Construção Naval Soldada
Welded Shipbuilding

Imperfections

Structural Strength

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Type of imperfections

- Geometric imperfections due to welding
- Misalignement os structural members
- Welding defects
  - Penetration
  - Inclusions
  - Porosity
  - Cracks
- Superficial grooves
- Material imperfections
- Residual stresses and stress concentration

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Imperfections due to fabrication

- Oxi-gas cutting
  - Indentation due anormal operation procedure
  - Indentation and grooves due to floatation of flux
  - Residual stresses
  - Dimensional control
- Heat straightening
  - Temperature from 480 to 570ºC
  - Low yield stress steel is more sensitive
  - It only works once

Welding defects

- Intrinsic relevance
  - Dimension
  - Location
  - Nature
- Additional Factors
  - Loading
  - Environment
  - Distribution of fillets
  - Material properties (HAZ), residual stresses

Nature of defects

- Geometrical
  - Misalignment
  - Deformation or distortions
    - Linear
    - Angular
  - Shortening
  - Instability
  - Profile
    - Convexity
    - Super-position
    - Burned edges
    - Insufficient lag
    - Excessive Concavity
  - Weld size
  - Stress concentration
- Structural
  - Tri-dimensional
    - Metallurgical discontinuities
    - Inclusions slag
    - Porosity
    - Penetration
  - Planar
    - Longitudinal
    - Crater
  - Superficial
  - Insufficient fusion
  - Lamellar tearing
  - Inclusions of tungsten
  - Micro segregation
  - Shape of the fusion pool

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Nature of defects

- Metallurgical
  - Cracking due to residual stresses relief
  - Embrittlement due to hydrogen in HAZ
  - Cracking on added material during solidification
  - Lamellar tearing on base metal
- Thermal residual stresses
  - Constraints (Restrições)
  - Boundary conditions (Encastramentos)
  - Welding repair (Soldadura de reparação)

Welding Quality Control

In the fabrication or repair of equipment, tests are used to determine the quality and soundness of the welds. Many different tests have been designed for specific faults. The type of test used depends upon the requirements of the welds and the availability of testing equipment. In this section, nondestructive and destructive testing are briefly discussed.

- Nondestructive Testing
  - Nondestructive testing is a method of testing that does not destroy or impair the usefulness of a welded item.
  - These tests disclose all of the common internal and surface defects that can occur when improper welding procedures are used. A large choice of testing devices is available and most of them are easier to use than the destructive methods, especially when working on large and expensive items.

Non-destructive Testing

- Visual Inspection
- Magnetic Particle Inspection
- Liquid Penetrant Inspection
- Radiographic Inspection
- Ultrasonic Inspection
- Eddy Current Testing

Destructive Testing

- Free Bend Test
- Guided-Bend Test
- Nick Break Test
- Impact test
  - Charpy & Izod
- Fillet-Welded Joint Test
- Etching Test
- Tensile test

