Presentation on

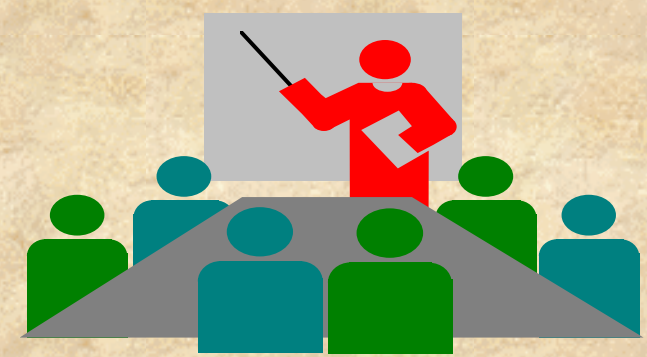
STEEL STRUCTURE

Mah Seong Wee

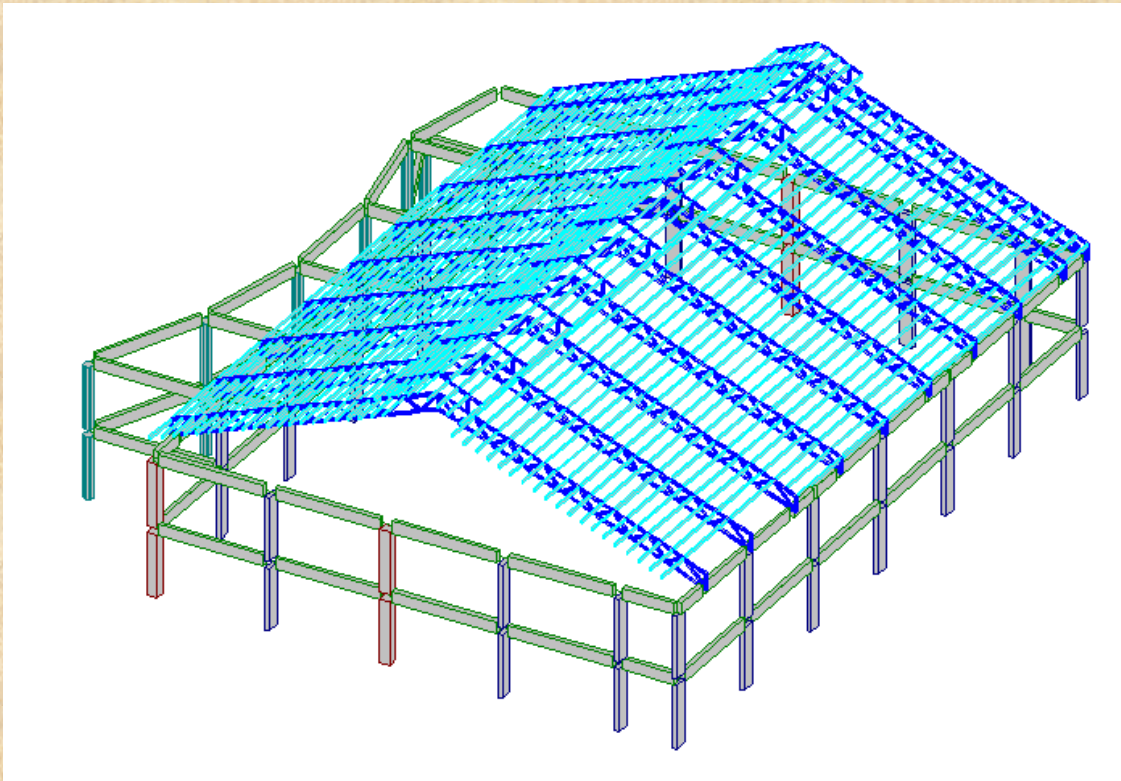
Construction Section

CONTENTS

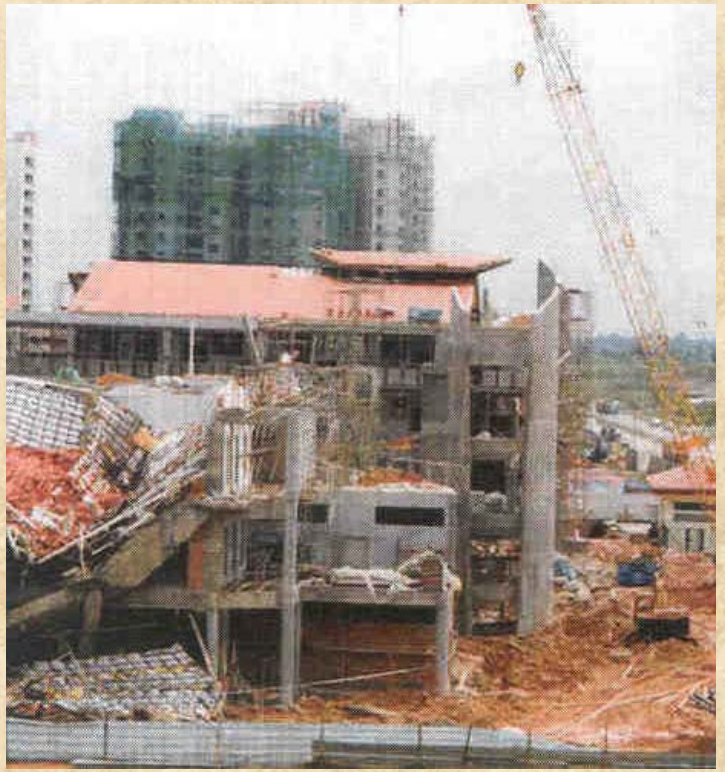
- **STEEL**
- **CONNECTIONS**
- **BOLTS**
- **WELDS**
- **HDB STEEL STRUCTURES**



