Field Realignment of Deformed Steel Reinforcing Bars – A Review

Introduction

In construction and research it is easy to lose sight of the fact that there are numerous compromises that must be made to maintain the balance between economy and safety. Field realigning, bending, and straightening (reworking) of steel reinforcing bars in the field is one example. Realigning and reworking of steel reinforcement in the field is not uncommon. For example, the proper alignment of steel reinforcing bars into their final position, as specified by the Structural Engineer, is a common practice by Ironworkers. Under normal circumstances, little thought is given to this activity. In contrast, bending and straightening steel reinforcement is not quite as common but an appreciation of the activity is warranted.

This Technical Note addresses this issue by reviewing the fundamentals, research reports, articles, and codes and standards requirements. For reference, Appendix A presents the bending and straightening guidelines or procedures of the ACI 318-11 Building Code [2011], ACI 301-10 Specifications [2010] and CRSI’s Manual of Standard Practice [2009].

Steel Reinforcement Properties

An understanding of strain hardening and strain aging of steel, and the stresses associated with the bending of deformed reinforcing bars, is in order. There are, in fact, considerable differences in the appropriate precautions that need to be taken when realigning and reworking reinforcing bars.

Steel reinforcing bars are hot-rolled and are not, as might be assumed by some, a highly machined steel component. Steel reinforcement is a commodity product sold by the ton and produced from recycled steel. Steel reinforcement is an economical construction material with the necessary properties and qualities for its intended purpose proven by use and a large body of research over the last 125 years. On this basis, ASTM A615/A615M [2013b] specifies the bar size, deformation geometry, minimum yield strength and tensile strength, and that the bars are to be bent around pins of specified diameters. ASTM A706/A706M [2013c] has many similar requirements to A615/A615M bars but has tighter mechanical properties (a maximum limit on the yield strength, higher elongation requirements and tighter bend tests). Therefore, ASTM A706/A706M steel reinforcing bars has superior ductility characteristics and is commonly specified in high seismic regions.

Prior to reviewing test data associated with realigning and reworking of steel reinforcing bars, one should be familiar with the concept of cold working or work hardening, and strain aging of steel. Depending on the specific context, work hardening of steel may or may not be desirable. Cold working or work hardening is altering the shape of a piece of metal by plastic deformation and is normally done through rolling, drawing, pressing, spinning and extruding. The work is performed on the metal at a temperature below the point in which the crystalline structure of the metal can reorganize. This means that the metal being worked has been deformed past the elastic limit and thereby exceeded the yield stress such that plastic deformations occur. At the atomic-crystalline level, when plastic deformation occurs, the bonds between the atoms are shifted so that when the load is removed the atoms cannot return to their original locations. If the cold working remains in the elastic range the atoms can shift back to the original location. When plastic strains or deformations occur the inter-atom bonds break and the atoms are re-arranged. This re-arrangement is called dislocation (see Wikipedia [2014]). This re-arranging of the atoms effectively increases the hardness and tensile strength of the steel while the ability of the steel to deform plastically before fracturing is decreased (see About [2013]). This loss in the ability of the metal to deform plastically is described as a “loss in ductility” or “work hardening.”

Strain aging or embrittlement is another phenomena associated with steel that has been cold worked. As the term implies, if steel is cold worked, then over time and depending on the temperature, the
ductility of the steel decreases and the yield strength and tensile strength increases. This is called strain aging or embrittlement. Strain aging occurs because some of the carbon and nitrogen atoms remain available in the crystalline structure and migrate to the dislocation area because of the cold working. The carbon and nitrogen atoms then “glue” the crystalline structure such that the yield strength and tensile strength increases (hardens) and ductility decreases. This increase in hardness results in an even higher yield strength than the original cold working causes. Heating cold worked steel to temperatures from 300 to 700°F [150 to 370°C] accelerates the phenomena of carbon and nitrogen movement to the dislocation sites without the temperature being high enough to allow the crystalline structure to reset or to reorganize. Heating the cold worked steel to above 1000°F [540°C] allows for the crystal structure to reorganize into strain-free grains.

The phenomena associated with steel, cold working and strain aging, are present in all steel and has been known for a long time. Consider the ancient sword smith working the initial shape of the sword to a red hot condition and then cold working the sword with a hammer to impart high tensile strength and hardness as it cools. A recent study by the Center for Advanced Technology for Large Structural Systems at Lehigh University notes that all structural and bridge steel are subject to strain aging (Pense [2004]), though it must be added that the micro-alloying elements of titanium (Erasmus [1981]) and vanadium (Mitchell) are reported to slow down the rate and magnitude of strain aging.

**Bending**

Bending is another topic that is not as straightforward as one might believe. One significant related to bending is that the bend tests as specified by ASTM A615/A615M and A706/A706M do not correspond to an actual strength property requirement or structural characteristic needed for the reinforced concrete structure. The ASTM bend test does not reflect a characteristic or quantitative quality necessary for the structure, but merely substantiates that the bars are capable of being bent for fabrication.

Another issue is the bend test itself. The ASTM specification for the testing of all steel products, ASTM A370 [2013a], states in Section 15.1:

“The bend test is one method for evaluating ductility, but it cannot be considered as a quantitative means of predicting service performance in all bending operations. The severity of the bend test is primarily a function of the angle of bend of the inside diameter to which the specimen is bent, and of the cross section of the specimen. These conditions are varied according to location and orientation of the test specimen and the chemical composition, tensile properties, hardness, type, and quality of the steel specified.”

Similar to ASTM A370, CRSI’s *Reinforcing Bar Testing* [1989] notes that there can be complications in performing a bend test. It is noted that there is no standard testing machine which allows for the various pin diameters, which range in size from 1-1/8 to 20-1/4 inches [29 to 514 mm] in diameter. In practice the bend test as specified by the ASTM reinforcing bar specifications is conducted on a bend test machine or on a production bender. The CRSI publication adds that it is important that all pins come in contact with the bar, that there is no friction developed along the length of the bar — meaning that the pins are free to rotate — and that no section of the bar containing mill markings should be bend tested. Note that due to springback, a 90° or 180° bend test has a final bend angle slightly less than 90° or 180°, respectively.

