Construção Naval Soldada
Welded Shipbuilding

Imperfections

Structural Strength

INSTITUTO SUPERIOR TÉCNICO

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

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

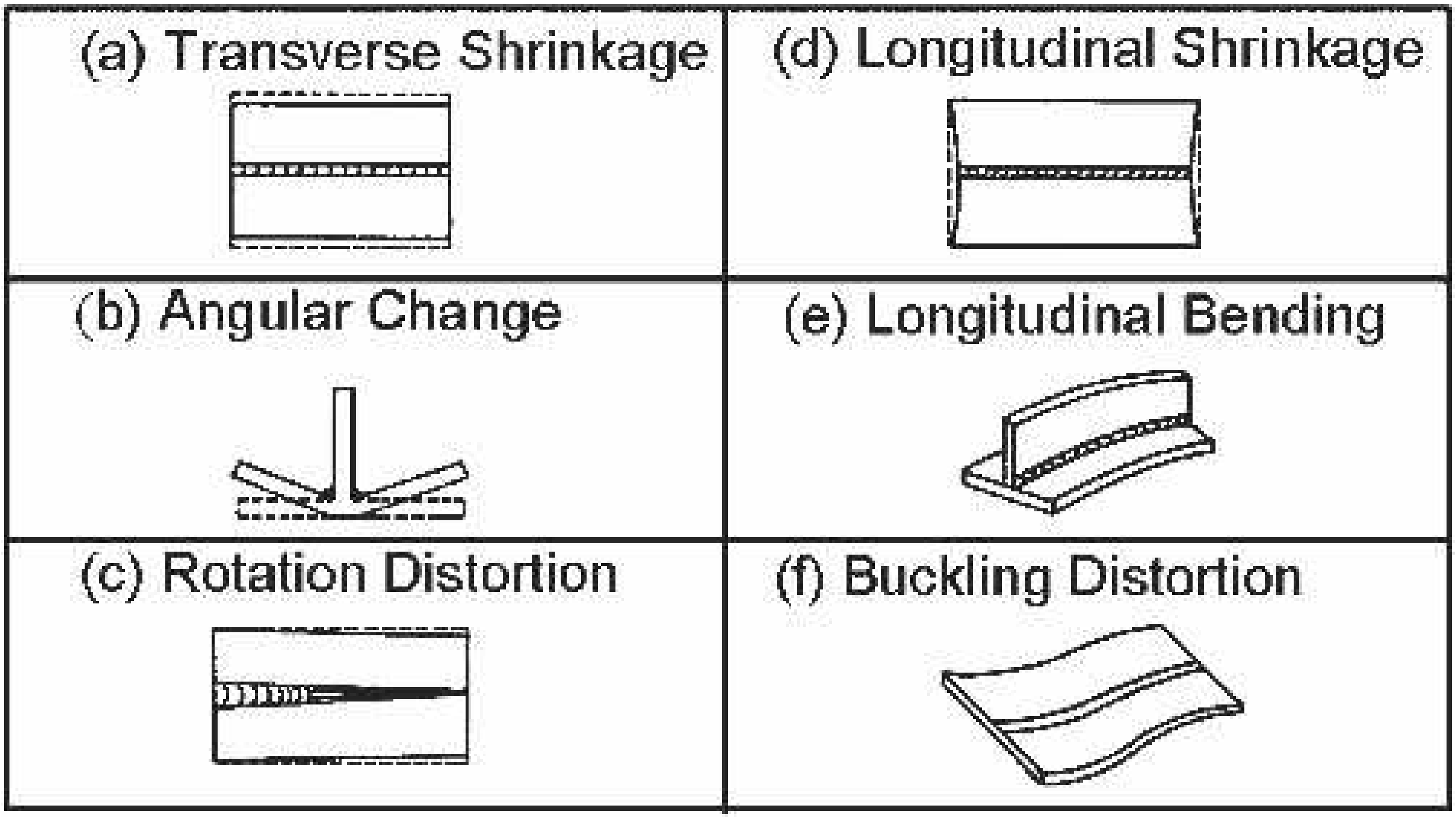
- Geometrical
  - Misalignment
  - Deformation or distortions
    - Linear
    - Angular
  - Shortening
  - Instability
  - Profile
    - Convexity
    - Super-position
    - Burned edges
    - Insufficient lag
    - Excessive Concavity
  - Weld size
  - Stress concentration
- Structural
  - Tri-dimensional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