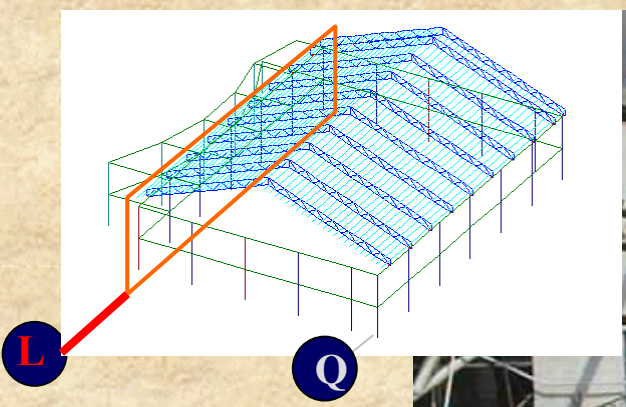
Roof Collapse at Compassvale School



Site Photo



Site Observation



Columns at Gridline L which were braced to adjoining structure remained intact.

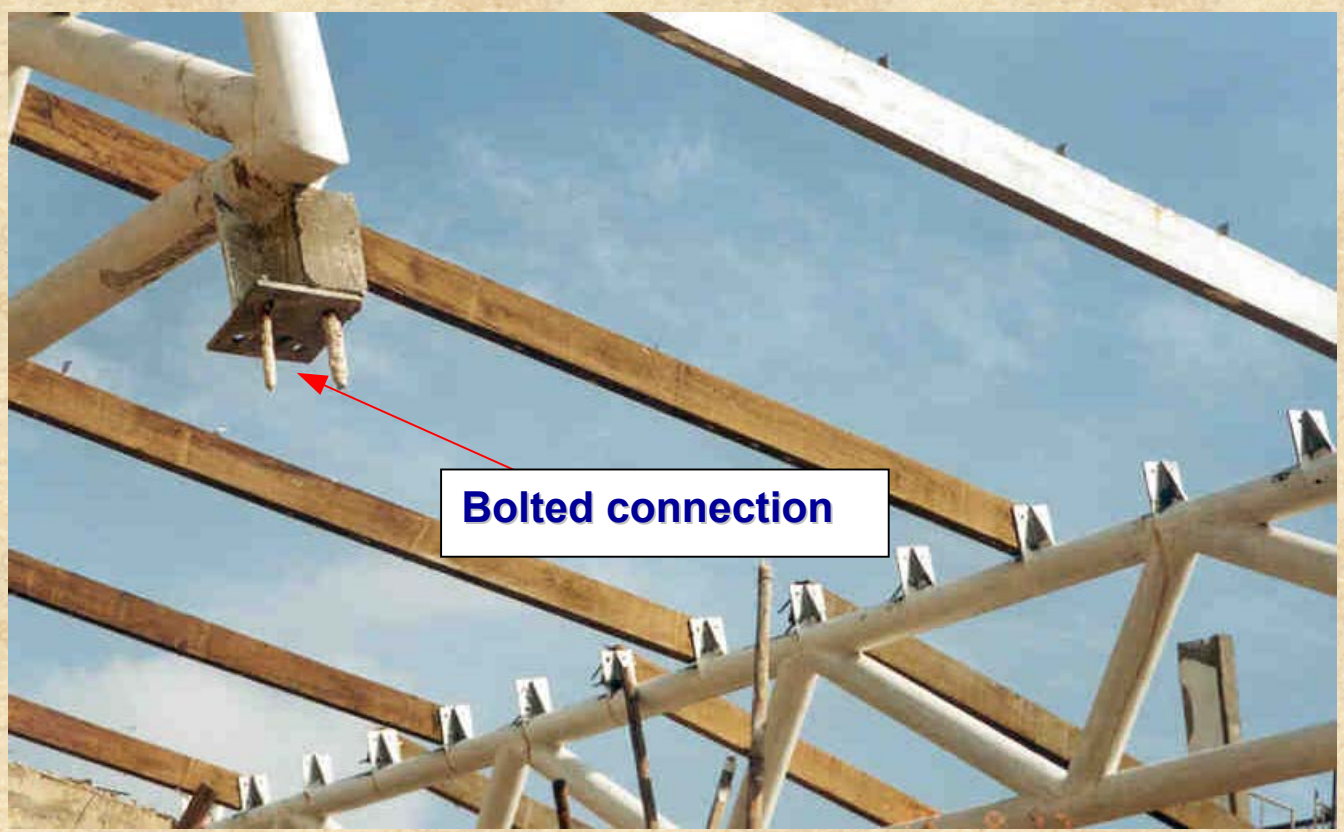
Site Observation

The roof trusses broke into two sections and the breakage occurred mainly at the center of truss.

Site Observation

Failures of trusses were at welding locations.

Site Observation



Bolted connections were pulled out of column.