Over the years, other issues related to bending and the breakage of bars has been reported. One issue is that since the ASTM A615/A615M specification does not require a specific material toughness (e.g. Charpy V-notch test), the toughness of steel reinforcement is normally low (Kusinski and Thomas [2005]) relative to other types of steels. It is thought, because the steel has a low Charpy value, that if any highly localized or sudden stresses are induced during the bending procedure, then the bars may exhibit brittle behavior. Another issue related to the bending of bars with deformations is that the inside radius of a bent bar actually has residual tensile stresses rather than compression stresses, because of springback or rebound. The tensile stress then exacerbates any localized flaws that may be present along the inside radius — particularly at the root of the deformations.

**Chronological Review of Research Studies and Articles**

Starting in the early 1970s, the issue of realigning and reworking of steel reinforcement received considerable attention as numerous in-depth studies were conducted and related articles published. Some of the conclusions drawn by the authors and investigators diverged from one another, resulting in increased confusion. Since the early 2000s, little additional work has been done in this area. However, from time to time, this issue does arise due to a difficulty in the field or interpretation of codes and specifications.

**Black, 1973**

In 1973, the first of many papers was published on this subject by William Black of Bethlehem Steel Corp (Black [1973]). His paper discussed the re-working of two grades of ASTM A615/A615M steel reinforcement. Black noted that there were various reasons for re-working of steel bars in the field, which included incorrect placement, accidental misalignment and even a design change. Black noted that the ACI 318-71 Code [1971] prohibited bars that were embedded in concrete from being bent without the engineer’s authorization and that
the temperature specified in the 1971 Code was
recognized by Bethlehem’s metallurgists as being
too low (strain aging). Black suggested that tem-
peratures in the range of 1100 to 1200°F [590 to
650°C] would be better. Black also recommended
that if the portion of steel being heated was within
6 inches [150 mm] of concrete that protective mea-
sures be taken (wet rag, C-clamp or vise grips). See
Tables 1, 2, and 3 for tension test results.

Lalik and Cusick, 1979

In 1979, Lalik and Cusick published a paper
(Lalik and Cusick [1979] that discussed test
results on #8 [#25] bars that were bent cold
and then cold straightened. The bends were
made by machine and by hand in a jig, which
was intended to represent a bar embedded in
concrete. Their primary message was that if
bars can be straightened without preheating,
cutting, or welding then significant costs could
be avoided. The authors noted that there were
gaps in what the ACI 318-77 Building Code
[1977] specified for realigning and reworking
since it did not technically address straight-
ening or correcting embedded bars. Many of
these details were left up to the Engineer. ACI
318-77 Commentary addressed bending cold
or with preheating and noted that preheated
bars could be straightened successfully but did
not specifically prohibit bars from being bent
cold. The Lalik and Cusick report noted that the
number of times a bar may be bent was not ad-
dressed in ACI 318-77, though once is implied.

Lalik and Cusick argued that field bent bars
should not be a concern so long as the mini-
mum bend radius per ACI 318-77 was met.
The actual statistical chance of failure by cold
straightening may be similar to reworking pre-
heated bars. Their other argument is that since
it is acceptable to cut and weld a bar then if
it does break during straightening operations
the remedial action can take place anyway.
They noted that even if there is a region of cold
worked bar, this would represent a small por-
tion of the overall bar length.

For this study a total of 122 #8 [#25] specimens
were bent, cold-straightened and tested to failure
to determine yield strength, tensile strength and
elongation (ductility). The bars were bent to 45°
and 90° with varying diameters in a machine and
jig. Two heats of steel were used.

The test results were:

- No cold-straightened bars broke;
- There was no difference between the “jig”
bent and machine bent either at 45° or 90°;

### Table 1 — Tension Test Results

<table>
<thead>
<tr>
<th>Size</th>
<th>Original Yield Strength, psi</th>
<th>Original Tensile Strength, psi</th>
<th>Final Yield Strength, psi</th>
<th>Final Tensile Strength, psi</th>
</tr>
</thead>
<tbody>
<tr>
<td>#11</td>
<td>66,000</td>
<td>103,200</td>
<td>61,500</td>
<td>99,200</td>
</tr>
<tr>
<td>#8</td>
<td>71,300</td>
<td>110,100</td>
<td>73,500</td>
<td>114,000</td>
</tr>
</tbody>
</table>

Black [1973]

### Table 2 — Test Results on Grade 40 Bars

<table>
<thead>
<tr>
<th>Bar Size</th>
<th>Condition*</th>
<th>Yield Point, psi</th>
<th>Tensile Strength, psi</th>
<th>Elongation 8 in., percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>#10</td>
<td>A</td>
<td>41,300</td>
<td>74,500</td>
<td>22.5</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>40,800</td>
<td>73,700</td>
<td>21</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>39,100</td>
<td>72,600</td>
<td>19</td>
</tr>
<tr>
<td>#10</td>
<td>A</td>
<td>44,100</td>
<td>77,400</td>
<td>24</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>46,500</td>
<td>72,200</td>
<td>24</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>44,100</td>
<td>75,600</td>
<td>20</td>
</tr>
<tr>
<td>#11</td>
<td>A</td>
<td>44,900</td>
<td>78,500</td>
<td>19.5</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>44,200</td>
<td>76,800</td>
<td>18.5</td>
</tr>
<tr>
<td>#11</td>
<td>A</td>
<td>45,600</td>
<td>75,300</td>
<td>23</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>44,500</td>
<td>74,600</td>
<td>21</td>
</tr>
<tr>
<td>#11</td>
<td>A</td>
<td>49,600</td>
<td>86,300</td>
<td>19</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>50,000</td>
<td>85,900</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>49,400</td>
<td>86,500</td>
<td>16</td>
</tr>
</tbody>
</table>

Black [1973]

A = As rolled
B = As rolled, bar heated to 1100 F and air cooled
C = As rolled, bar heated to 1100 F, free bend to 45 degrees, straightened,
and air cooled
D = As rolled, bar bent (cold) to 45 degrees around 6d pin, heated to 1100 F,
straightened, and air cooled