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)

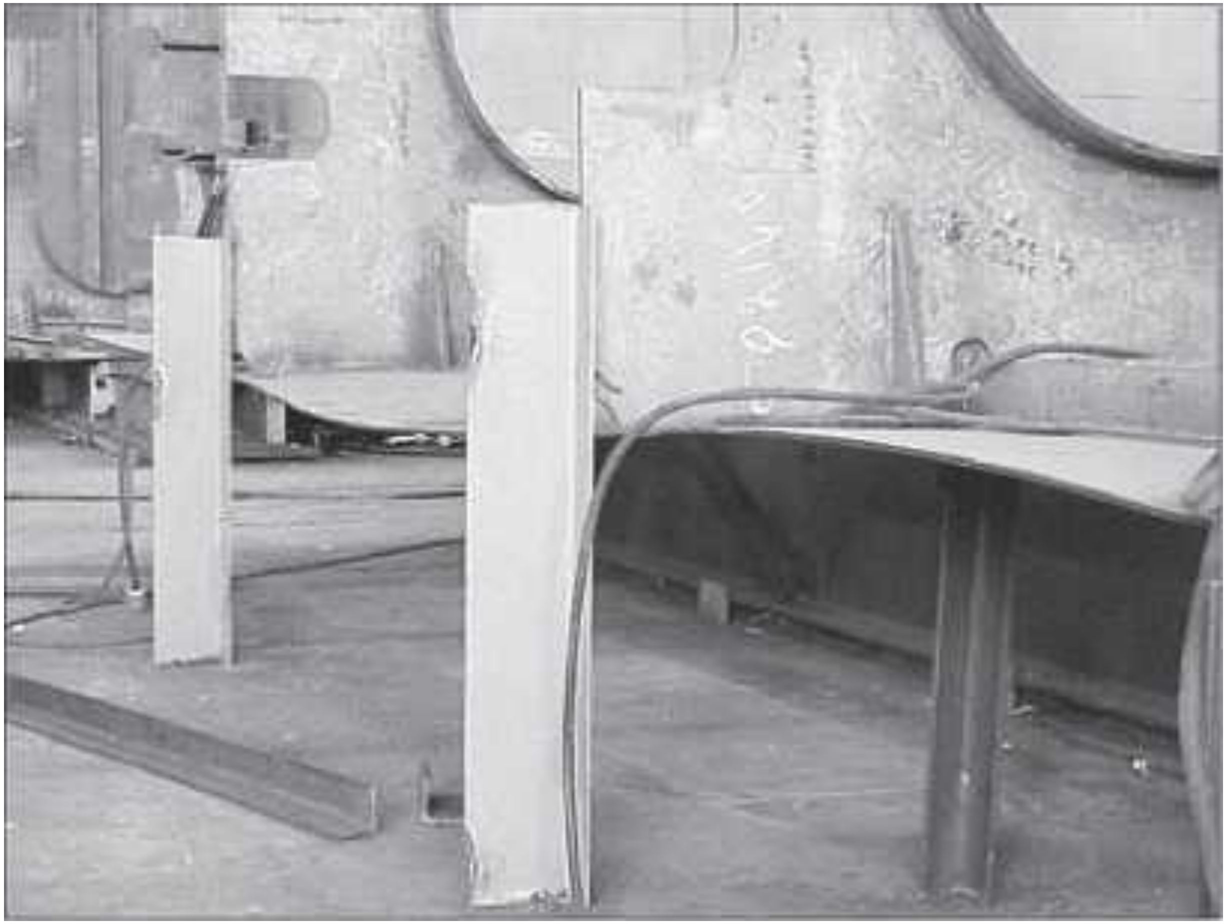
Basic types of welding distortion.