Visual Inspection

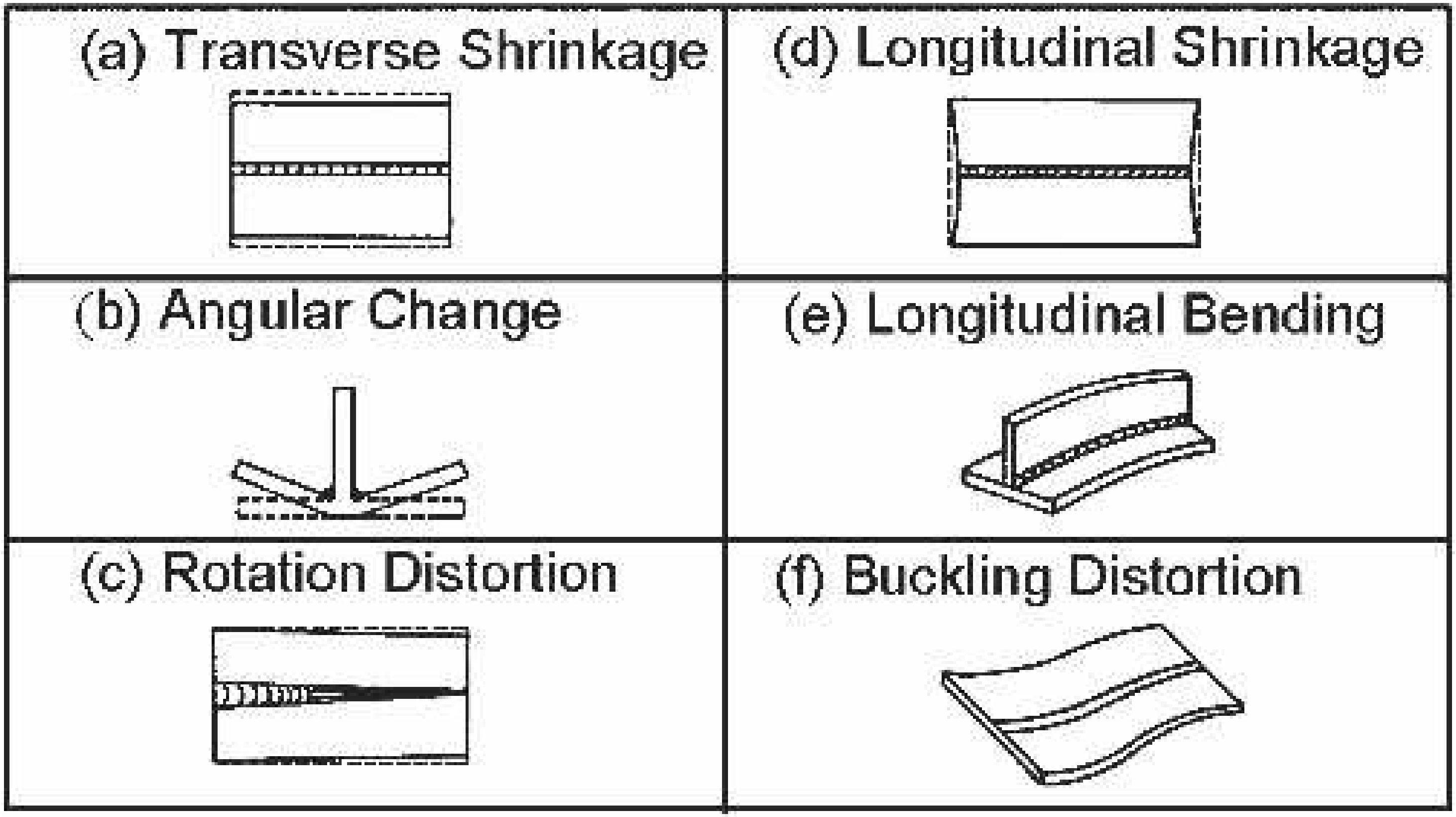
- Visual inspection is usually done automatically by the welder as he completes his welds. This is strictly a subjective type of inspection and usually there are no definite or rigid limits of acceptability. The welder may use templates for weld bead contour checks. Visual inspections are basically a comparison of finished welds with an accepted standard. This test is effective only when the visual qualities of a weld are the most important.

Magnetic Particle Inspection

- Magnetic particle inspection is most effective for the detection of surface or near surface flaws in welds. It is used in metals or alloys in which you can induce magnetism. While the test piece is magnetized, a liquid containing finely ground iron powder is applied. As long as the magnetic field is not disturbed, the iron particles will form a regular pattern on the surface of the test piece. When the magnetic field is interrupted by a crack or some other defect in the metal, the pattern of the suspended ground metal also is interrupted. The particles of metal cluster around the defect, making it easy to locate.
- You can magnetize the test piece by either having an electric current pass through it or by having an electric current pass through a coil of wire that surrounds the test piece. When an electric current flows in a straight line from one contact point to the other, magnetic lines of force are in a circular direction. When the current flow is through a coil around the test piece, the magnetic lines of force are longitudinal through the test piece.

