribbing as shown in Figure 15b.

Embossing the flat material for composite deck purposes is common. If the embossing is not properly lined up with the bending lines (see Figure 15c) a similar effect to the one shown in Figure 15a can happen.

In the case of a prefabricated metal building panel for curved buildings, the original bend line was straight but the improper method of curving destroyed the continuity of the bend line resulting in reduced strength of the entire building. By improving and modifying the edge condition in the curving die the strength of the panel was improved by close to 40%.

The left part of Figure 15e illustrates a typical acoustic panel. The perforation in the web barely influences the strength of the deck. However, forming a fully perforated panel with holes at the bending line, as shown on the right hand side of the same figure, may reduce the strength by 70%! Drainage holes in the decoratively perforated stainless steel can contribute to the buckling of shelves in refrigerated supermarket displays or punched out holes at the bend line may induce a weakness in the upright of a storage rack (see Figure 15f).
6. Profiles Manufactured in Different Sizes

To meet different load or other requirements economically the designer frequently has the option to select from shapes made in different thicknesses and in a variety of sizes. The tooling cost to manufacture a profile in more than one size varies from practically nothing to the cost of a full set of tooling for each size.

The designer of the roll formed profile greatly influences the tooling and production costs by specifying the right, variable dimensions before the tool design starts. For example, different diameters of corrugated spiral pipes can be produced by simply changing the entry angle of the strip without additional tooling. A 36" (914.4 mm) wide building profile can be converted to 900 mm (35.43") metric coverage for practically no extra tooling cost if the rolls are split at the right place and an insert prepared when the roll set is made. The length of the legs of a "U" channel can be varied within a certain limit by varying the blank size when roll formed with conventionally designed rolls shown on Figure 9a.

In the case of "C" channels, which is basically a "U" channel with legs bent inwards, the above mentioned change cannot be achieved so simply because the inward facing legs are usually formed in the early passes, restricting size changes in the subsequent passes. However, multiple widths of both "U" and "C" channels can be easily manufactured within certain limitations by changing the position of rolls, as shown in Figure 16. Figure 17 illustrates this principle for both "C" and "Z" sections. Changing the "W" dimension shown in Figures 17a and 17c does not require additional rolls and frequently both types of sections are rolled with a combination set of dies. Changing the "H" dimension indicated in Figures 17b and 17d requires a complete set of tooling for each size. Extra cut off dies or cut off die insert would be required for all different sizes regardless of whether the "W" or "H" dimension is different.

The forming of a "C" channel is a symmetrical process, bending both legs upwards while the rolling of a "Z" channel is an asymmetrical process because one edge of the strip is forced up and the other one down during forming (see Figures 18a and 18b). The forcing of one leg up and the other down induces stresses into the finished "Z" section resulting in a twist of the finished product. To eliminate or minimize this "twist" and keep the edge of the strip at about the same height, the roll designers prefer to shape the "Z" section at an angle as shown in Figure 19.

The forming of the "Z" section at an angle does not lend itself for width adjustment and each size of section requires a separate set of rolls. Therefore, this method is usually used only in the case of large run quantity requirements.

Table 11 provides the price ratio of rolls, using the price of tooling for one size of "C" channel as one.

Time and space does not permit to detail other influencing factors such as the effect of pre-cutting or post-cutting, set up time, operator's skill, or to list other examples in storage racks, prefabricated buildings, etc.
Width of "U" Channel can be Changed by Exchanging Rolls on the Shaft

FIGURE 16
One Set of Rolls can be Used To Manufacture Sections with Variable "H" (Fig. 17a and 17c) but Separate Set of Rolls are Required for each Different

FIGURE 17

Symmetric and Asymmetric Forming

FIGURE 18
**TABLE 11**

Relative Cost of Roll Sets for Different Size and Shape Combinations  
(approximate guide only)