Buckling distortion dominates
on thin panels

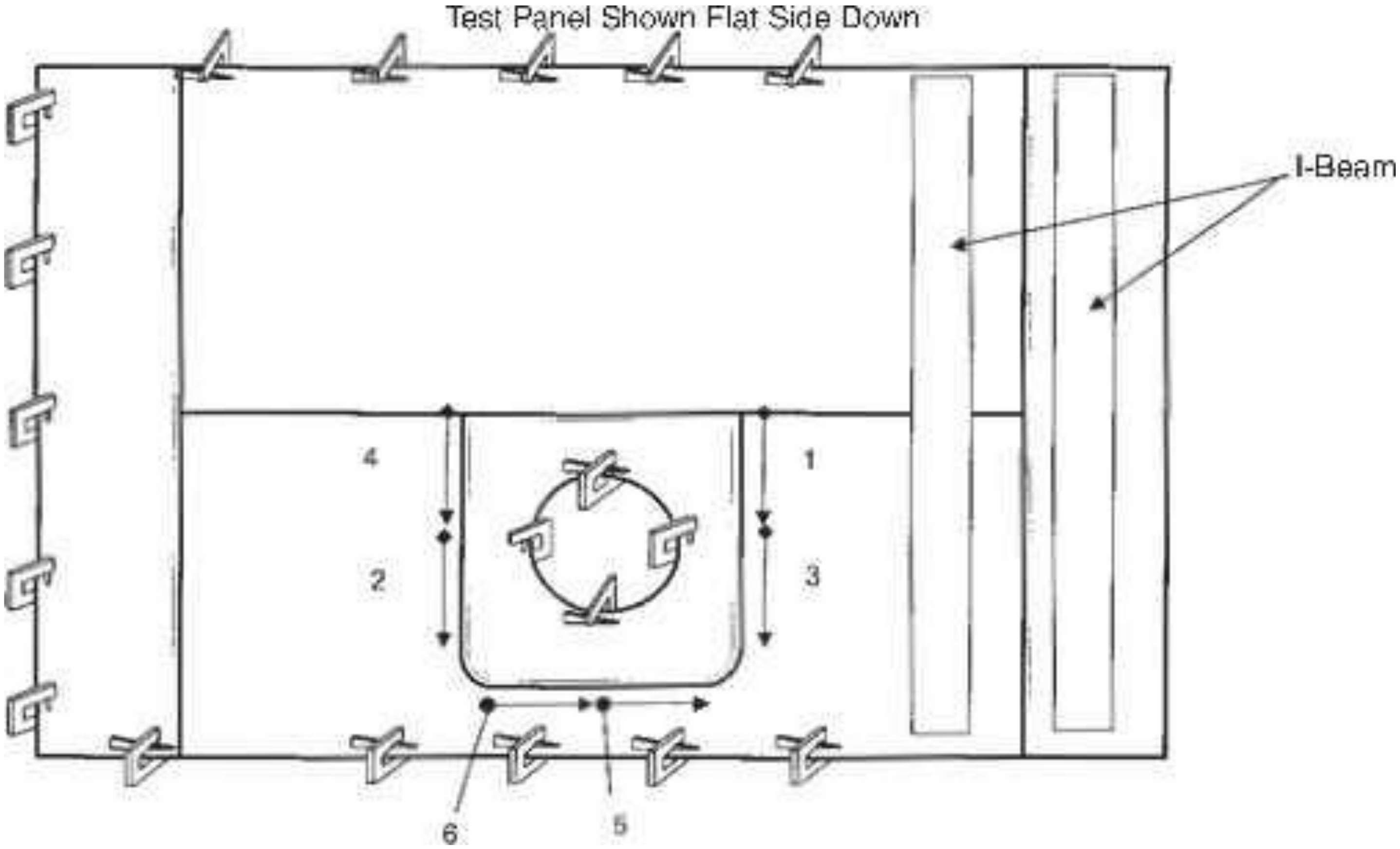


Clip and wedge clamping to a rigid foundation provides panel edge restraint

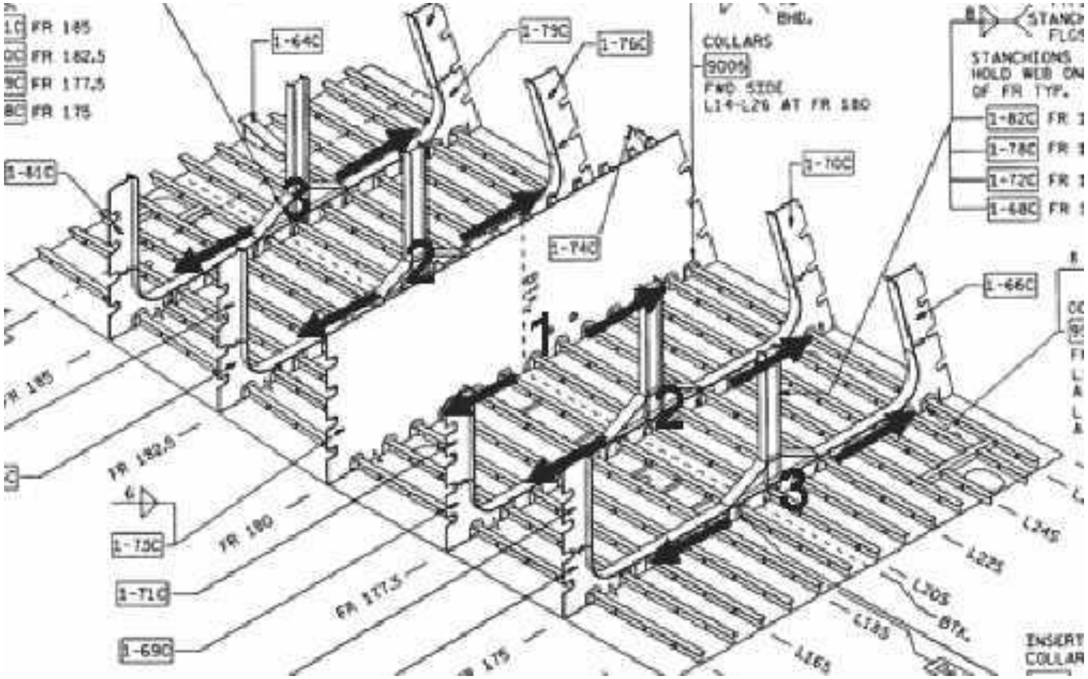
Inadequately restrained edge can result in large out-of-plane distortion