### Table 3 — Test Results on Grade 60 Bars

<table>
<thead>
<tr>
<th>Bar Size</th>
<th>Condition*</th>
<th>Yield Strength, psi</th>
<th>Tensile Strength, psi</th>
<th>Elongation, percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>#11</td>
<td>A</td>
<td>69,900</td>
<td>107,100</td>
<td>14.0</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>66,700</td>
<td>104,500</td>
<td>16.0</td>
</tr>
<tr>
<td></td>
<td>C**</td>
<td>67,100</td>
<td>102,600</td>
<td>7.5</td>
</tr>
<tr>
<td>#11</td>
<td>A</td>
<td>73,200</td>
<td>111,500</td>
<td>15.0</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>67,900</td>
<td>107,300</td>
<td>15.5</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>Bar broke in straightening</td>
<td></td>
<td></td>
</tr>
<tr>
<td>#10</td>
<td>A</td>
<td>70,600</td>
<td>105,800</td>
<td>15.0</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>65,000</td>
<td>103,900</td>
<td>11.0</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>64,900</td>
<td>88,200</td>
<td>3.0</td>
</tr>
<tr>
<td>#10</td>
<td>A</td>
<td>78,000</td>
<td>115,700</td>
<td>10.5</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>72,100</td>
<td>111,000</td>
<td>12.0</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>Bar broke in straightening</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Black [1973]

A = As rolled
B = As rolled, bar heated to 1100 F and air cooled
C = As rolled, bar heated to 1100 F, free bend to 45 degrees, straightened,
and air cooled
D = As rolled, bar bent (cold) to 45 degrees around 6d pin, heated to 1100 F,
straightened, and air cooled
** = Bar broke in bend area
There was no significant difference in yield strength after bending and straightening;

Tensile strength went up slightly in one heat and down very slightly in the other heat after bending and straightening;

There was no significant difference in elongation for the 45° jig bent and control machine bent bars;

The average elongation decreased for bars that were 90° bent by machine and straightened;

It is easier to straighten large diameter bends than small diameter bends;

Results are not applicable to larger diameter bars (e.g. greater than #8 (#25)); and

Many of the bars broke outside the gage length - outside where the bars had been cold worked.

Erasmus asserted that field failures of bent bars were due to:

- Strain aging;
- Highly localized stresses at the root of the deformations (See Fig. 1);
- High strain rate if bend area was altered by (say) hammer blows; and
- Bending made at low temperatures.

Erasmus’ conclusions regarding realigning and reworking of bars were:

- Restraining bent bars carries significant risks;
- Incidence of breakage increased with:
  - A decrease in initial bend diameter;
  - An increase in bar diameter;
  - An increase in elapsed time between initial bend and straightening;
  - A shock or impact load during restraightening; and
  - Low temperature during restraightening.
- Failures are difficult to repair properly since accelerated strain aging can occur adjacent to the heated portion of the splice;
- There is a long term risk of failure at these reworked locations in a seismic event if the repair is in the plastic hinge; and

In response to the testing methodology and conclusions drawn in the Lalik and Cusick report, Erasmus published an article in 1981 (Erasmus [1981]) which challenged the notion that it was appropriate to bend the bars (cold work) and then immediately straighten and test them since this prevents – or avoids – strain aging. As evidence, Erasmus noted that reports from the field were not at all unusual of bent bars suddenly breaking some months after being bent. Erasmus noted that strain aging is not a major construction job-site issue because it is a slow process that continues after bars are placed in concrete for the life of the structure. Concerning the Lalik and Cusick report, Erasmus noted that the specimens actually broke outside the length of bar that had been cold worked and therefore was evidence that work hardening had occurred and given the proper time to strain age would occur as well. Erasmus’ other observation was that there is a tendency for bar breakage to occur when the bends were straightened rather than being bent further. His concern was that during an earthquake these normally low-stressed bars could break if located in a plastic hinge. Erasmus noted that from a metallurgical point of view there were three distinct property changes that are normally lumped together under “aging.” These are: strain aging, strain age hardening and strain age embrittlement.
**Table 4 — Averages of Tensile Test Results**

<table>
<thead>
<tr>
<th>Bar Size</th>
<th>Supplier</th>
<th>Control Bars</th>
<th>Y yield Point (ksi)</th>
<th>T yield Strength (ksi)</th>
<th>T tensile Strength (ksi)</th>
<th>Unheated Straightened Bars</th>
<th>Y yield Point (ksi)</th>
<th>T yield Strength (ksi)</th>
<th>T tensile Strength (ksi)</th>
<th>Heated Unstraightened Bars</th>
<th>Y yield Point (ksi)</th>
<th>T yield Strength (ksi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>#11</td>
<td>A</td>
<td></td>
<td>64.4 (444)</td>
<td>106.0 (734)</td>
<td>63.8 (440)</td>
<td>103.7 (715)</td>
<td>61.7 (425)</td>
<td>91.0 (633)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>B</td>
<td></td>
<td>65.1 (449)</td>
<td>105.1 (725)</td>
<td>64.7 (446)</td>
<td>103.9 (716)</td>
<td>65.1 (449)</td>
<td>93.5 (645)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>C</td>
<td></td>
<td>64.8 (447)</td>
<td>105.1 (725)</td>
<td>64.6 (445)</td>
<td>103.6 (714)</td>
<td>65.1 (449)</td>
<td>97.5 (672)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>#8</td>
<td>B</td>
<td></td>
<td>68.2 (470)</td>
<td>96.5 (665)</td>
<td>66.2 (456)</td>
<td>95.6 (659)</td>
<td>—</td>
<td>—</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>#5</td>
<td>B</td>
<td></td>
<td>—</td>
<td>—</td>
<td>64.5 (445)</td>
<td>104.5 (720)</td>
<td>—</td>
<td>—</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Recommend the use of preheating per ACI 318-77 Commentary, when bars are reworked, unless non-strain aging reinforcement is used.

**Stecich & Hanson 1982 and Stechich, Hanson & Rice 1984**

In 1982, Stecich and Hanson authored a report (Stecich and Hanson [1982]) and published a paper (Stecich, Hanson and Rice [1984]). The study was on a series of bending and straightening tests on Grade 60 [420 MPa] steel reinforcing bars. The tests were intended to replicate field bending and were performed on #5, #8 and #11 [#16, #25 and #36] bars. One source was used on #5 and #8 [#16 and #25] bars and two sources for the #11 [#36] bars. Tests were conducted at 30°F and 70°F [-1°C and 21°C] and two different bend diameters: the minimum specified diameter allowed by ACI 318-77 and the other was as small as possible to replicate an accidental bend. Bends were also conducted in the strong and weak direction of the bar. That is, the two main longitudinal ribs of the bar were in the plane and out of the plane of bending, respectively. Additional tests were conducted and consisted of heating the bars to 1500°F [820°C]. Assessments of the bars were then conducted by tension testing the bent and unbent specimens. Results of tension tests are summarized in Table 4.

