LEARNING LESSONS FROM DESIGN CASE STUDIES OF STEEL STRUCTURES

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LESSON 1
WEB BEARING & BUCKLING

The Straits Times, 3 August 2004

HOME

WHAT HAPPENED DOWN

April 12-19
No strruts to hold up walls at the lowest le
to move.

2:30PM More walers buckle and

WHAT WENT W

Experts were bro
of Inquiry. Five
Nishimatsu-Lum
Consultants, L&

Where expert
- Contractor over-e
100 per cent. It unde
supporting structure
- Wrong method wa
- When the wall mo
the contractor's exp
rather than re-exam

Where there'
- Gap in retaining
structures.
- Design under-est
site.
- Walers not strong
- Concrete layer at

H2

HOW IT FELL APART

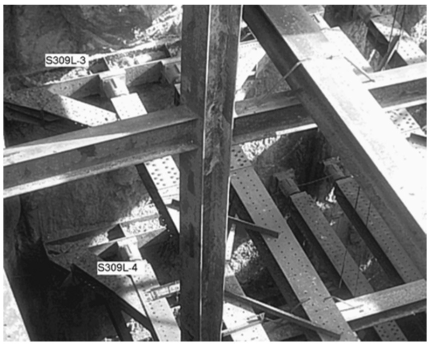
Four men working on a tunnel for the new MRT Circle Line died when a retaining wall collapsed on April 20 this year, causing a giant cave-in. This is what happened and what the experts say are the causes of it.

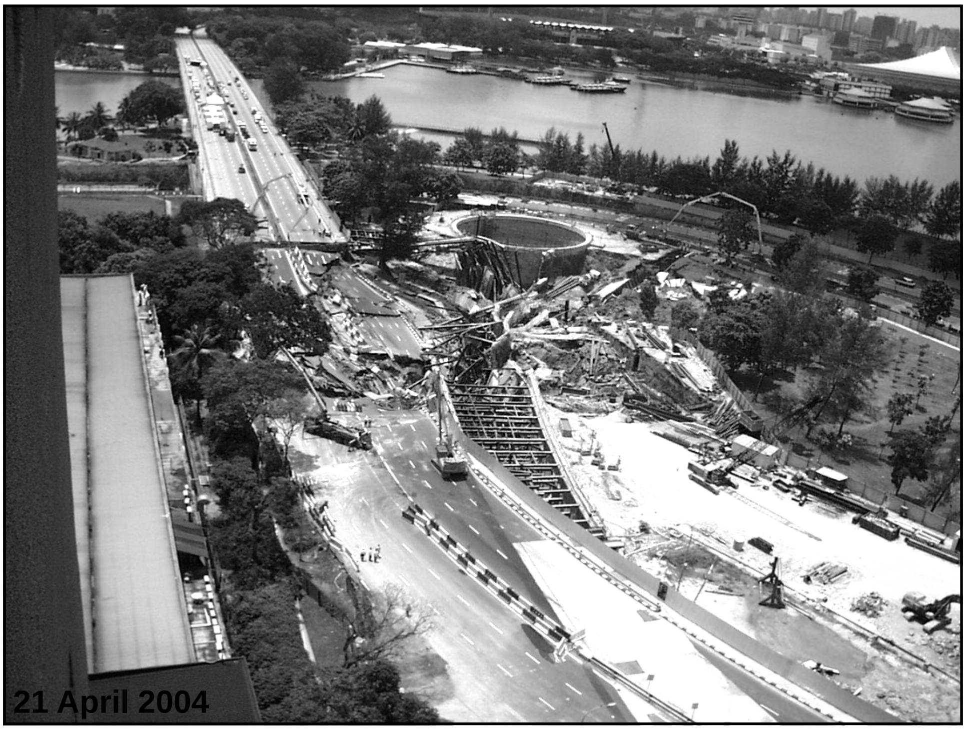
THE WEAK LINKS (ON DAY OF TRAGEDY)

Wall
Designed to shift slightly with soil movement. It moved more than it should.

Waler
Connects a metal strut to the wall. It buckled under pressure.

Strut
Holds up the walls on opposing sides. It fell when the walers buckled.





21 April 2004

CONCLUSIONS OF THE COMMITTEE OF INQUIRY (COI, MAY 2005)

The collapse was rooted in two critical design errors:

1) **Under-design of the diaphragm wall**

   This was associated with the use of the PLAXIS soil simulation model that over predicted the undrained shear strength of the clay.