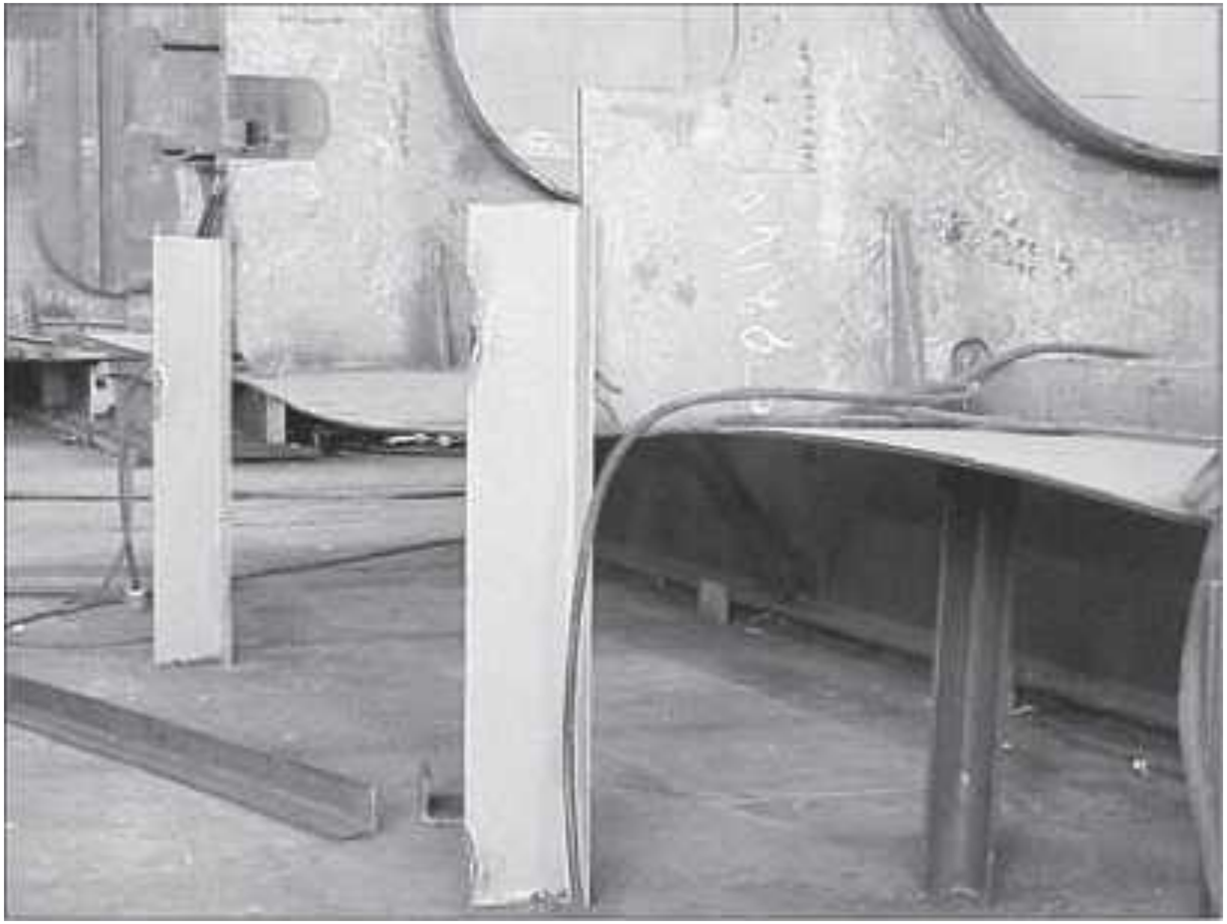
Basic types of welding distortion.