Lessons (Construction)

- **No pre-welding and post-welding inspections was carried out.**
- **Shop drawings submitted by contractor were not checked**
- **Welded joints should not be located at the critical locations of the truss (e.g. at the Apex)**
- **Full butt welds should have been used instead of fillet welds for joining two steel sections of similar dimensions together.**

CONNECTIONS OF STRUCTURE ARE AS IMPORTANT AS THE JOINTS OF A HUMAN BODY

The Lesson is :

Back to Basic :

STEEL

Structural Steel

Steel = 98% of Iron with Main Alloying Elements Carbon, Silicon, Manganese

- Copper and chromium added to increase corrosion resistant
- Rarely contains more than 0.25% of carbon
- Higher the carbon content, the brittle the steel
- Grade 43 (most common), 50 and 55 (strongest)
- Design Grade -> Thickness -> Design Strength
- Hot Formed and Cold Formed Hollow Sections

Structural Steel

- Ductile at temperature above 10 degree C and more brittle as temperature falls below that.
- Performs badly in fires, with strength decreases with rise in temperature.
- Fire protection is needed such as encasing steel member with concrete.

Structural Steel

- Exposed steelwork easily subjected to corrosion.
- For corrosion protection, use :
- Metallic coating - dipping in a bath of molten zinc in galvanizing process **or**
- - spray on coating of aluminium or zinc is used on the member
- Painting - primer of zinc chromate followed by coats of iron oxide

HDB Requirement for Structural Steel

- Grade 275 series steel for all members
- All steel area to be painted shall be primed with a coat of red lead primer or 1 coat of zinc chromate primer
- All steel purlins and all steel members for building 5 storey and above shall be hot dipped galvanized
- All bolts, nuts and washers for connecting purlins and for building 5 storey and above shall be zinc-electroplated

CONNECTIONS

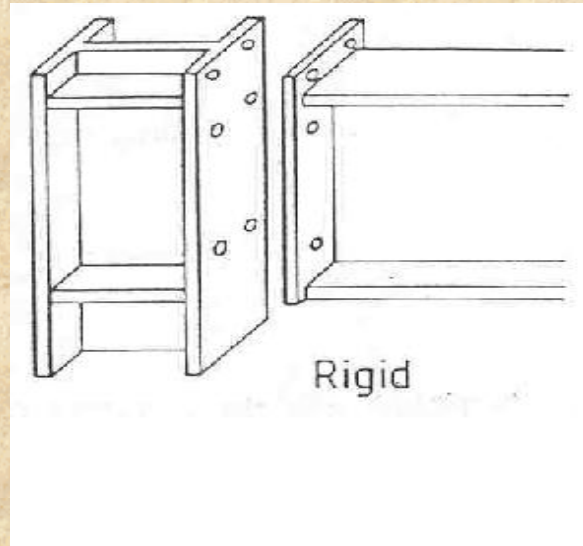
Design of Connections

- BS 5950 mentioned "Connections should be designed on the basis of a realistic assumption of the distribution of internal forces,having regard to relative stiffness"
- Joint should be designed to act in accordance with the assumptions already made in the design
- Ductility of steel assists in the distribution of force generated within a joint
- Means that not a need to consider residual forces due to lack of fit, or bolt tightening

Types of Design

- ***Rigid Design***

- Joints in structure are assumed to be able to fully transfer the forces and moments in members which they attach

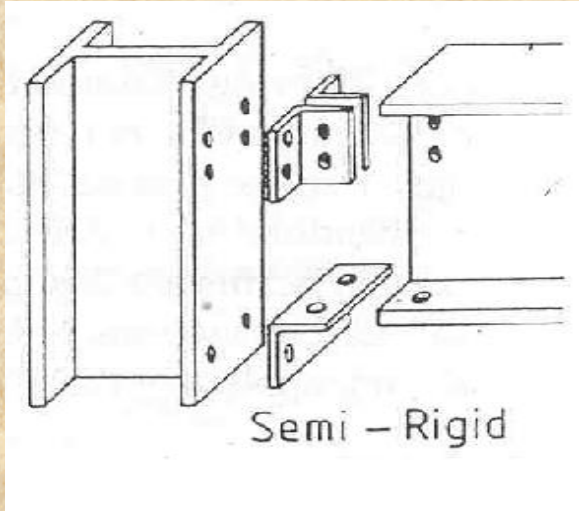


Types of Design

- ***Semi-Rigid Design***

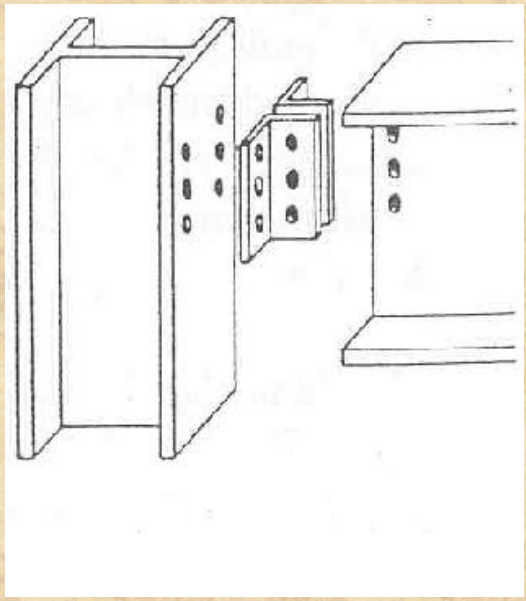
- Joints in structure are assumed to transmit some restraint moment

- Not recommended as the design concept is not matured enough for practical design use



Types of Design

- ***Simple Design***
- Pinned joints, and significant moments are not developed at connections
- Beams are designed as simple supported