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

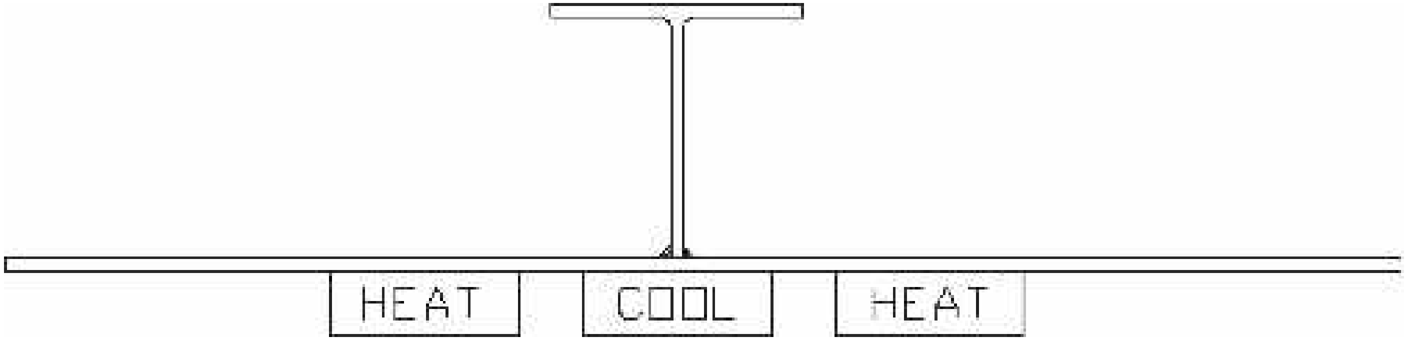
Design modifications

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

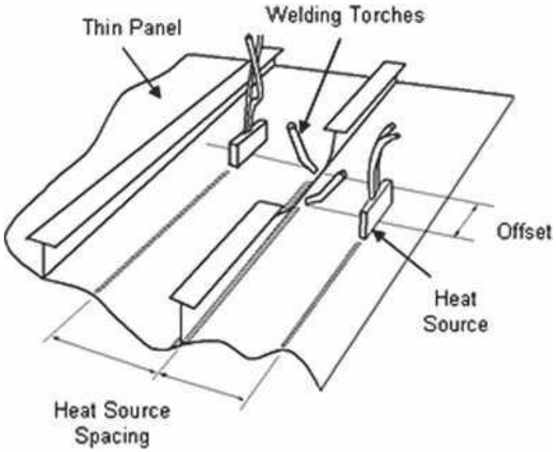
Active mitigation approaches

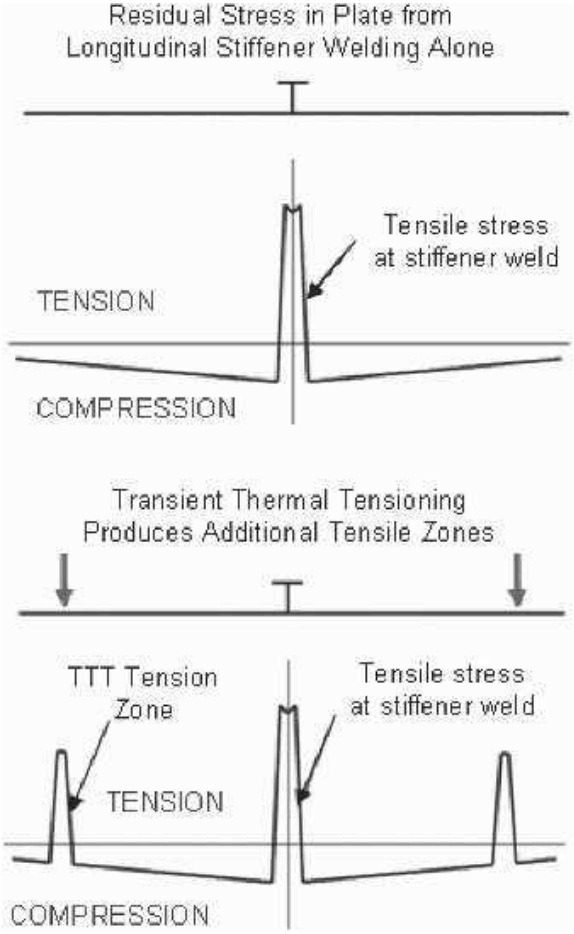
Technique	Benefits	Detriments
Balance heat input	Reduces angular distortion In use for double-sided submerged arc welding	• Requires double-sided welding • No benefit for buckling