2) **Under-design of the strut-waler connection**

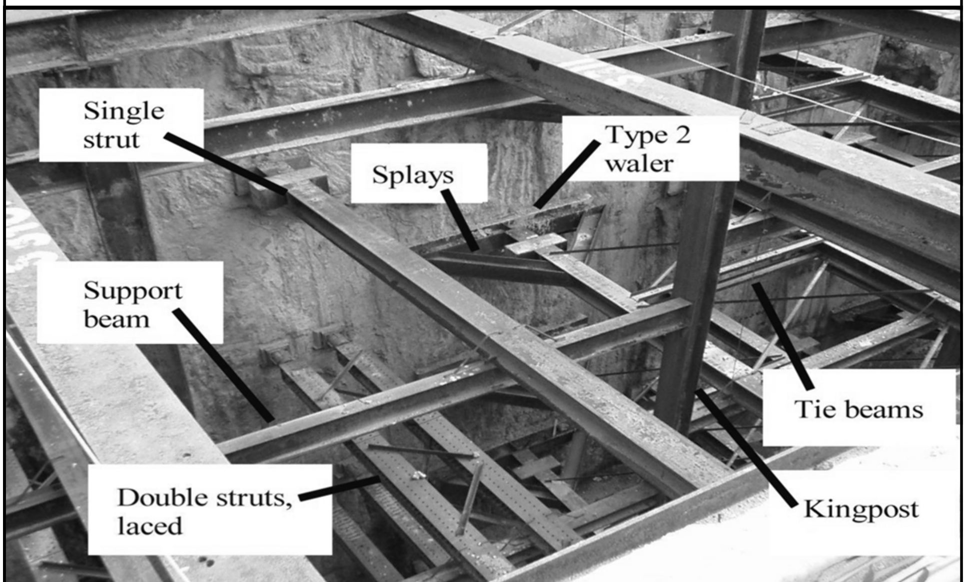
   Over-estimation of capacity based on BS5950 and splays omitted.

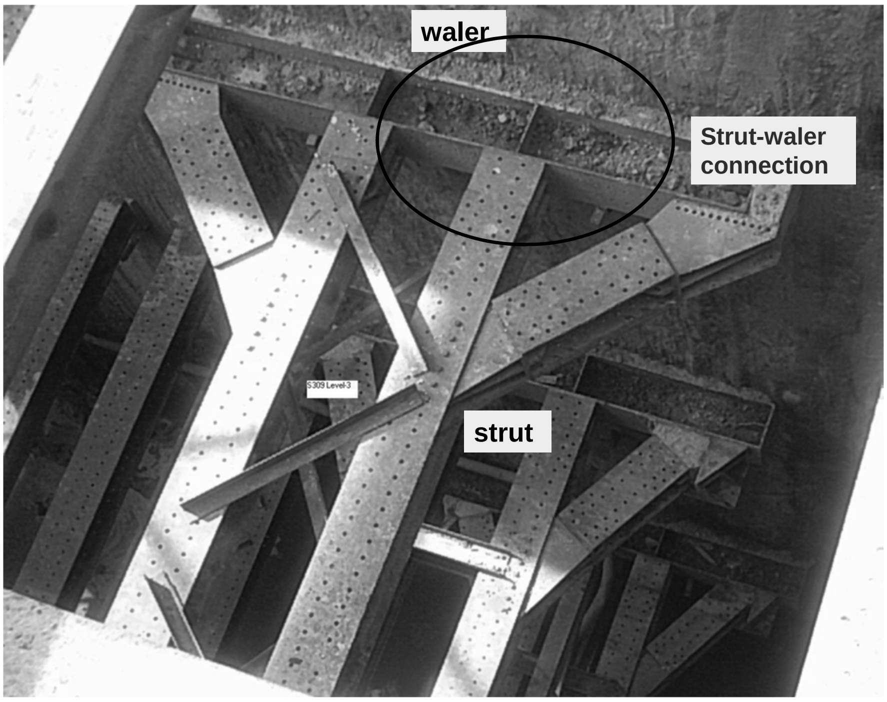
CONCLUSIONS OF THE COMMITTEE OF INQUIRY (COI, MAY 2005)

'*These design errors resulted, in the event, in the failure of the 9th level strut-waler connections together with the inability of the overall temporary retaining wall system to resist the redistributed loads as the 9th level strutting failed. The catastrophic collapse then ensued.'*

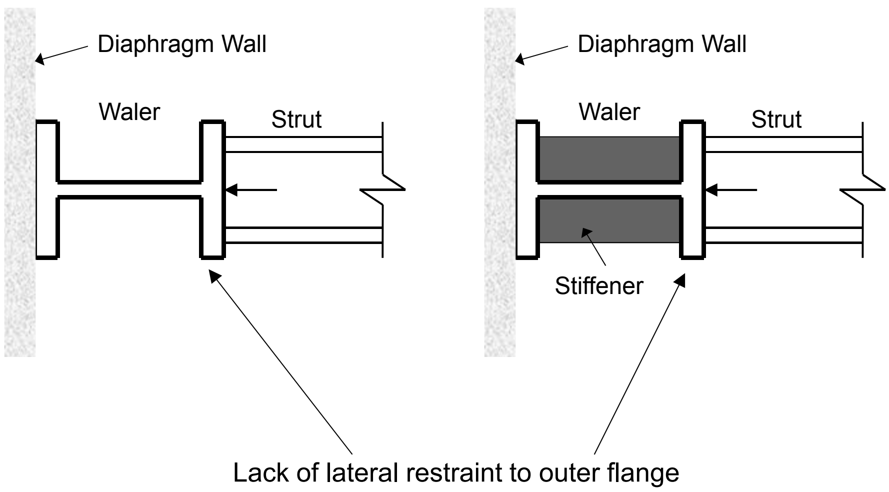
The Steel Strutting System

STEEL STRUTTING SYSTEM





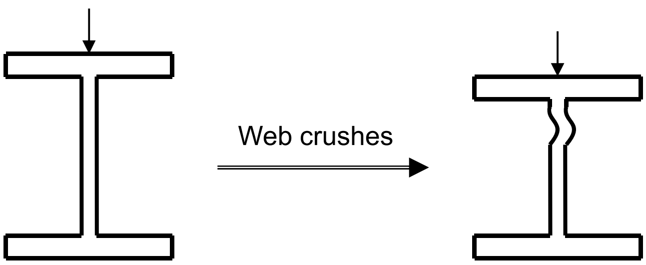
Strut-Waler Connection



Web Bearing & Stiff Bearing Length

Stiff Bearing Length

Web bearing failure is the localised crushing of the web near the root radius at the junction with the flange of the section