- **Simple Construction**

BOLTS

Types of Bolts

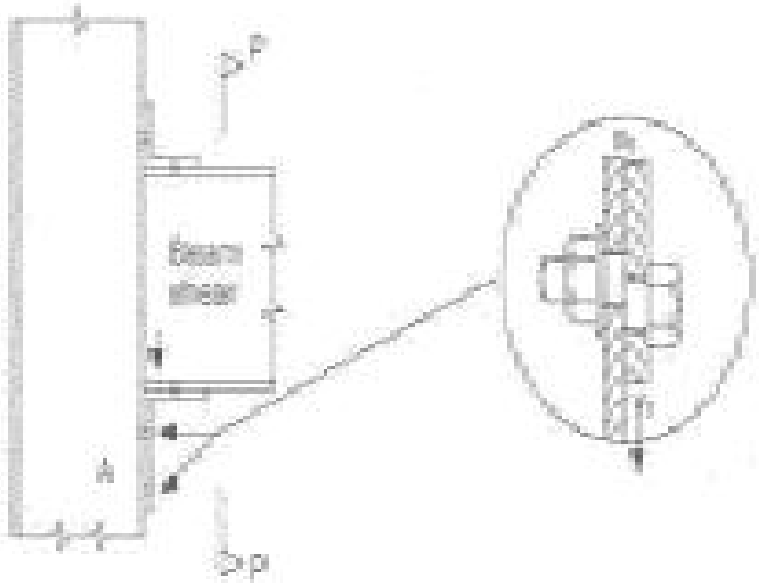
Type of Bolt	Abbreviation	Standards
Black Bolt	Black Bolt	BS4190
High Strength Bolt	HS Bolt	BS3692
High Strength Friction Grip Bolt	HSFG Bolt	BS4604

Ordinary Bolts

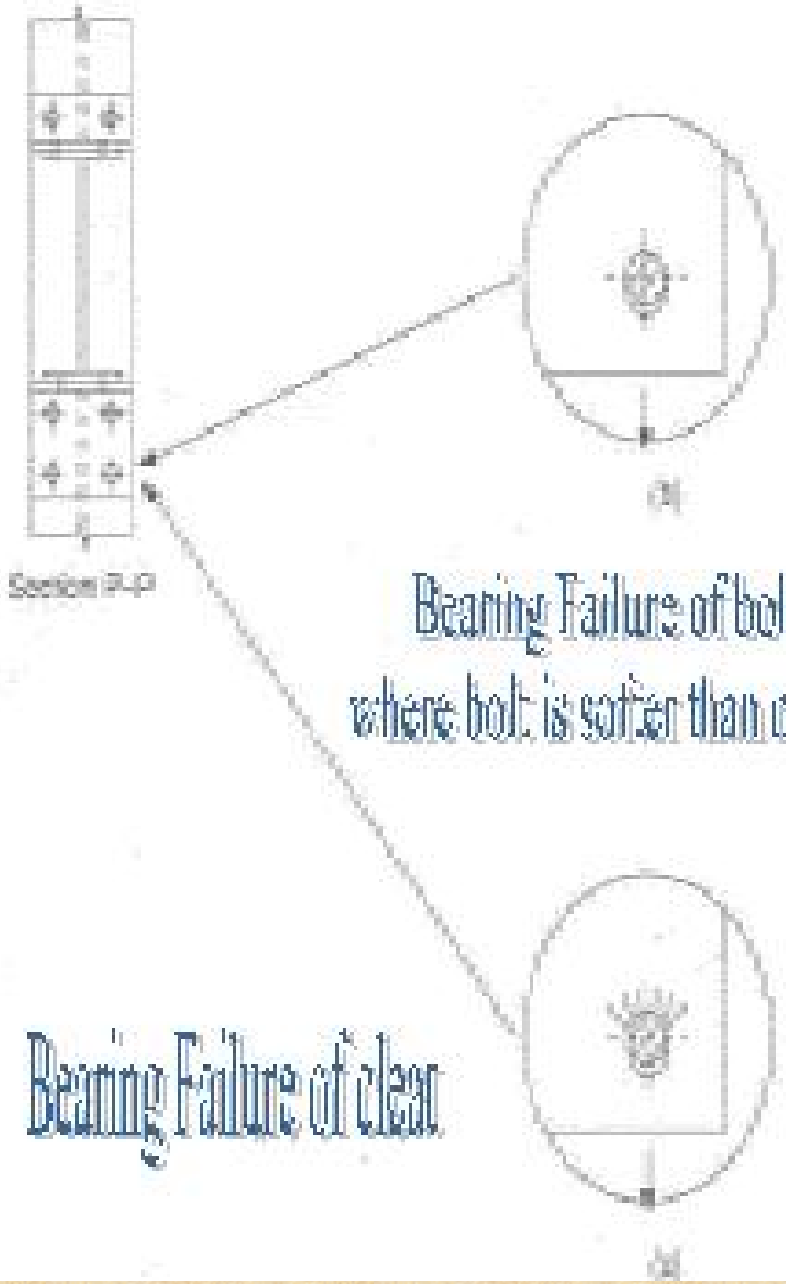
- **(Grade 4.6 or 8.8)**

- Grade 4.6 => mild steel =>Yield Stress = 235 N/mm2
- Grade 8.8 => high strength steel => Yield Stress = 627 N/mm2
- Black Hexagon head bolt is most commonly used