Results of the 254 ASTM A615/A615M Grade 60 [420 MPa] bar specimens tested were:

- #5 and #8 [#16 and #25] bars exhibited better bending and straightening performance than #11 [#36] bars. The #5 and #8 [#16 and #25] bars were tested at 70°F [21°C] to the ACI 318-77 bend diameter and three times the bar diameter and straightened with no breaking or (visual) cracking.
- #11 [#36] bars were successfully bent at 70°F [21°C] to the ACI 318-77 specified diameter in the weak axis without breakage. Some of the bars broke when bent to the strong axis. Breakage increased when bent to smaller diameters in both weak and strong axis.
- #11 [#36] bars bent to 90° at the ACI 318-77 specified diameter on the weak axis were straightened without breakage. Some breakage did occur when the bars were bent in the strong axis. Similarly, breakage increased when bars were bent to smaller bend diameters in weak and strong axis.
- Breakage and cracking is more likely when straightening is done at cold temperatures.
- Bending or straightening of #11 [#36] bars were related to deformations patterns when bent in strong axis when transverse deformation patterns run into longitudinal rib. Breakage was less likely when bends around strong axis for the deformation patterns which tapered out before meeting the longitudinal rib.
- Heating the #11 [#36] bars to 1500°F [820°C] significantly improved the ability to bend and straighten them. Bend diameters as small as 5 inches [27 mm] in the strong axis could be straightened without breakage.
- Tensile properties of uncracked reinforcing bars that were straightened without heating were virtually the same as the unbent control bars. Fracture during tensile testing occurred both inside and outside the bent area.
- Yield strength of #11 [#36] reinforcing bars that were heated during bending or straightening was the same as that of the unheated bars. Tensile strength was approximately 10 percent less than
that of the corresponding control bar. Most of the tensile fractures occurred within the bent and heated area.

- The yield and tensile strength of #11 [#36] straightened reinforcing bars with transverse cracks, tested shortly after straightening, was slightly less than that of uncracked specimens. Fractures were reported to occur at an existing crack.
- The yield and tensile strength for #11 [#36] cracked, straightened bars that were allowed to age for one year after straightening was higher than for the uncracked specimens. The location of fracture was outside the bend region.

Stecich and Hanson concluded that field bending and straightening bars up to #11 [#36] should be satisfactory. Most bars could be bent about the weak axis up to 90° to ACI 318-77 bend diameters and straightened at normal temperatures. When conditions were more severe, such as for tighter bends, use of heating up to 1500°F [820°C] may be desirable. The minor reduction in strength from local heating to this temperature compared to the limit recommended by ACI 318 of 1200°F [650°C], was more than offset by the minimization of breakage and the ability to restore the bar to a straight or desired alignment.

**Kudder and Gustafson, 1983**

Though not specifically applicable to the realignment and reworking studies of the prior reports, in 1983 Kudder and Gustafson presented a paper (Kudder and Gustafson [1983]) that examined bend tests. This report was based on 945 bend tests and 540 tension tests performed on five different sizes of ASTM A615/A615M Grade 60 [420 MPa] bars from eighteen different producers. The setup procedure is shown schematically in Figure 2. They noted the heightened concerns over realignment and reworking of bars and the inquiry for more restrictive bends in codes and specifications.

The authors noted that tension tests are used to determine yield strength, tensile strength and percentage of elongation. These properties, in turn, translate into necessary strength characteristics. Bend tests, in contrast, are largely utilized in the material specification as an indication of the material being capable of being bent during fabrication. Similarly, they noted that they were not familiar with any structural deficiency or failure due to bent bars and in general unfamiliar with excessive breakage of bars due to conventional fabrication bending. On this basis, they questioned the significance of a bar breaking during a bend test and pointed out that related problems had not been found in day-to-day experience.

The primary objective of the research was to predict bend diameter, based on elongation, in order to avoid bend tests in the material specifications. The authors also noted that there was little overall objective research on this particular aspect of steel reinforcing bar material properties. Of 945 specimens that were tested, 225 broke and 40 were terminated. A test was terminated when one of two similar specimen bars broke.

The authors summarized that no bars broke that were bent to a diameter at least as large as that specified by the ACI 318-77 Building Code. In addition, statistical analysis of the breakage indicated that the probability of bar breakage was very low when the bend diameters conformed to ACI 318-77. In contrast, if the bend diameters were smaller than ACI 318-77 minimums, then there was a high degree of probability of bar breakage. Similarly, correlation between bendability of bars and elongation and tensile properties was not established. The final conclusion was that the bend test itself was relatively sensitive to the test machine and various other aspects of the bend test.

Black, 1983

In 1983 William Black authored a report on behalf of CRSI as an Engineering Data Report (EDR) (Black [1983]). The report reviewed the most current provisions of ACI 318-77, and the recent research publications - provided herein. Black’s summary of this work was:

> There have been numerous papers written on this subject. See References 1 through 3. The data from Reference #1 was used to establish the recommendations in the ACI 318 Commentary. It supports the use of preheating the rebar for field bending or re-bending of bars partially embedded in concrete. The authors of Reference #2 (1979) took issue with this and performed a series of tests of their own. They came to conclusion that partially embedded rebars could be successfully bent and straightened in the field without the application of heat. Their tests were performed on #8 rebars (A615-Grade 60) only and they cautioned that “Additional testing is necessary to substantiate the foregoing conclusions for bar sizes larger than #8.”
The author of Reference #3 (1981) espoused a contrary view, i.e. that cold restraightening of partially embedded rebars is hazardous and he does not recommend it. He advocates the use of nonstrain aging steels for reinforcing but then finally concludes that "For safe re-bending of embedded reinforcing bars the recommended preheat of 900 - 650°C (1100 - 1200°F) from the Commentary of ACI 318-77 provides the best overall solution, and in the absence of improved nonstrain aging reinforcing steel grades this recommendation should be closely followed."