Buckling distortion dominates
on thin panels

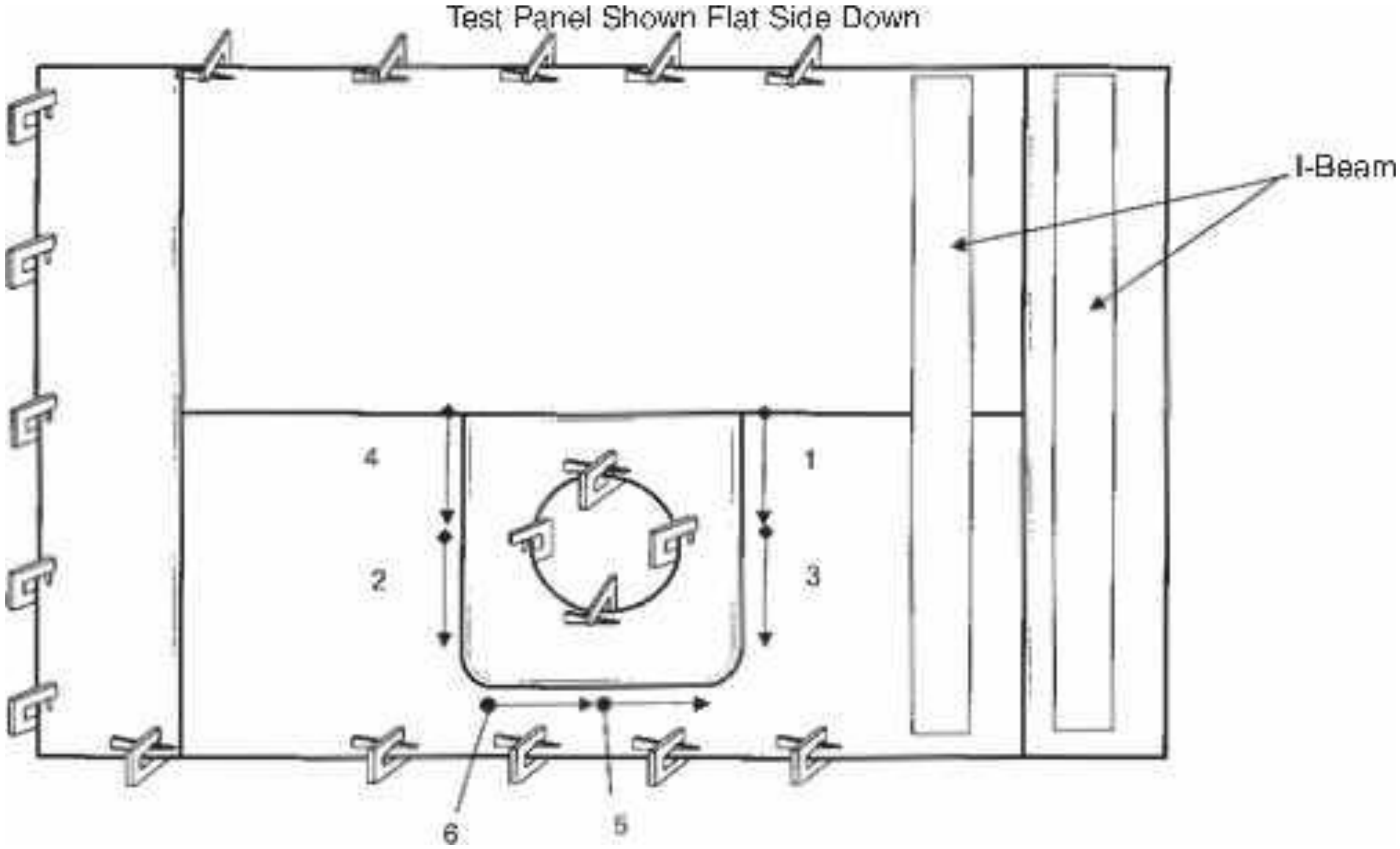


Clip and wedge clamping to a rigid foundation provides panel edge restraint

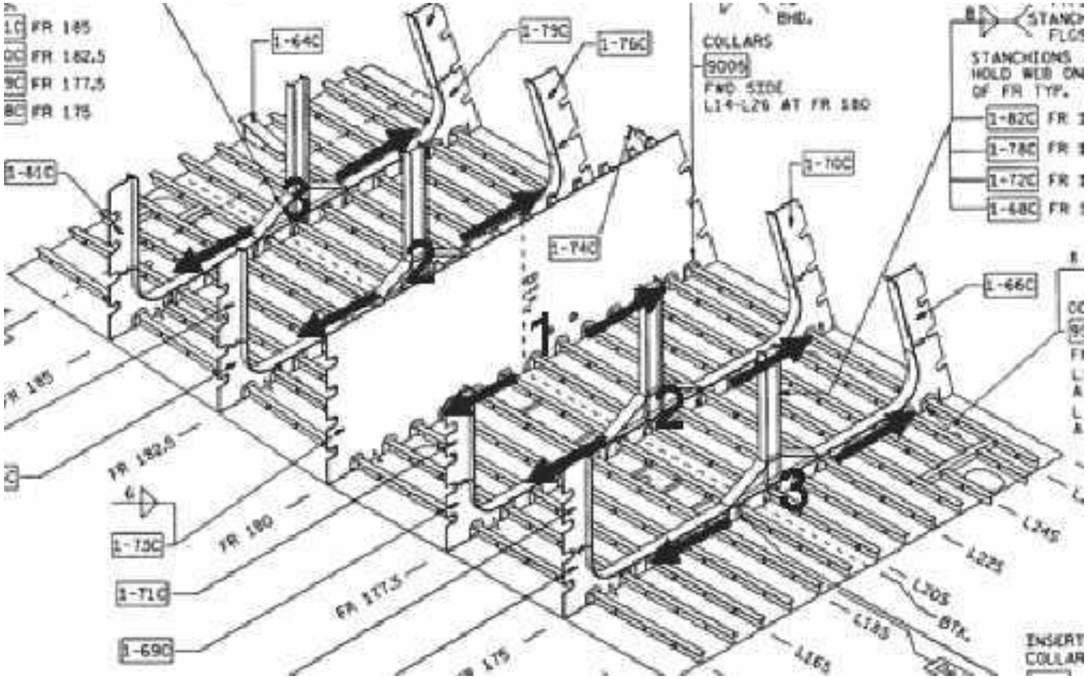
Inadequately restrained edge can result in large out-of-plane distortion



Manufacturing plan showing clamping locations on a complex panel



Center-out welding sequence



Distortions Control Techniques

- Minimize welding heat input
- Maximize restraint
- Design modifications
- Active mitigations approaches

Minimize welding heat input

Technique	Benefits	Detriments
Improve fit-up	Reduction in weld size Reduces all forms of distortion	May require more time to fit Upstream operations must be controlled Investment in fitting aids
Minimize tack weld size	Reduction in weld size	Requires more fitter training Additional QC needed May require different welding process for fitting
Optimize process parameters	Increase welding speed and reduce heat input	Less applicable to manual welding
QC program to reduce over welding	Reduce all forms of distortion	Requires additional training and vigilance Requires better fitting
Increase use of mechanization	Increase welding speed and reduce heat input Improve weld consistency	Less flexible Joint access limits applicability May increase setup time
Deploy low-heat input welding processes	Increase productivity and reduce heat input	Capital investment New procedures May require better fit-up
Reduce weld repairs	Improve productivity Reduce heat input from extra welding	Requires additional training and vigilance May need to reduce cosmetic appearance requirements

Maximize restraint

Technique	Benefits	Detriments
Optimize fit-weld sequence	Reduces dimensional variability	Requires tighter control of operations
Use back-step sequence	Reduces rotational distortion	Less productive Not easily automated
Employ tooling/fixtures	Reduces angular and buckling distortion	• Tooling investment • Additional operations to restrain and release components
Remove tabbed cut-outs after welding	Increases buckling resistance	• Subsequent operation required to remove cut-outs
Employ egg-crate construction	Increases resistance to all forms of distortion	• More difficult to fit • Makes welding automation difficult