Web crushing occurs when the yield strength of the web (p_{yw}) is reached

Stiff Bearing Length

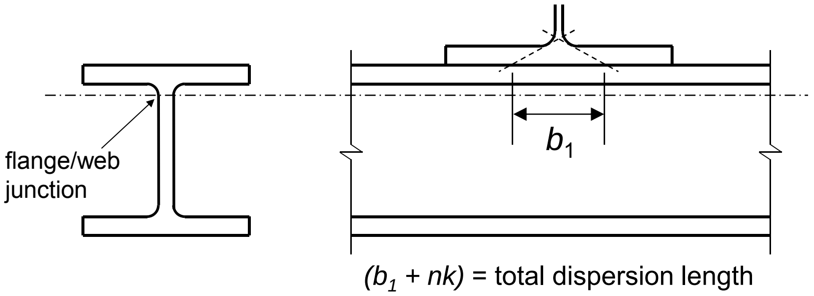
Introduction

- Web bearing depends on the effective area at the flange/web junction of the web which is resisting the load
- Defined in BS5950: Part 1: 2000 – Cl 4.5.1.3 as the Stiff Bearing Length (b_1)
- Stiff bearing length is the length of support that cannot deform appreciably in bending

Stiff Bearing Length

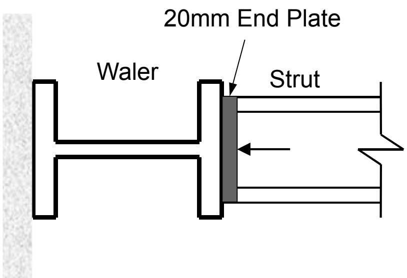
Background

For load bearing on the flange of the beam, stiff bearing length is not always equal to the width of the supported beam but to be calculated with reference to BS5950: Part 1: 2000 – Cl 4.5.1.3 (Figure 13)



Stiff Bearing Length

DESIGN EXAMPLE – Unstiffened Web Bearing



Strut Force = 3000 kN

Waler Properties

UC 356x406x287 kg/m
Grade 355 N/mm^2

Strut Properties

UC 305x305x240 kg/m

Stiff Bearing Length

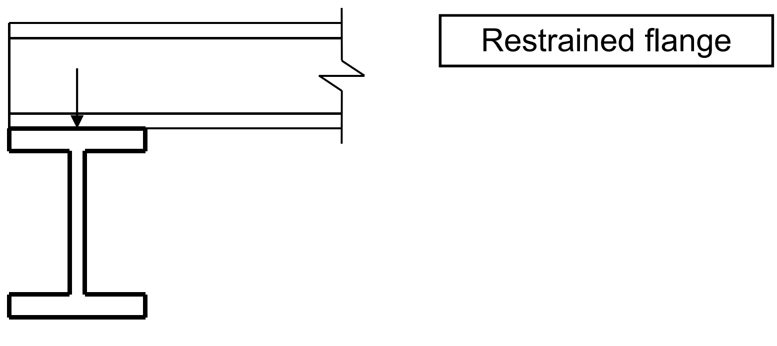
DESIGN EXAMPLE – Unstiffened Web Bearing

BS5950: Part 1: 2000 – Cl 4.5.2.1

Stiff Bearing Length	P_{bw} (kN)
b_1 = 317.9 mm *(Width of 305x305x240 kg/m)*	4494
$b_1 = t + 1.6s + 2t_p$ b_1 = 79.0 mm *(Based on Figure 13)*	2631