Bolts Failure



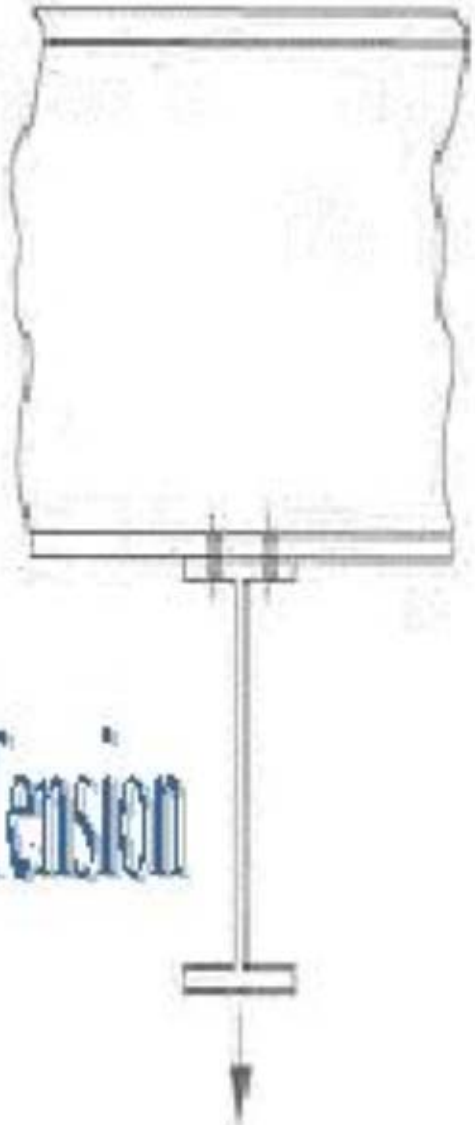
Single Shear Failure



Bearing Failure of bolt
where bolt is softer than metal

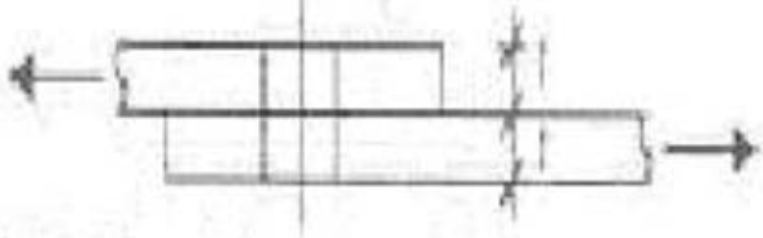
Bearing Failure of plate

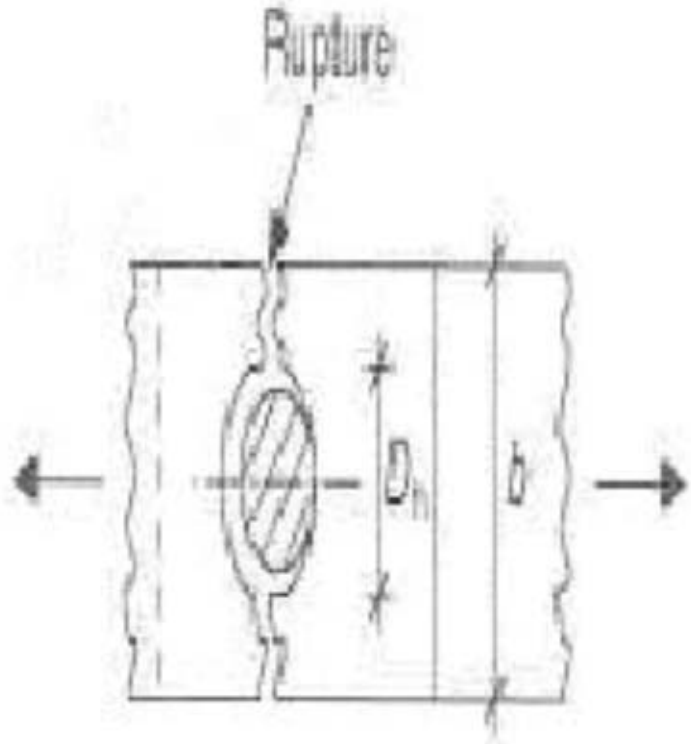
Bolts Failure



Bolts in Tension

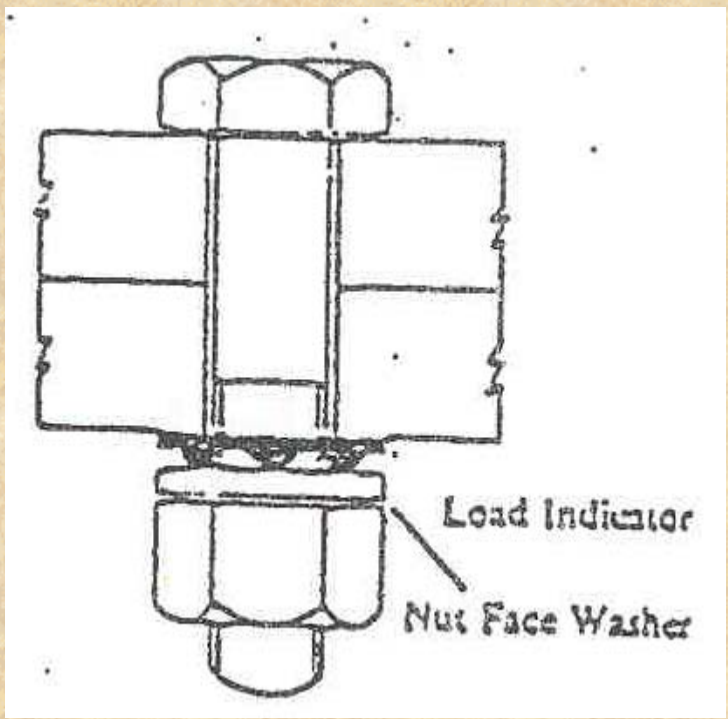
Covers in Tension

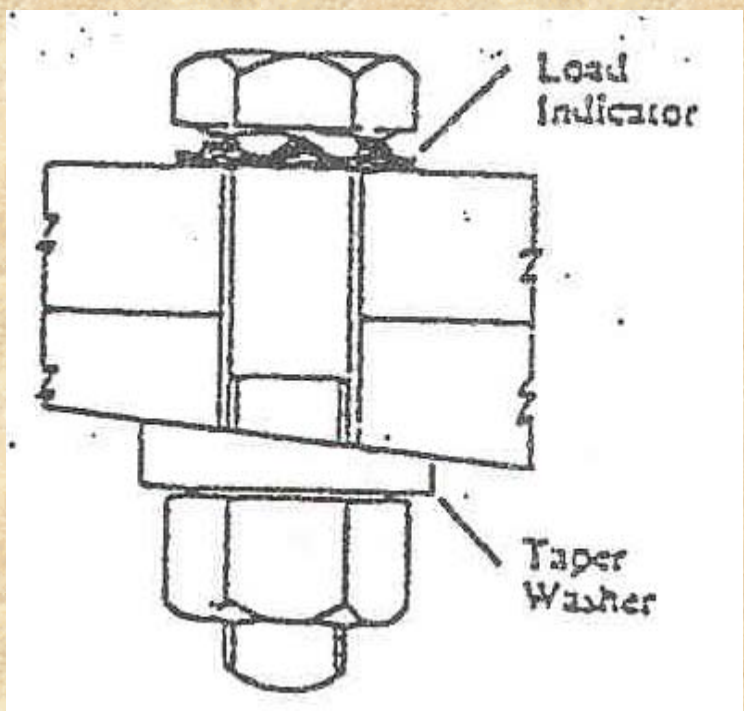




High Strength Friction Grip Bolt

High Strength Friction Grip Bolt





High Strength Friction Grip Bolt

- HSFG bolts consist of high-tensile bolt and nut and hardened steel washer.
- Hardened steel washer will prevent damage to connected parts
- Special type of washers such as “load indicator” can be used
- Load indicator washer has projections that squash down as bolt is tightened. Ensure correct shank tension

High Strength Friction Grip Bolt

- Bolts are tightened to a predetermined shank tension so that clamping force will transmit force in connected members by friction
- Bolts do not act in shear or bearing
- No slip or movement between connected parts due to shank tension and thus good in rigid connection