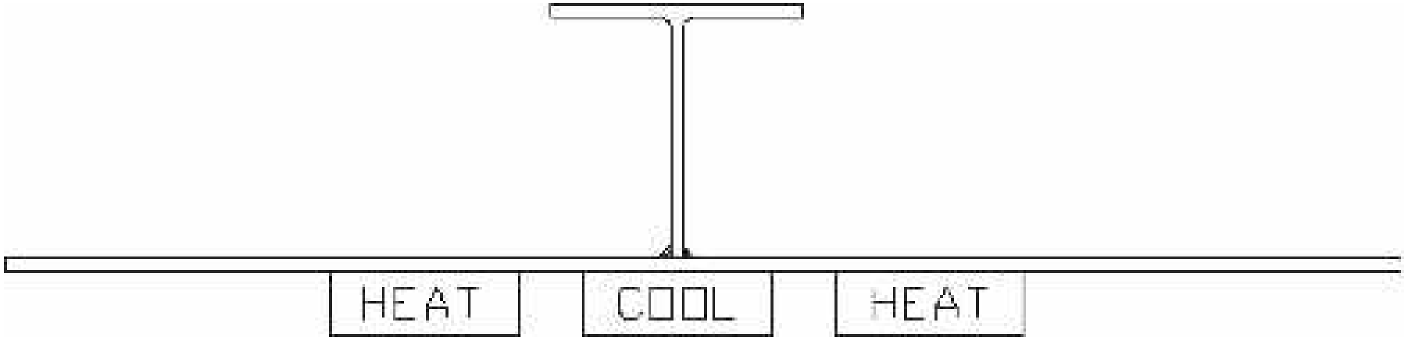
Design modifications

Technique	Benefits	Detriments
Reduce stiffener spacing	- Reduces buckling tendency	- May increase weight if stiffener size not reduced -More welding required
Increase plate thickness	• Reduces buckling tendency	• Increases weight • May increase angular distortion • Higher heat input for butt welds
Reduced cutouts	• Reduce buckling tendency	• Increases weight
Reduce insert thick-thin transitions	• Reduce distortion in thin plate	• Increases weight
Reduce design weld size	• Reduce all forms of distortion	• Less factor of safety
Employ intermittent welding	• Reduce buckling distortion	• More difficult to control segment length and location • May be corrosion, fatigue, and shock issues
Beveled T stiffener joint	Reduce angular distortion	Adds a manufacturing operation