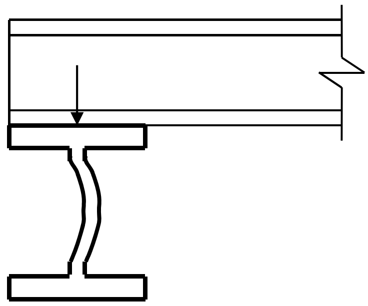
Web Buckling & Effective Length

Web Buckling & Effective Length



Effective Length of web, $L_E \leq 1.0d$

Web Buckling & Effective Length

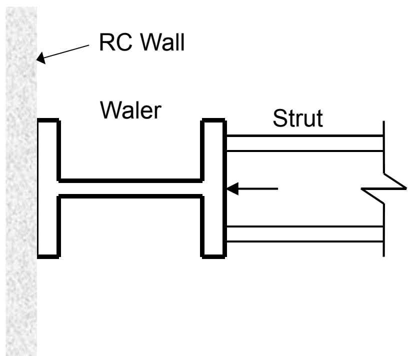


Restrained flange

Swaying & rotation of the flange is prevented by the supported beam

Effective Length of web, $L_E \leq 1.0d$

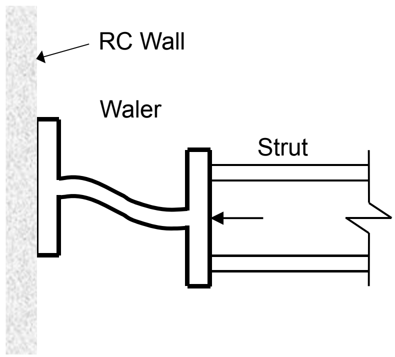
Web Buckling & Effective Length



Unrestrained flange

Effective Length of web, $L_E > 1.0d$

Web Buckling & Effective Length

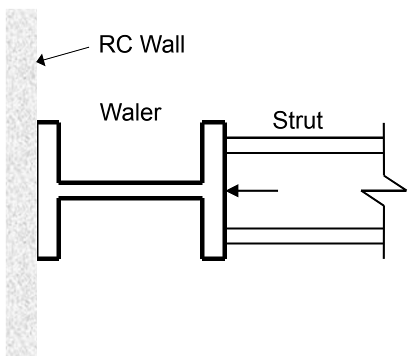


Unrestrained flange

Flange free to sway sideways

Effective Length of web, L_E > 1.0d

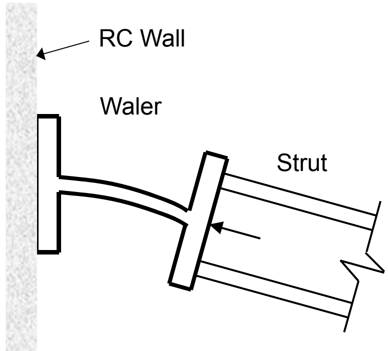
Web Buckling & Effective Length



Unrestrained flange

Effective Length of web, L_E > 1.0d

Web Buckling & Effective Length

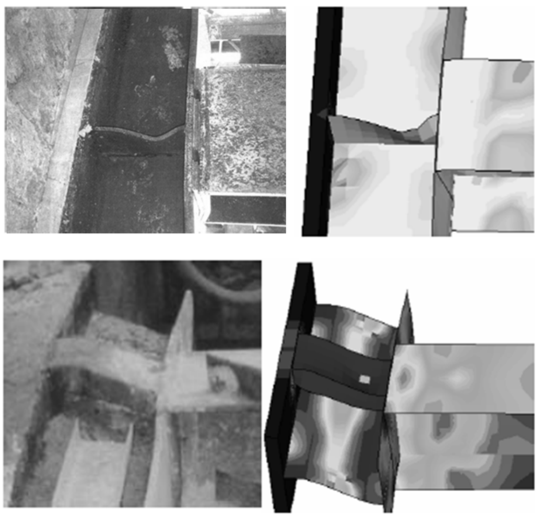


Unrestrained flange

Flange rotation relative to the web

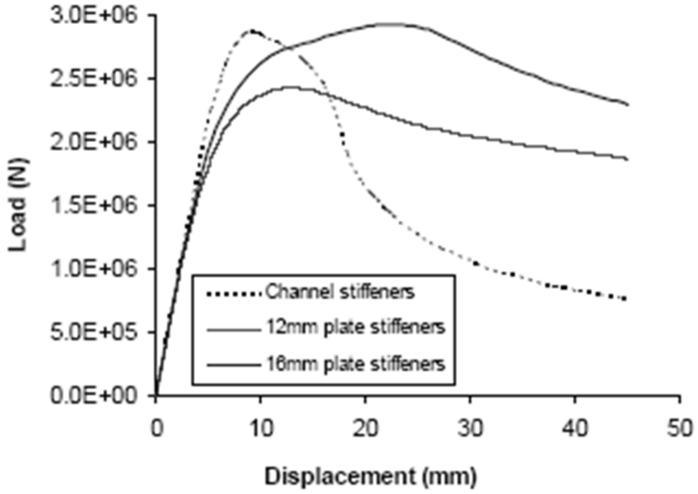
Effective Length of web, $L_E > 1.0d$

Failure Modes



Site Observations Numerical Simulations

Channel vs. Plate Stiffeners



The Committee of Inquiry (COI, May 2005) commented:

The change from the plate stiffeners to the C-channels was a major contributing factor.

'If only the plate stiffeners had been used throughout, the failure would probably have been localised and slower'