The next portion of the report reviewed work that had not been published. As Black noted:

There has been considerable additional research work in this area which unfortunately has not been published.

Summarization of this unpublished work was:

- ASTM A615/A615M Grade 40 [300 MPa] bars #7 and #9 [#22 and #29] were successfully bent and straightened after heating to 1200°F [650°C].
- ASTM A615/A615M Grade 60 [420 MPa] bars: #6, #8 and #11 [#19, #25 and #36] bent cold and straightened cold but the angle of bend was 20° and 60°. While there was some breakage of the #8 [#25] bars bent to 60° the overall conclusions was that all bar sizes through #11 [#36] can be straightened if bent cold if not more than 30° with a radius of bend equal to or greater than ACI 318 Building Code minimums.
- ASTM A615/A615M Grade 60 [420 MPa] #11 [#36] bars heated and bent to 90° with ACI 318 bend diameter had approximately 15% of these bars break.
- 8% of the ASTM A615/A615M Grade 60 [420 MPa] #11 [#36] bars that had been accidentally bent but were heated for straightening broke or had visible cracks.
- ASTM A615/A615M Grade 60 [420 MPa] #11 [#36] bars with a series of tests manually bending and straightening the bars. Bends were made after heating the bars in accordance with ACI 318-77 Commentary recommendations of 1100 to 1200°F [590 to 650°C]. The conclusion was that this temperature did not appear to be adequate for bending or straightening of #11 [#36] and larger bars and that 1400 to 1500°F [760 to 820°C] be used for #14 and #18 [#43 and #57] bars. Tension tests of straightened bars indicated only a slight reduction in tensile properties.
- A report on field bending of ASTM A615/A615M Grade 60 [420 MPa] #11 [#36] bars partially embedded, and using a hydraulic ram, resulted in some bar breakage when ACI 318-77 procedures were followed. Additional tests indicated that the method of bending was significant, as was the use of a ram, and even the type of shoe.
- The final unpublished report mentioned by Black was called the Associated Reinforcing Bar Producers (ARBP) report but this report has, from a practical standpoint, already been reviewed herein under the work of Stecich and Hanson.

Black's conclusion of the work that had been done up to then was:

"Reworking of rebars that are partially embedded in concrete entails some level of risk. It looks as if bar sizes #8 and smaller may be successfully bent or straightened in the field without the application of preheat although this should be further qualified to say "at temperatures above 32°F" or something similar. Bar sizes #9, #10 and #11 would seem to have a better chance of successfully bending or straightening if the bend area were preheated uniformly to 1400 - 1500°F and extreme care were exercised in the bending/straightening operation. It would be tempting to include #14 and #18 in the foregoing but research data available is all on #11 and smaller."

**Reed, 1984**

In 1984 Frank O. Reed issued a report for the Department of Transportation Division of Engineering Services Office of Transportation Laboratory for the State of California (Reed [1984]).

Notes and recommendations of the report:

- Do not bend and straighten bars more than once;
- Do not cold bend and cold straighten #8 [#25] bars and larger;
- Locate splices no closer than 2 inches [50 mm] from concrete surface for welding, preheating or straightening;
- Use butt welded or threaded splices as an alternative;
- Heat the bars 1400 to 1500°F [760 to 820°C] when the carbon equivalent is not known and to use the largest bend diameter possible;
- Do not overheat the bars - above 1800°F [980°C];
- Use temperature sticks and do not rely on the color of the heated bar;
- Avoid using too low of temperature because a set of bars bent cold and then heated to 600°F [320°C] all broke upon straightening;
- Cold bending and cold straightening was not significant since yield strength and tensile strength increased slightly and percentage elongation reduced slightly - up to certain sizes of bars;
Heated bending and heated straightening reduced the yield strength and tensile strength while the elongation percentage increased slightly; #5 [#16] bars bent cold to a 2-inch [50-mm] diameter radius and successfully straightened cold resulted in a large reduction in percent elongation, while yield strength increased and tensile strength decreased slightly; Another set of #5 [#16] bars bent cold to 1-inch [25-mm] diameter and then straightened hot at 1400 to 1500°F [760 to 820°C] resulted in a decrease in elongation to near specification limit, yield strength increased and tensile strength decreased 5 percent; #8 [#25] bars were very difficult to bend cold without special equipment and harder to straighten. Also noted that bending #8 [#25] bars cold is dangerous as brittle failure is possible cold; One set of #8 [#25] bars were bent cold around 8-inch [200-mm] diameter pin and straighten cold resulted in one bar breaking with yield strength, tensile strength, and elongation all exhibiting drastic reductions; and Two groups of #8 [#25] bars were bent hot and straightened at 1400 to 1500°F [760 to 820°C] but

### Table 5 — Test Results for Cold-Bent Reinforcing Bars

<table>
<thead>
<tr>
<th>Bar Condition</th>
<th>Yield Strength (psi)</th>
<th>Ultimate Strength (psi)</th>
<th>8-inch gage length elongation (in./in. x 100)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Control</td>
<td>Bend/straighten</td>
<td>Bend/straighten; two cycles</td>
</tr>
<tr>
<td>#4</td>
<td>75,350</td>
<td>75,923¹</td>
<td>77,027</td>
</tr>
<tr>
<td></td>
<td>105,541</td>
<td>105,222¹</td>
<td>106,496</td>
</tr>
<tr>
<td></td>
<td>12.9</td>
<td>12.6¹</td>
<td>9.9</td>
</tr>
<tr>
<td>#6</td>
<td>67,940²</td>
<td>63,562²</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>99,904</td>
<td>99,147</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>14.3</td>
<td>11.5</td>
<td>—</td>
</tr>
</tbody>
</table>

¹ Fracture outside of bent metal; properties do not represent bent metal.
² Yield determined by ASTM method at 0.04 in. elongation; no plateau.