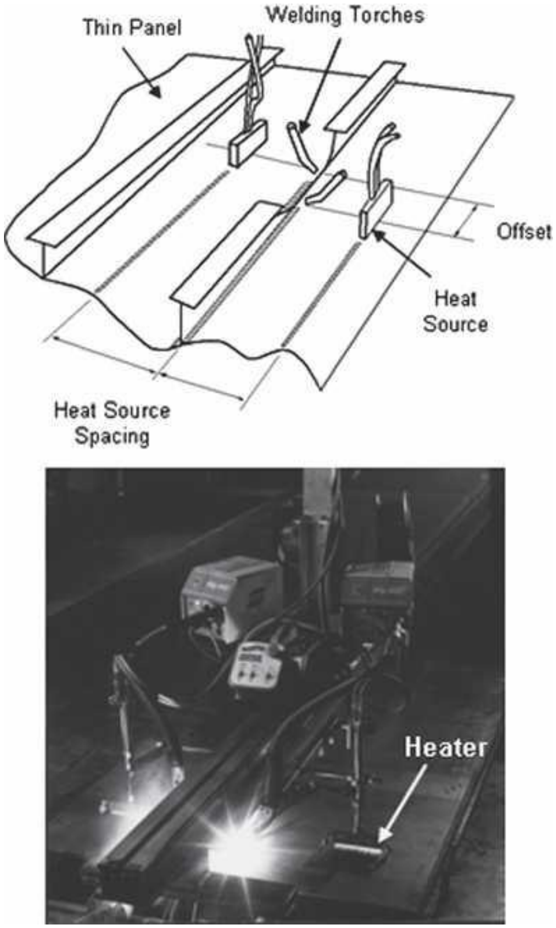
Active mitigation approaches

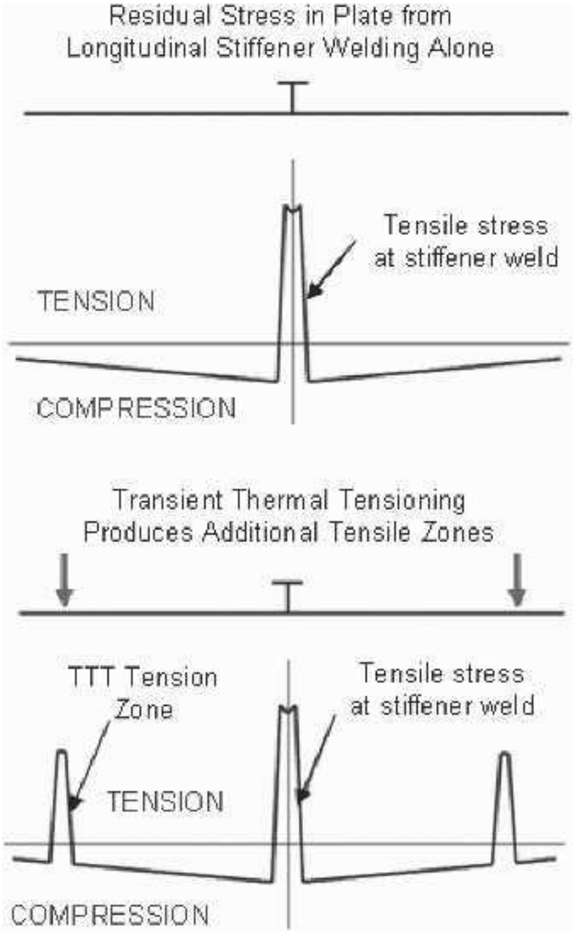
Technique	Benefits	Detriments
Balance heat input	Reduces angular distortion In use for double-sided submerged arc welding	• Requires double-sided welding • No benefit for buckling
Presetting butt joints	Can eliminate angular distortion	• No benefit for buckling • Degree of preset depends on plate thickness and welding procedure • Special tooling required
Pre-cambering beams	Can counteract bowing and buckling distortion	• Difficult to fit and weld beams • Special tooling required
Back-bending fillet joints	Can counteract angular distortion	• Major tooling investment • Applicable only to angular distortion on longitudinal stiffeners • Degree of preset depends on plate thickness and welding procedure
Forced cooling	Can reduce buckling distortion	• May adversely affect steel weld properties
Thermal tensioning	Reduces buckling distortion Shown effective in shipyard tests	• Procedure dependent on panel design • Not tested for complex panel geometries

Thermal tensioning uses temperature gradients to produce stresses that oppose the development of welding stresses that cause buckling

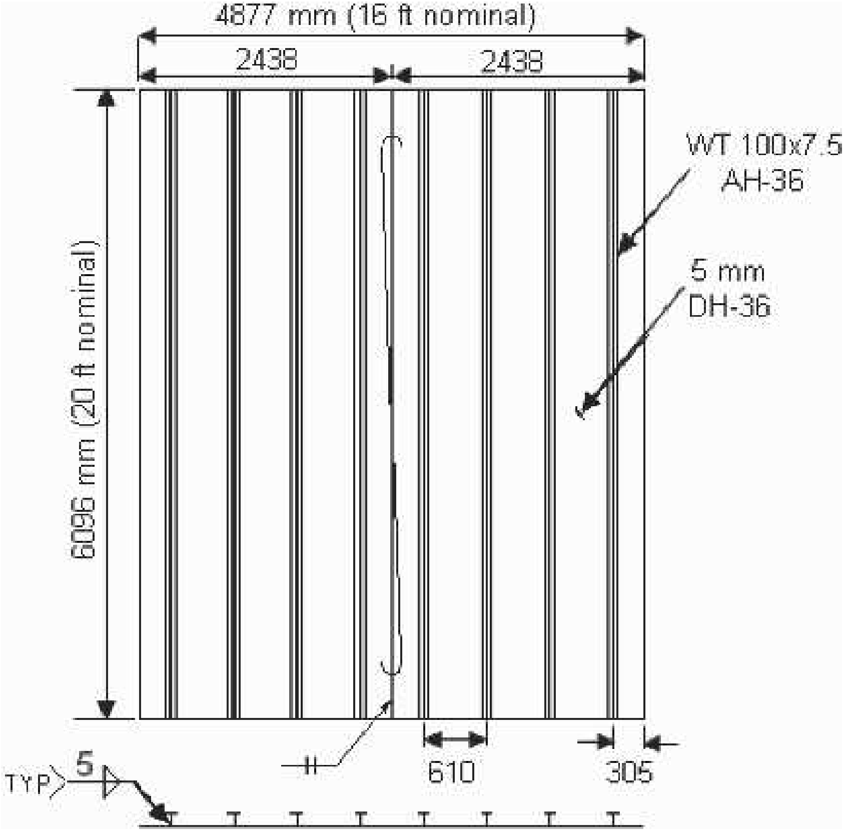


Schematic illustration of the residual stress pattern produced (left) without and (right) with transient thermal tensioning





Numerical model prediction of buckling distortion (top) without transient thermal tensioning (TTT) and (bottom) with TTT on a 4.8 × 6 m panel



Displacement measured along the edges of the 3 × 12 m panels with and without transient thermal tensioning