Three(3) Rules for Good Practice in Structural Engineering

- Rule No.1

  Ductility can be forgiving of one's mistake

- Rule No.2

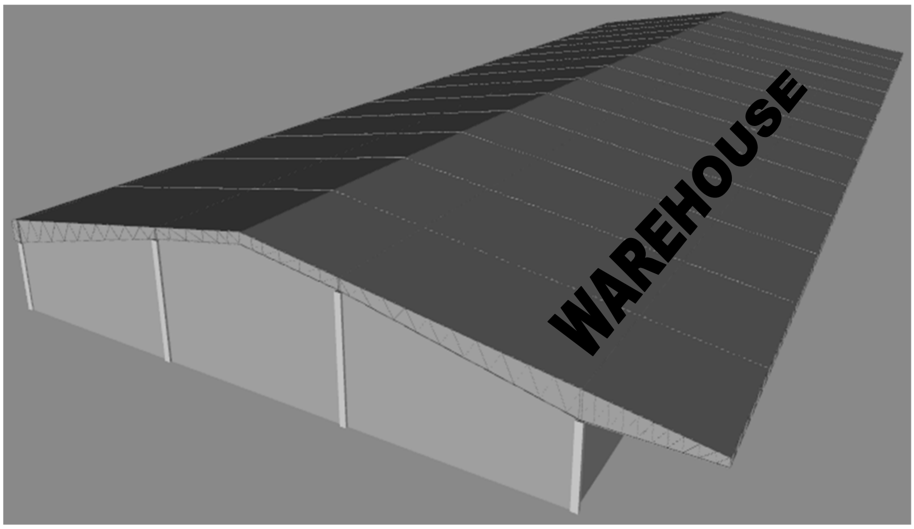
  Connection detailing is everything

- Rule No.3

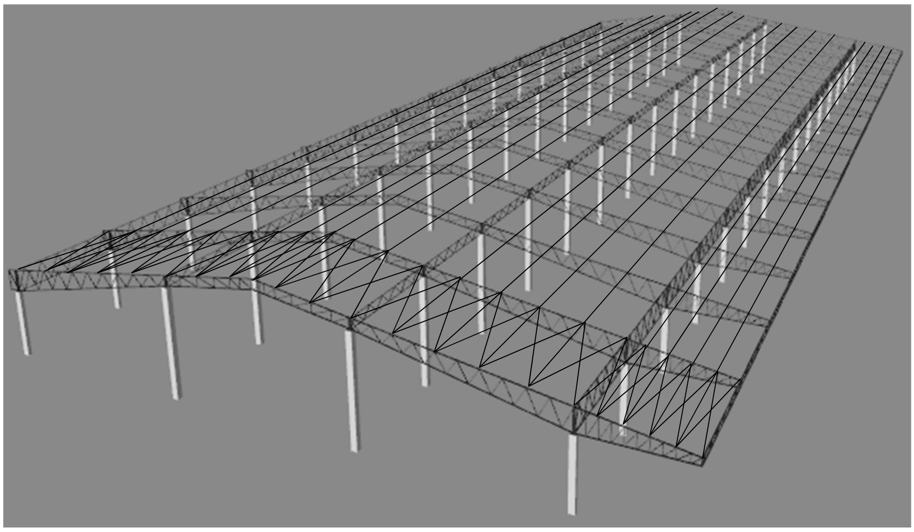
  Redundancies are our best defense against unexpected failure

LESSON 2
EFFECTIVE BUCKLING LENGTH

Cantilever Roof Truss

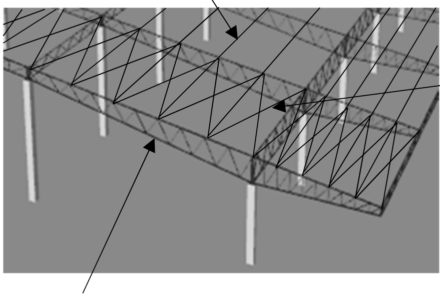


Cantilever Roof Truss



Effective Length of Compressive Bottom Chords

Purlins placed along the top chord provide out-of-plane lateral restraints to the top chord under compression → **Effective length is the purlin spacing**

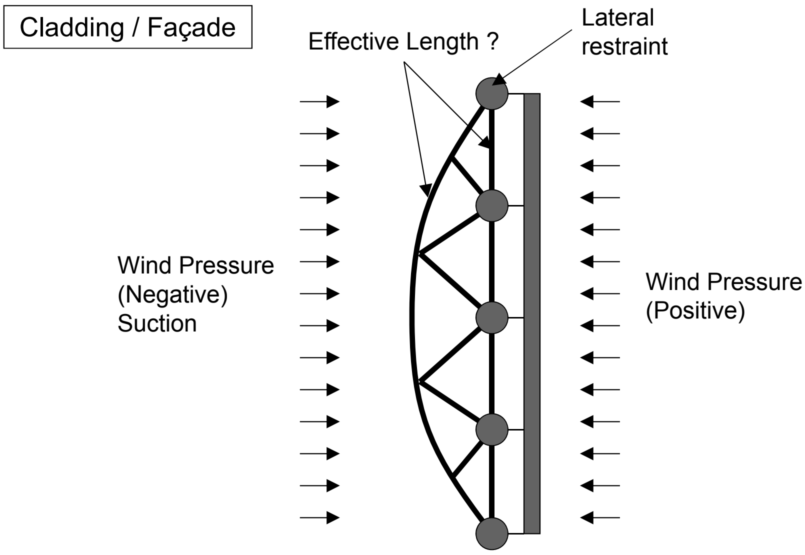


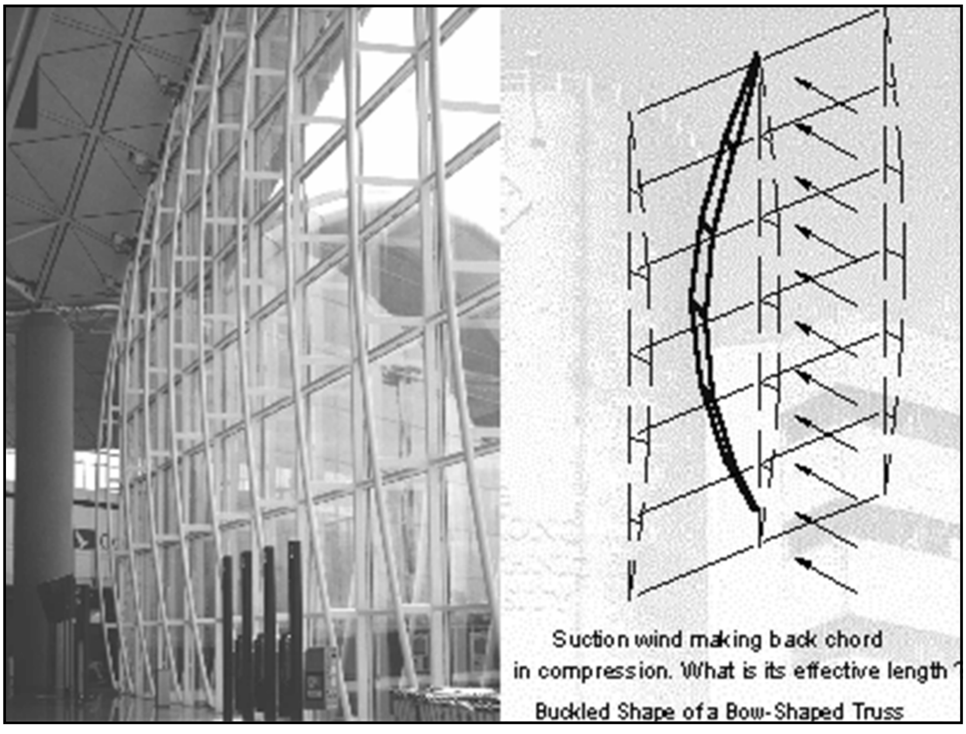
Cross bracings to provide restraints to the purlins