Presetting butt joints	Can eliminate angular distortion	• No benefit for buckling • Degree of preset depends on plate thickness 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

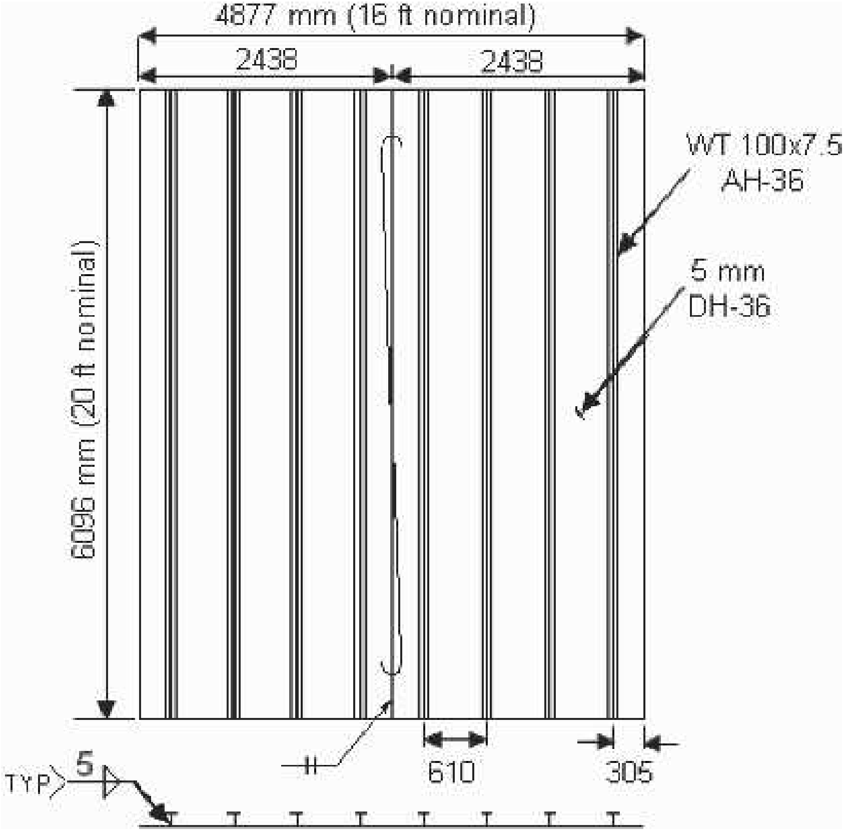


Schematic illustration of the residual stress pattern produced (left) without and (right) with transient thermal tensioning





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