### Table 6 — Test Results for Hot-Bent Reinforcing Bars

<table>
<thead>
<tr>
<th>Bar Condition</th>
<th>Yield Strength (psi)</th>
<th>Ultimate Strength (psi)</th>
<th>8-inch gage length elongation (in./in. x 100)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Control</td>
<td>Bend/straighten</td>
<td>Bend/straighten; two cycles</td>
</tr>
<tr>
<td>#7</td>
<td>59,343</td>
<td>55,849²</td>
<td>58,317¹</td>
</tr>
<tr>
<td></td>
<td>98,444</td>
<td>91,844</td>
<td>94,589</td>
</tr>
<tr>
<td></td>
<td>18.1</td>
<td>13.5</td>
<td>15.4¹</td>
</tr>
<tr>
<td>#9</td>
<td>67,101</td>
<td>Not Practical</td>
<td>61,398²</td>
</tr>
<tr>
<td></td>
<td>105,517</td>
<td></td>
<td>97,297</td>
</tr>
<tr>
<td></td>
<td>15.2</td>
<td></td>
<td>14.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

¹ Fracture outside of bent metal; properties do not represent bent metal.
² Yield determined by ASTM method at 0.04 in. elongation; no plateau.
³ Fracture outside of bent metal and outside of gage length; strength does not represent bent metal and elongation does not represent gage length.
to different diameters: one set at 4-inch [100-mm] and one set at 8-inch [200-mm]. The set bent to the larger diameter suffered the least reduction and the smaller diameter the greater reduction.

**Babaei and Hawkins, 1992**

Sponsored by the Department of Transportation for Washington State (WSDOT), Babaei and Hawkins conducted two in-depth research projects:

1. Reviewed WSDOT’s specification guidelines for field bending/straightening reinforcing bars and prepared recommendations for WSDOT’s specification guidelines for resin grouting epoxy-coated reinforcing bars (Babaei and Hawkins [1988]), and

2. Conducted a series of “hot” and “cold” bending and straightening bars and to propose WSDOT standard specifications for bending/straightening reinforcing bars (Babaei and Hawkins [1991]).

The author’s findings were also presented in a paper in ACI’s *Concrete International* (Babaei and Hawkins [1992]).

The authors noted that there were essentially two options for addressing the need to bend then straighten reinforcing bars. These two options were to cut and splice the bars or to field bend the bars. Neither of these options were “ideal” but they recognized that it was necessary from time to time. The primary concern was the effects that bending/straightening has on the reinforcing bar properties. The primary factors they focused on was if the bars could be bent cold or if heating was necessary for the bar size, number of plastic strain cycles, and ambient temperature. Test results for cold bending are summarized in Table 5 and results for hot bending are summarized in Table 6.

**Table 7 — Minimum Heated Bar Length**

<table>
<thead>
<tr>
<th>Bar Length</th>
<th>#3 through #8 [#10 through #25]</th>
<th>#9 through #11 [#29 through #36]</th>
</tr>
</thead>
<tbody>
<tr>
<td>45°</td>
<td>6d</td>
<td>8d</td>
</tr>
<tr>
<td>90°</td>
<td>9d</td>
<td>12d</td>
</tr>
</tbody>
</table>

*d = nominal diameter of bar

WSDOT developed a cold bending criteria and a hot bending criteria. The WSDOT cold bend criteria is:

- Applicable for #6 [#19] bars or smaller;
- The bar has not been previously bent;
- Ambient temperature above 40°F [4°C];
- Tight control over radius of bend;
- No sharp bends and use a bending tool;
- Bend diameter is no smaller than 6-bar diameter; and
- Bend is to be gradual and no impact loads, such as hammer blows.

The WSDOT hot bending criteria is:

- This criteria is permitted when cold bending criteria is not applicable;
- Heating to 1100 to 1300°F [590 to 700°C] but not to exceed 1300°F [700°C];
- Use insulation on concrete if heating the bars within 6 inches [150 mm] of concrete;
- Heat both sides of bars simultaneously;
- Minimum bend diameter of 6 bar diameters for #3 through #8 [#10 through #25] bar sizes;
- Minimum bend diameter of 8 bar diameters for #9 through #11 [#29 through #36] bar sizes;
- Bend angle not to exceed 90° for #9 through #11 [#29 through #36] bar sizes;
- #14 and #18 [#43 and #57] bars are not to be bent;
- Heating is to occur for entire length of bend;
- Cooling of heated bars with water or forced air is not permitted; and
- Minimum length of heated bar in accordance with:

The authors noted that there were two types of metal degradation related to the bending and straightening operations of reinforcing bars. One was a distress of the bar without visible signs such as a reduction in ductility and strength. The other was cracking of the bar. Factors such as strain, strain-aging, cyclic strain, ambient temperature and chemical composition of steel were thought to influence cracking of the bars. To address bar properties, specimens can be bent and tested to generally understand the effects, and to address cracking bars they can be visually inspected.

The other issue investigated was the effect of heating bars embedded in concrete. #5 and #8 [#16 and #25] bars were equipped with thermo couples and then monitored during the installation of a welded splice. The #8 [#25] bar was originally protruding 2 inches [50 mm] and the #5 [#16] bar was protruding 3 inches [75 mm]. After the welded splices were made, the specimens were sectioned to investigate the possibility of cracking. The #8 [#25] bar specimen cracked 1-1/2 inches [38 mm] from surface of concrete while the #5 [#16] bar specimen cracked at a distance from the concrete surface of 1/2 inches [13 mm]. Discussed in this report was their view, based on American Welding Society’s *Structural Welding Code-Reinforcing Steel (AWS D1.4/D1.4M:2011 [2011])*, and the carbon equivalent of ASTM A706/A706M bar, was that #6 [#19] A706/A706M bars with 5-inch [130-mm] diameter bend and larger did not need preheating, while #7 [#22] A706/A706M bars with 6-inch [150-mm] diameter did need preheating.

**Restrepo, Crisafulli & Park, 1999**

In 1999, Restrepo, Crisafulli, and Park authored an article (Restrepo, Crisafulli and Park [1999]) concerned with bending of bars already in concrete. The authors were
concerned that when reinforcement is embedded in concrete a kink will remain after straightening because of work hardening. Figure 3 highlights the main changes caused by strain-aging steel. The authors noted that bars were often bent on purpose for constructability issues and sometimes bars were field bent into place such as the bottom of tilt-up walls. Likewise, they noted that sometimes bent bars have to be straightened.