There are no purlins to provide lateral restraint to the bottom chord. → **Effective length is between points of contraflexure**

<u>Question</u>: what is the effective length of the compressive top chord member?

Effective Length



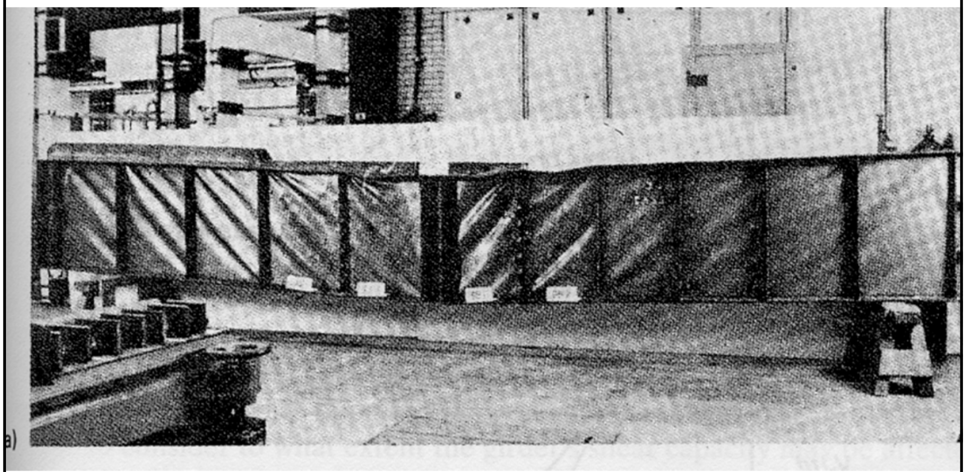


Pipe Strut vs. Laced Strut

Pipe Strut

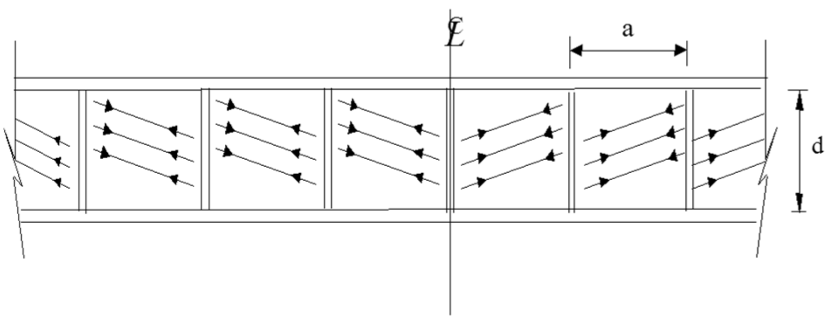
Laced Strut

LESSON 3
SHEAR BUCKLING

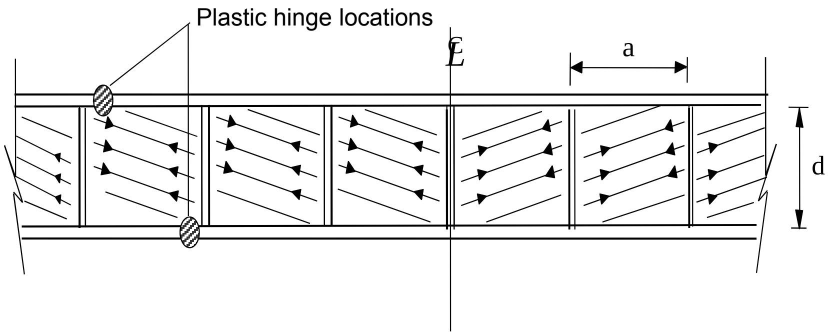


Shear Buckling of Thin Web

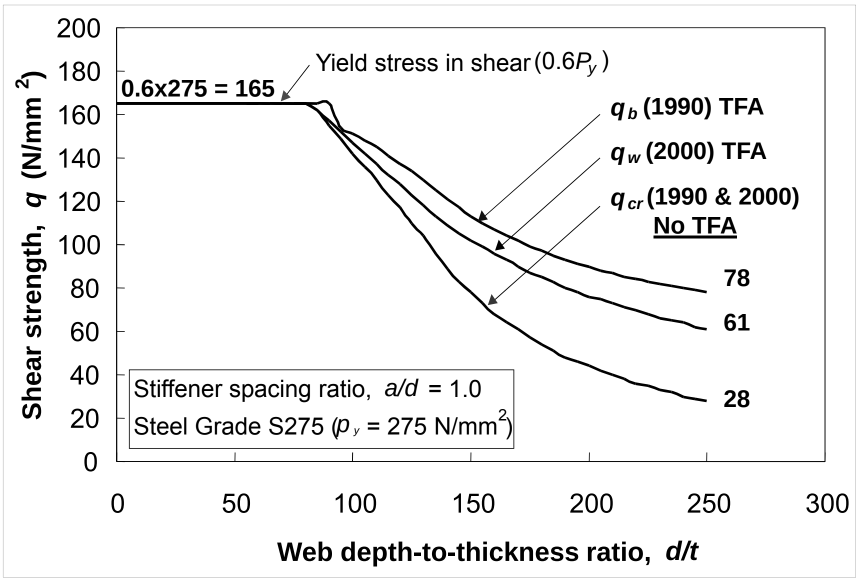
Tension field action causes the web to act as the diagonals of an N girder truss



Shear Buckling of Thin Web

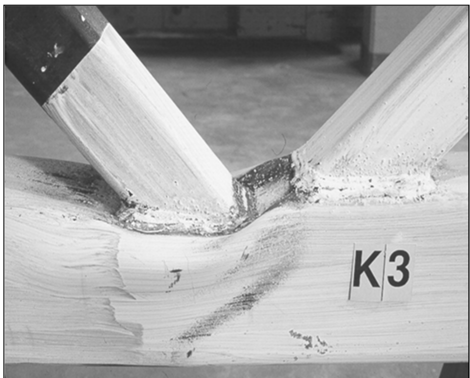


Comparison of (1990) with (2000) version for shear buckling strength of thin web



LESSON 4
HOLLOW SECTION JOINTS