<table>
<thead>
<tr>
<th></th>
<th>&quot;C&quot; Section</th>
<th>&quot;Z&quot; Section</th>
<th>Total No. of Sections</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>Single Set of Rolls</td>
<td>10&quot;</td>
<td>1</td>
<td>1.0</td>
</tr>
<tr>
<td>b</td>
<td>Single Set of Rolls</td>
<td>10&quot;</td>
<td>1</td>
<td>1.05</td>
</tr>
<tr>
<td>c</td>
<td>Adjustable Rolls</td>
<td>8&quot; 10&quot; 12&quot;</td>
<td>3</td>
<td>1.10</td>
</tr>
<tr>
<td>d</td>
<td>Adjustable Rolls</td>
<td>8&quot; 10&quot; 12&quot;</td>
<td>3</td>
<td>1.20</td>
</tr>
<tr>
<td>e</td>
<td>Combination Set</td>
<td>8&quot; 10&quot; 12&quot; 8&quot; 10&quot; 12&quot;</td>
<td>6</td>
<td>1.35</td>
</tr>
<tr>
<td>f</td>
<td>Rolls Forming at Angle</td>
<td>10&quot;</td>
<td>1</td>
<td>1.0</td>
</tr>
<tr>
<td>g</td>
<td>Rolls Forming at Angle</td>
<td>8&quot; 10&quot; 12&quot;</td>
<td>3</td>
<td>3.0</td>
</tr>
</tbody>
</table>

*FIGURE 19*
Another example is the grain bin side sheets, rolled in the thickness range of .025" - .135" (0.65 mm - 3.4 mm) and curved to radii 3' - 50' (0.91 m - 15.2 m) without extra tooling cost. However, the variation in hole pattern requires serious consideration. The cost of a piercing die to punch all holes in one hit may be in the $25,000 - $30,000 range. Depending on design, one company can pierce all grain bin and feed tank sheets with one die, another needs over 15 such piercing dies.

7. Secondary Operations

Many products are used, applied or erected as rolled only, but the largest percentage of them require additional manufacturing operations. The shaping of the profile during roll forming is usually called primary operation and all others are referred to as secondary operations.

The secondary operations are:

- Piercing
- Notching
- Lancing
- Stitching
- Stitching
- Louvering
- Mitreing
- Slitting
- Cutting
- Embossing
- Bending
- Curving
- Marking
- Coining
- Arc Welding
- Resistance Welding
- Adhesive Bonding
- Painting
- Caulking
- Interleafing
- Etc.

All these operations may be performed separately, before or after roll forming. In practice the handling of each piece individually, at each operating station requires considerably more production time than needed for the highly productive roll forming.

Combining the above operations in the roll forming line can eliminate or minimize the manufacturing and material labour cost required for the secondary operations and eliminates extensive in-between operation storage space.

To demonstrate the influence of the manufacturing or dimensioning and tooling cost method the possibilities of manufacturing "C" channels will be discussed in detail.

The "C" channel with end holes only or with holes in-between the end holes (see Figure 19) can be manufactured in the following sequence:

- pre-cut, pre-pierce, ROLL FORM
- pre-cut, ROLL FORM, post-pierce
- PRE-CUT, ROLL FORM, post-pierce
- ROLL FORM, CUT, post-pierce
- ROLL FORM, CUT, PIERCE
- PIERCE, ROLL FORM, CUT
- ROLL FORM, PIERCE IN THE CUT OFF DIE, CUT TO LENGTH
- ROLL FORM, PIERCE AND CUT IN ONE HIT DIE

Note: Operations performed in the roll forming line are noted in capital letters.
The length tolerance on the product ("L") will depend on the accuracy of the pre-cutting operation or on the accuracy of the roll forming mill. The tolerance on the hole distance ("H") will depend on the method of piercing, gauging and the number of holes pierced in one hit.