- Surface in contact must be free of oil,grease,scale and paint so as not to lower the slip resistance

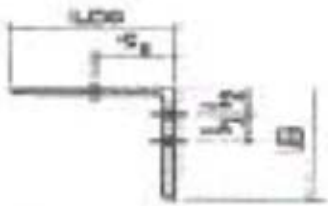
High Strength Friction Grip Bolt

- **Advantages**
- Stiff in shear because of friction
- Stiff in tension than bearing bolts because of preloading
- Good fatigue resistance
- **Disadvantages**
- Expensive to install
- Bolts are not reusable

SPACING OF HOLES IN CHANNELS

NOMINAL FLANGE WIDTH (mm)	g_1 (mm)	RECOMMENDED DIA. OF RIVET OR BOLT (mm)
100	55	24
150	60	20
75	45	20
65	35	16
50	30	16
380	40	-

SPACING OF HOLES IN ANGLES



NOMINAL LEG LENGTH (mm)	SPACING IN MILLIMETRES						NOMINAL LEG LENGTH (mm)	g_3 (mm)
	g_1	g_2	g_3	g_4	g_5	g_6		
200	-	75	100	65	65	65	90	45
200	-	70	75	60	50	50	80	35
175	-	60	75	-	-	-	90	32
150	80	60	90	-	-	-	70	30
130	70	45	60				60	25
127	70	45	60				50	22
100	60	-					45	20
90	55	-	-	-	-	-	40	16

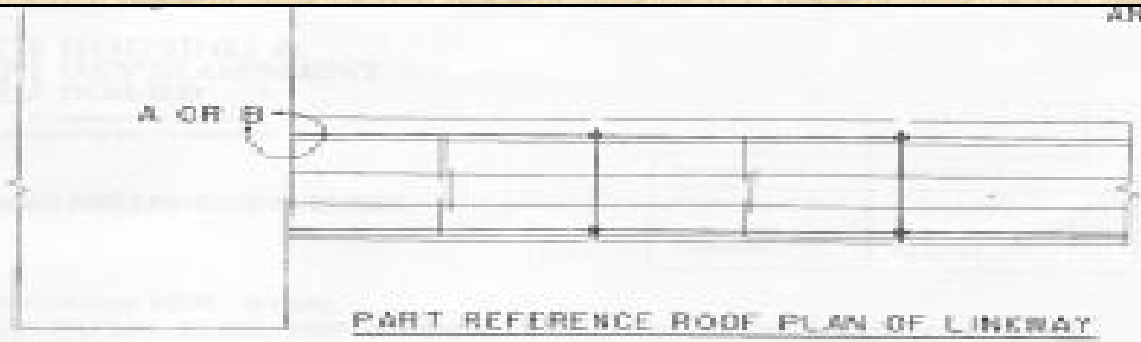
Inner gauge lines are selected for normal conditions and may require adjustment for unusually large diameters of fasteners or thick members. Outer gauge lines may require consideration in relation to a specified edge distance.