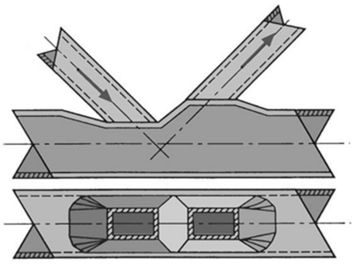
Why the fuss about Hollow Section Joint Design?



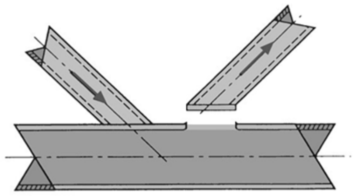
Hollow Section Joints can be very flexible!

Designing un-stiffened joints is a skilled task and must be done at the member design stage

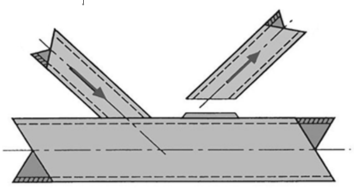
Potential Failure Modes for Welded Hollow Section Joints



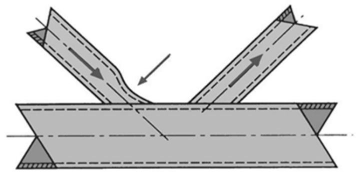
Mode A: Plastic failure of the chord face



Mode B: Punching shear failure of the chord face

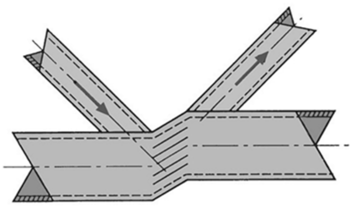


Mode C: Tension failure of the web member

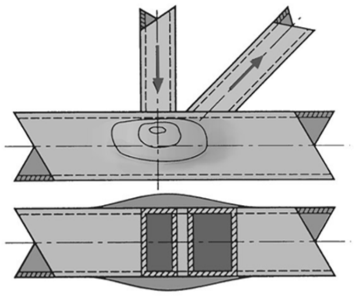


Mode D: Local buckling of the web member

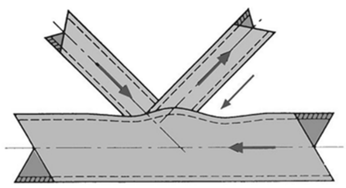
Potential Failure Modes for Welded Hollow Section Joints