If the endholes are pierced with punches incorporated into the cut off die then the hole distance from the edges (distances marked as "e" and "f" in Figure 19) will be very accurately held but the tolerance on the end hole to end hole distance (dimension "H") depends on the length tolerance capability of the roll forming line.

If all holes are pierced in one hit before or after forming the tolerance on hole distances can be kept within .005" (0.13 mm). The method of piercing holes between the end holes will similarly influence the tolerance. If all holes are pierced from gauging one end then the drawing should be dimensioned accordingly. If holes are pierced in the cut off die then dimensioning and tolerances will be different. This little example indicated the interaction between dimensions and tolerances, manufacturing method and the cost of manufacturing equipment capable of producing goods to the dimensions and tolerances specified on drawings.

PREPARATION OF DRAWINGS FOR MANUFACTURING

The product design, after all the calculations and consultation with plant personnel, tool designers, and other groups must be displayed in the form of drawings. The drawings should be easily understandable "instructions" to the plant, regarding what, and often how, to manufacture the product. All information required to make product should be on the drawings without ambiguity.

The method of dimensioning and applying tolerances is governed by the manufacturing method. The method of dimensioning should match the method of gauging and measuring the product. Tolerances must be realistic. Unnecessarily tight tolerances lead to increased manufacturing cost and scrap. The manual recalculating of dimensions, by the machine operator, to suit the manufacturing method is a waste of time and can lead to errors.

It is the responsibility of the designer that drawings prepared by draftsman or by computer be carefully checked. In both cases, the drawings must be "shop oriented". In a progressive organization, drawing of the products may be revised to suit improved manufacturing methods or equipment. Material specification may also be changed if cost reduction warrants it. Care should be taken however, not to make "final" revisions if changes are temporary, caused by breakdown of equipment or lack of specified material. The frequent argument between plant and design engineering on reporting back errors or making suggestions by marked up drawings can be easily avoided by using proper forms and procedures.

The designer's opinion is not always asked when a company decides to enter into manufacturing of new products under licence agreement or takes over manufacturing products from other plants. Designers should however, review all drawings to see that they suit local manufacturing plant equipment, methods and tooling. Just because the previous manufacturing plant rolled a product, let's say on a 50.8 mm (2") shaft diameter mill, to a certain length tolerance doesn't mean that a 50.8 mm (2") shaft diameter mill in the newly appointed plant can do the same job. Maybe the shafts are twice as long, therefore deflection will be about 4 fold. Maybe the horizontal centre distances are too short. Maybe it has a different length
measuring system and cannot cut the product to the same tight tolerances. It also can happen that the line at the new plant can pre-pierce holes that the original plant could not. All of these changes require modification to the drawings. Not making changes may reduce productivity as much as 50% thus reducing the chances of competitive introduction of new products.

ERECTION AND ASSEMBLY

As most of the formed products are either assembled in the factory or erected in the field, it is very important to consider all possible avenues for saving. A small taper or radius at the end of the section, direction of burr, or a one or two degree change in the angle can make a significant difference during assembly or erection. Sections have been designed, tooled up and fabricated just to have it realized on the job site that tools cannot reach the desired locations. Other products are too confirmed for welding, bundles of roof decks could not be separated in the field, barn roofing could not be nailed. Closed sections of some products collect liquid during chemical treatment in the paint line and cannot be drained. Hundreds of actual examples prove that most of the problems can be avoided and product cost reduced when the designer takes the complete process into consideration from raw material purchase to the final stage of assembly.

CONCLUSION

Practical examples cited in this presentation are intended to prove that, in addition to the strength and dimensional requirements, a designer should also consider other influencing factors, such as formability, cost and availability of material, capacity and cost of manufacturing equipment, flexibility in tooling, material handling, transportation, assembly and erection. The cost of the product and its final success is often dependent upon the designer's foresight when the shape and manufacturing process is determined. Good communication between the product designer, manufacturing personnel, tool designer, material handler, erector, salesman and/or customer is critical and important to achieve the best combination of product function and price.