TABLE 5.15

Structural Steel End Connection to Concrete Structure At Linkways

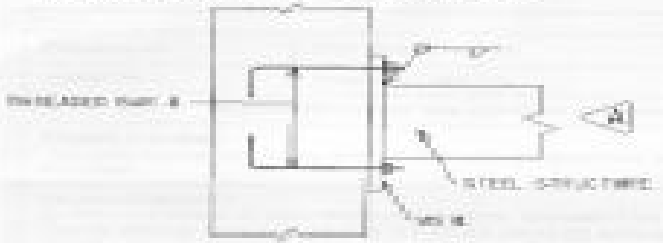
- For connection to new concrete structure, threaded bars with tension anchorage are to be adopted
- For connection to existing concrete structure, mechanical anchor bolts are to be used
- Threaded bars shall be high yield deformed bar Type 2

ANNEX 1



PART REFERENCE ROOF PLAN OF LINKWAY

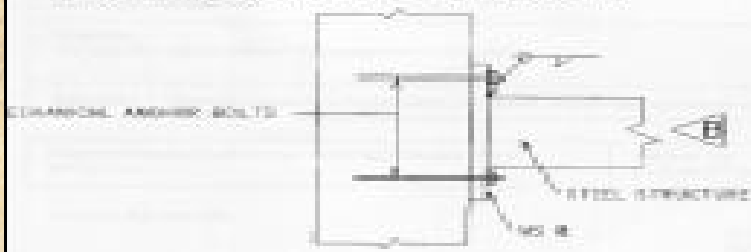
NEW CONCRETE STRUCTURE



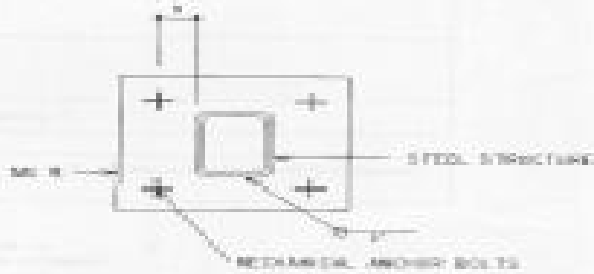
DETAIL A

VIEW A