Mode E: Overall shear failure of the chord

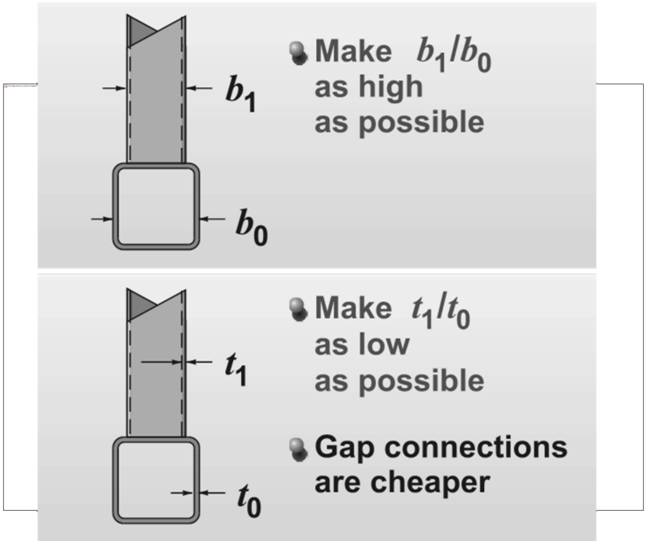


Mode F: Local buckling of the chord walls



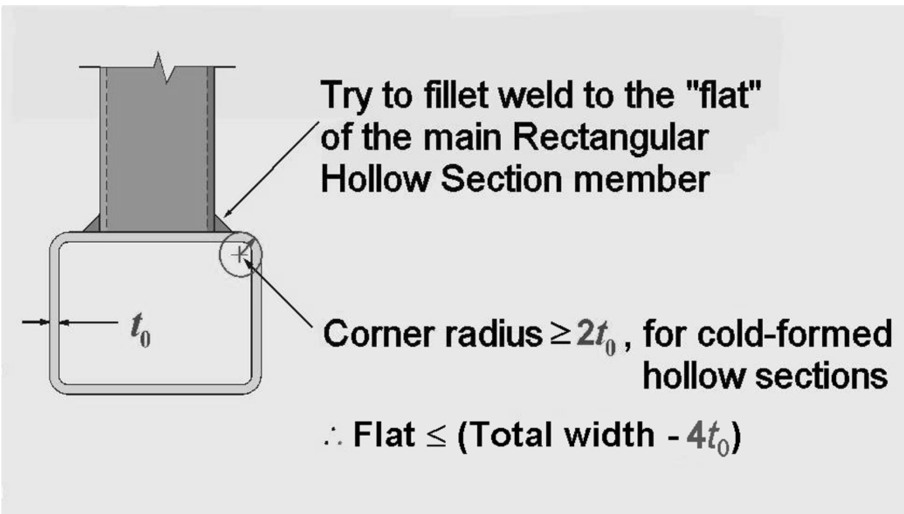
Mode G: Local buckling of the chord face

Some Golden Rules to Avoid Tubular Joint Problems



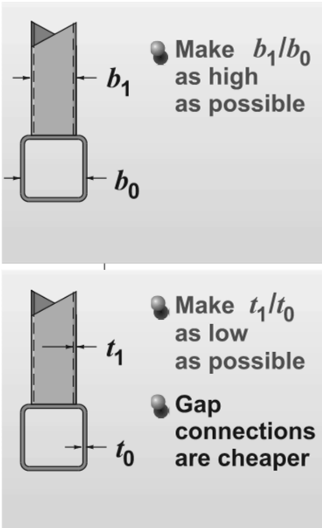
General Tips for Designers

Welding of Rectangular Hollow Sections

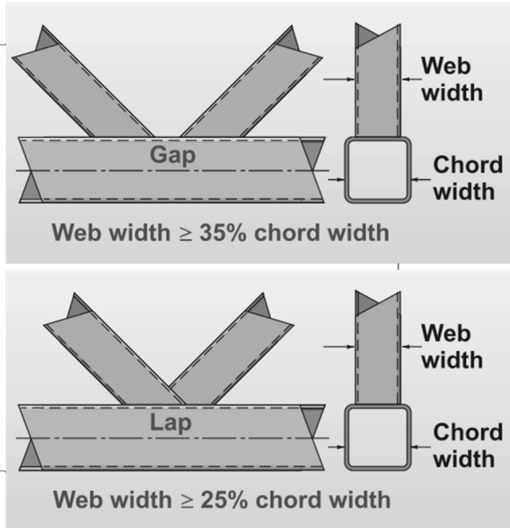


Some Golden Rules to Avoid Tubular Joint Problems

General tips for designers

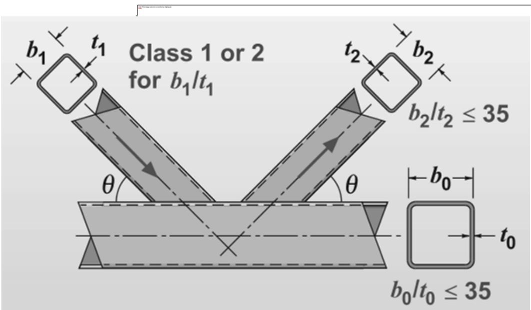


Width Ratios

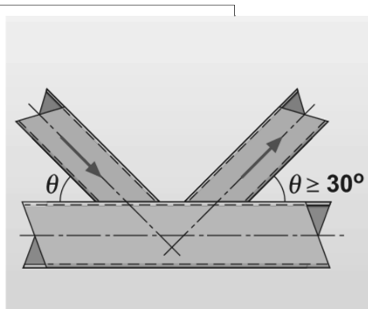


Some Golden Rules to Avoid Tubular Joint Problems

Wall Slenderness

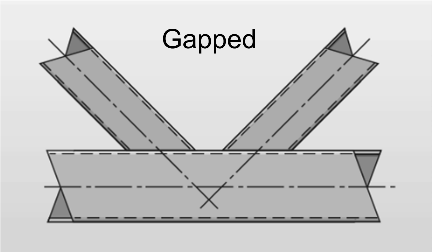


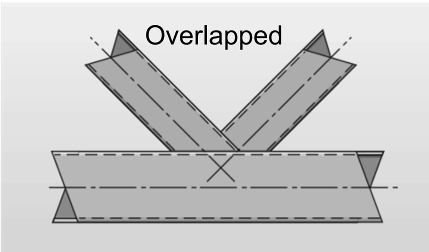
Web Angles



Gapped vs. Overlapped Truss Joints

- Design tips to optimize welded HSS joint design
  - Select relatively stocky chord
  - Select relatively thin branch
  - Consider virtues of gapped K-connections





- Easier and cheaper to fabricate

- Higher static and fatigue strength, generally
- Produces stiffer truss (reduces truss deflections)

Thank You!/Terima Kasih!

Source: The Straits Times (2 April 2014)

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