The tests specimens were selected from bars available in New Zealand, Grade 40 [300 MPa] and Grade 62 [430 MPa], 0.39 and 0.47 inches [10 mm and 12 mm] in diameter with a carbon equivalents of 0.45 and 0.51, respectively. Tension tests were conducted on the bars after they were bent cold and straightened cold at a low-static strain rate and at a high strain rate but at a 32°F [0°C]. Two sets of bend angles were used: 45° and 90°.

Based on the test results, the conclusion drawn by the authors was that there is no need to restrict the practice of bending and straightening small diameter bars so long as:

- The bar is not bent beyond 90°;
- Bars are bent and straightened only once; and
- Uniform strain of reinforcement $\varepsilon_{su}$ corresponds to tensile strength of steel is not less than 14 percent.

**Cautionary Notes**

- Field bending is a last resort and should not be considered “typical” practice.
- Realigning and reworking of bars is not risk-free.
- Best practice is to identify concrete cover problems in the design phase, not at the construction site.
- If the building is in an area subject to seismic events then best if the reworked bars are outside any plastic hinge.
- If possible locate the bars to be reworked in an area with low structural demand.
- Bending and straightening should not occur more than once per bar location.

**Bar Characteristics**

- Some differences between various deformation patterns should be expected.
- Some differences between heats of steel should be expected.
- If optional, bar markings should not be in the zone of the bend.
- Smaller sized bars should perform better than larger sized bars when bending straight bar in the field and when bending and straightening bars.
- Where bending large diameter bars - #11, #14 and #18 [#36, #43 and #57] - the Engineer may specify the use of heat (breakage) and magnetic particle and liquid penetrant (dye) testing (cracking).
- Majority of research is based on uncoated deformed ASTM A615/A615M Grade 60 [420 MPa] steel.
- ASTM A706/A706M bars should perform better when reworking is necessary.
- ASTM A706/A706M bars should perform better if small diameter bending and straightening is necessary.
- If straightening bent bars, heating all sizes may be warranted for other types of reinforcing bars, such as ASTM A615/A615M Grade 75 and 80 [520 and 550 MPa], ASTM A1035/A1035M (ASTM [2014]), galvanized bars and epoxy-coated bars.

**Bending Characteristics**

- Smaller angle bends are better than large angle bends.
- The larger the bend diameter the better.
- Bar bend diameters should not be smaller than those specified in ACI 318.
- Best practice is to re-straighten the bars as soon as possible after the initial bend.

**Conclusions**

Observations, recommendations and guidelines for field realigning, bending and straightening deformed steel reinforcing bars, based on referenced documents are summarized herein:
Heated bending is better than cold bending though not necessary on all bars sizes.

- Bending of bars at warmer ambient temperatures is preferred over colder ambient temperatures.
- Where heat is used, use temperature crayons - do not over-heat (above 1800°F [980°C]) nor under-heat (below 1000°F [540°C]).
- If heating #8 (#25) bars and smaller closer than 6 inches [150 mm] to concrete surface then use C-clamps /Vise-Grips and wet rags to dissipate heat from the concrete surface.
- If possible, bend the bars in weak orientation. That is, the two main longitudinal ribs are out of the plane of bending.

**Alternatives**

- Other corrective actions are to use ASTM A706/A706M reinforcing bars, mechanical splices or welded splices, headed bars, or grouted dowels.

**References**


American Concrete Institute – ACI [1971], Building Code Requirements for Reinforced Concrete (ACI 318-71) and Commentary (ACI 318R-71), American Concrete Institute, Farmington Hills, MI.

American Concrete Institute – ACI [1977], Building Code Requirements for Reinforced Concrete (ACI 318-77) and Commentary (ACI 318R-77), American Concrete Institute, Farmington Hills, MI.

American Concrete Institute – ACI [2010], Specifications for Structural Concrete (ACI 301-10), American Concrete Institute, Farmington Hills, MI.

American Concrete Institute – ACI [2011], Building Code Requirements for Structural Concrete (ACI 318-11) and Commentary (ACI 318R-11), American Concrete Institute, Farmington Hills, MI.


ASTM [2013a], Standard Test Methods and Definitions for Mechanical Testing of Steel Product (A370-12a), ASTM, West Conshohocken, PA.

ASTM [2013b], Standard Specification for Deformed and Plain Carbon-Steel Bars for Concrete Reinforcement (A615/A615M-13), ASTM, West Conshohocken, PA.

ASTM [2013c], Standard Specification for Low-Alloy Steel Deformed and Plain Bars for Concrete Reinforcement (A706/A706M-13), ASTM, West Conshohocken, PA.

ASTM [2014], Standard Specification for Deformed and Plain, Low-Carbon, Chromium, Steel Bars for Concrete Reinforcement (A1035/A1035M-14), ASTM, West Conshohocken, PA.

Babaei, K. and Hawkins, N. M. [1988], Bending/Straighening and Groating Concrete Reinforcing Steel: Review of WSDOT’s Specifications and Proposed Modifications (WA-RD 168.1), Washington State Transportation Center, Seattle, WA.

Babaei, K. and Hawkins, N. M. [1991], Development of Standard Specifications for Bending/Straighening Concrete Reinforcing Steel (WA-RD 216.1), Washington State Transportation Center, Seattle, WA.

Babaei, K. and Hawkins, N.M. [1992], Field Bending and Straightening of Reinforcing Steel, Concrete International, American Concrete Institute, Farmington Hills, MI. pp. 67-72.

Black, W. C. [1973], Field Corrections to Partially Embedded Reinforcing Bars, ACI Journal, American Concrete Institute, Farmington Hills, MI. pp. 690-691.

Black, W. C. [1983], Field Corrections to Rebars Partially Embedded in Concrete, Engineering Data Report Number 12, Concrete Reinforcing Steel Institute, Schaumburg, IL.

Concrete Reinforcing Steel Institute - CRSI [1989], Reinfocing Bar Testing, 2nd edition, Concrete Reinforcing Steel Institute, Schaumburg, IL.

Concrete Reinforcing Steel Institute - CRSI [2009], Manual of Standard Practice, 28th edition, Concrete Reinforcing Steel Institute, Schaumburg, IL.

Erasmus, L. A. [1981], Cold Straightening of Partially Embedded Re-inforcing Bars – A Different View, Concrete International, American Concrete Institute, Farmington Hills, MI, pp. 47-52.

Kudder, R. J. and Gustafson, D. P. [1983], Bend Tests of Grade 60 Reinforcing Bars, ACI Journal, American Concrete Institute, Farming- ton Hills, MI, pp. 202-209.


Lalik, J. R. and Cusick, R. L. [1979], Cold Straightening of Partially Embedded Reinforcing Bars, Concrete International, American Concrete Institute, Farmington Hills, MI, pp. 26-30.

Mitchell, P. S., The Use of Vanadium, http://www.vanitec.com/pdfs/67377791d7b7a86e4a82b08bc3c89a2d.pdf

Molloy, D. [2004], Site-Bending of Reinforcing Steel, Build, Porirua City, New Zealand.

Pense, A. [2004], HPS Corrugated Web Girder Fabrication Innovations - Final Report Part 4: Literature and Experimental Study of Strain Aging in HPS and Other Bridge Steels, Center for Advanced Technology for Large Structural Systems, Lehigh University, Bethlehem, PA.

Reed, F. O. [1984], Develop Guidelines For Bending and Splicing Re- bar, State of California Department of Transportation Division of Engineer- ing Services Office of Transportation Laboratory. Sacramento, CA.

Restrepo, J. I., Crisafulli, F. J. and Park, R. [1999], How Harmful is Cold Bending/Straightening of Reinforcing Bars?, Concrete Interna- tional, American Concrete Institute, Farmington Hills, MI. 45-48.

Stech, J. P. and Hanson, J. M. [1982], Bending and Straightening Grade 60 Reinforcing Bars, Concrete Reinforcing Steel Institute, Schaumburg, IL.

Stech J. P., Hanson, J. M. and Rice, P. F. [1984], Bending and Straightening of Grade 60 Reinforcing Bars, Concrete International, American Concrete Institute, Farmington Hills, MI. 14-23.


**APPENDIX A – Guidelines and Procedures for Bending and Straightening Reinforcing Bars**

Current codes and standards, and consequently some Engineers and Inspectors, group all scenarios associated with realigning and reworking of bars together. The provisions of ACI 318-11 Building Code Requirements for Structural Concrete and Commentary, ACI 301-10 Specifications for Structural Concrete, and CRSI's recommendations in its Manual of Standard Practice, are presented in this Appendix. Obviously there are many differences between these three sets of provisions.
ACI 318-11. American Concrete Institute’s ACI 318-11 states in Section 7.3.2:

7.3.2 Reinforcement partially embedded in concrete shall not be field bent, except as shown in the contract documents or permitted by the licensed design professional.

The Commentary Section R7.3.2 states:

R7.3.2 Construction conditions may make it necessary to bend bars that have been embedded in concrete. Such field bending should not be done without authorization of the licensed design professional. Contract documents should specify whether the bars will be permitted to be bent cold or if heating should be used. Bending should be gradual and should be straightened as required.

Tests have shown that A615/A615M Grade 40 and Grade 60 [300 and 420 MPa] reinforcing bars can be cold bent and straightened up to 90 degrees at or near the minimum diameter specified in 7.2. If cracking or breaking is encountered, heating to a maximum temperature of 1500°F [820°C] may avoid this condition for the remainder of the bars. Bars that fracture during bending or straightening can be spliced outside the bend region.

Heating should be performed in manner that will avoid damage to the concrete. If the bend area is within approximately 6 in. [150 mm] of the concrete, some protective insulation may need to be applied. Heating of the bar should be controlled by temperature-indicating crayons or other suitable means. The heated bars should not be artificially cooled (with water or forced air) until after cooling to at least 600°F [320°C].

ACI 301-10. American Concrete Institute’s ACI 301-10 states:

3.3.2.8 Field bending or straightening—When permitted, bend or straighten reinforcing bars partially embedded in concrete in accordance with procedures 3.3.2.8.a through 3.3.2.8.c. Reinforcing bar sizes No. 3 through 5 may be bent cold the first time, provided reinforcing bar temperature is above 32°F. For other bar sizes, preheat reinforcing bars before bending.

3.3.2.8.a Preheating—Apply heat by methods that do not harm reinforcing bar material or cause damage to concrete. Preheat length of reinforcing bar equal to at least five bar diameters in each direction from center of bend but do not extend preheating below concrete surface. Do not allow temperature of reinforcing bar at concrete interface to exceed 500°F. Preheat temperature of reinforcing bar shall be between 1100 and 1200°F. Maintain preheat temperature until bending or straightening is complete. Unless otherwise permitted, measure preheat temperature by temperature measurement crayons or contact pyrometer. Do not artificially cool heated reinforcing bars until bar temperature is less than 600°F.

3.3.2.8.b Bend diameters—Minimum specified inside bend diameters shall conform to requirements of Table 3.3.2.8. In addition, beginning of bend shall not be closer to concrete surface than minimum bend diameter.

3.3.2.8.c Repair of bar coatings—After field bending or straightening zinc-coated (galvanized) or epoxy-coated reinforcing bars, repair coating damage in accordance with 3.2.1.2.a or 3.2.1.2.b.

CRSI Manual of Standard Practice. Concrete Reinforcing Steel Institute’s Manual of Standard Practice states in Section 8.4, Field Bending of Reinforcing Bars, that:

Reinforcing bars should not be field bent or straightened in a manner that will not reduce their strength or ductility. Bars with kinks or improper bends should not be used. No reinforcing bars partially embedded in hardened concrete should be field bent, except for:

1. Realignment of #3 through #6 [#10 through #19] bars up to about 45° bend.
2. Realignment of #7 through #18 [#22 through #57] bars up to about 30° bend.
3. Those reinforcing bars as shown on the project drawings or permitted by the Architect/Engineer.

Contributors: Scott R. Humphreys, PE, SE, and Anthony L. Felder, PE

Keywords: Bending, Cold Working, Embrittlement, Realignment, Rebending, Straightening, Strain Aging, Strain Hardening, Work Hardening.


Historical: None. New Technical Note.

Note: This publication is intended for the use of professionals competent to evaluate the significance and limitations of its contents and who will accept responsibility for the application of the material it contains. The Concrete Reinforcing Steel Institute reports the foregoing material as a matter of information and, therefore, disclaims any and all responsibility for application of the stated principles or for the accuracy of the sources other than material developed by the Institute.