EXISTING CONCRETE STRUCTURE

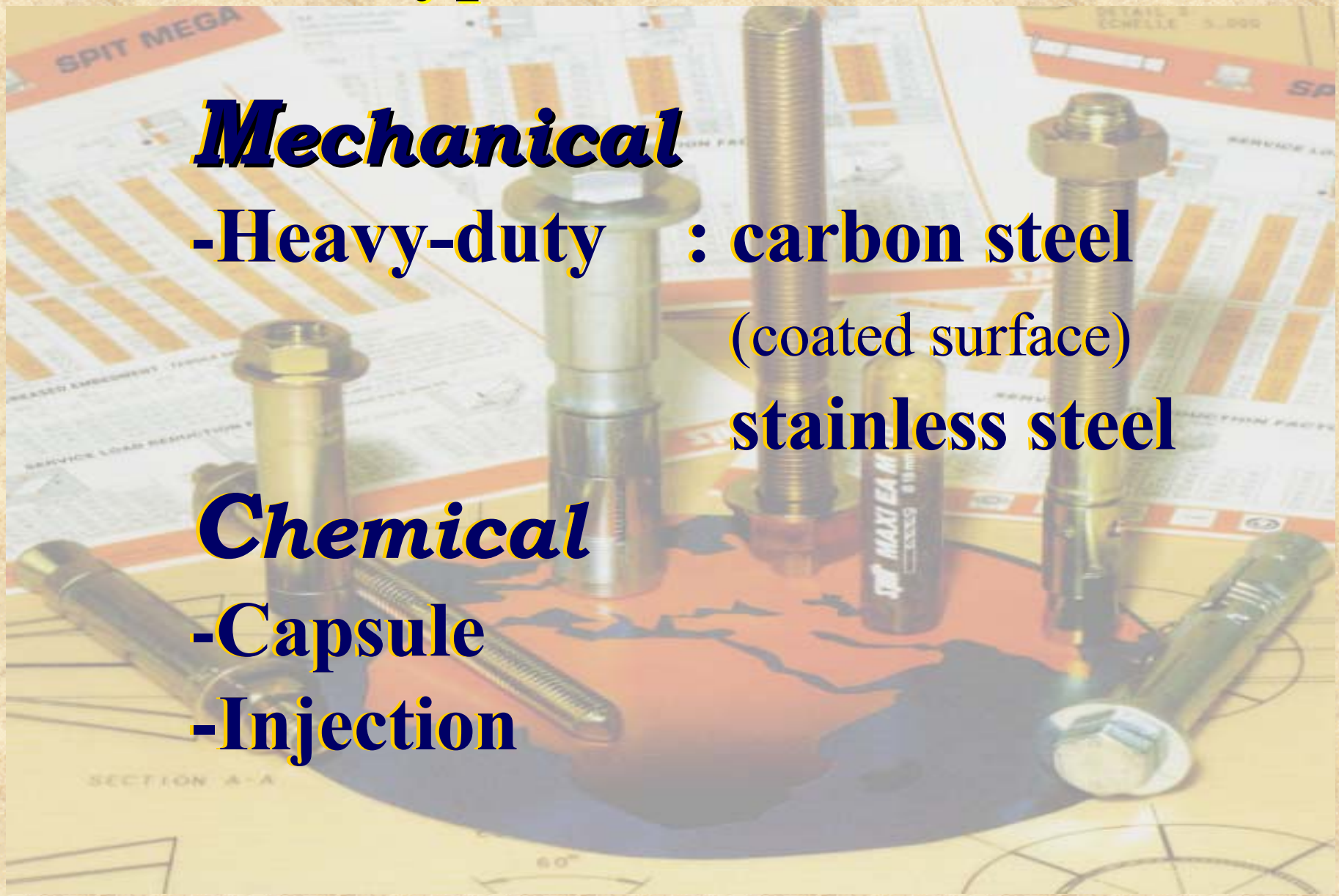


DETAIL B



VIEW B

Types of Anchor



Mechanical

-Heavy-duty : carbon steel

(coated surface)

stainless steel

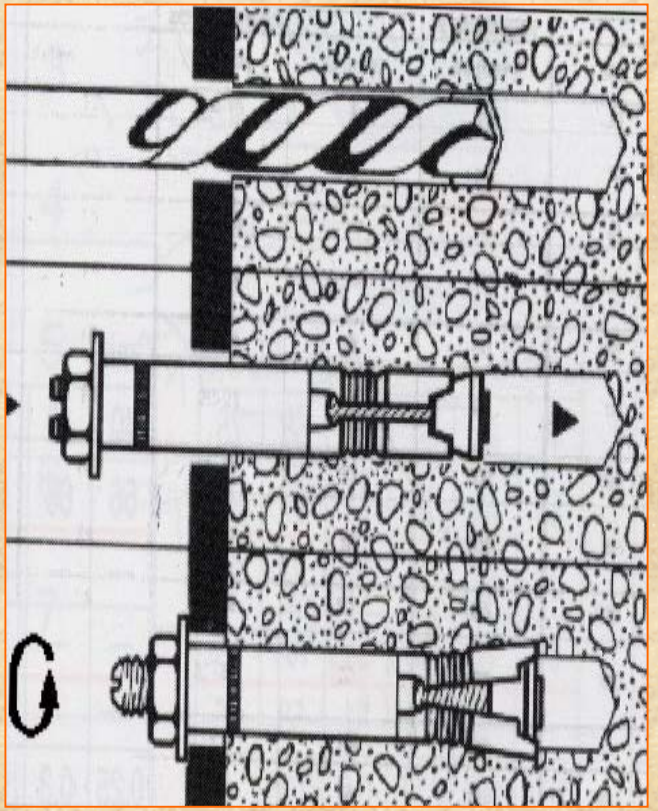
Chemical

-Capsule

-Injection

Installation

-Mechanical Anchor-

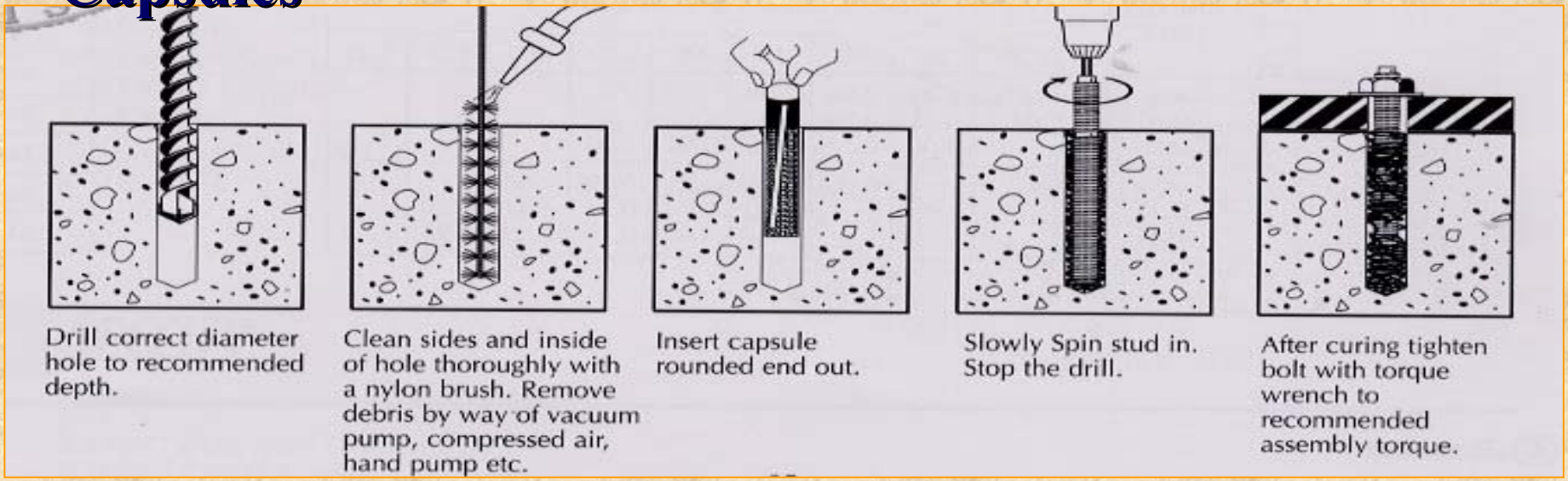


- Drill the hole to required depth
- Remove the drilling debris from the hole by compressed air
- Insert Anchor through fixture and drive in until contact fixture
- Tighten bolt with torque wrench to recommended assembly torque

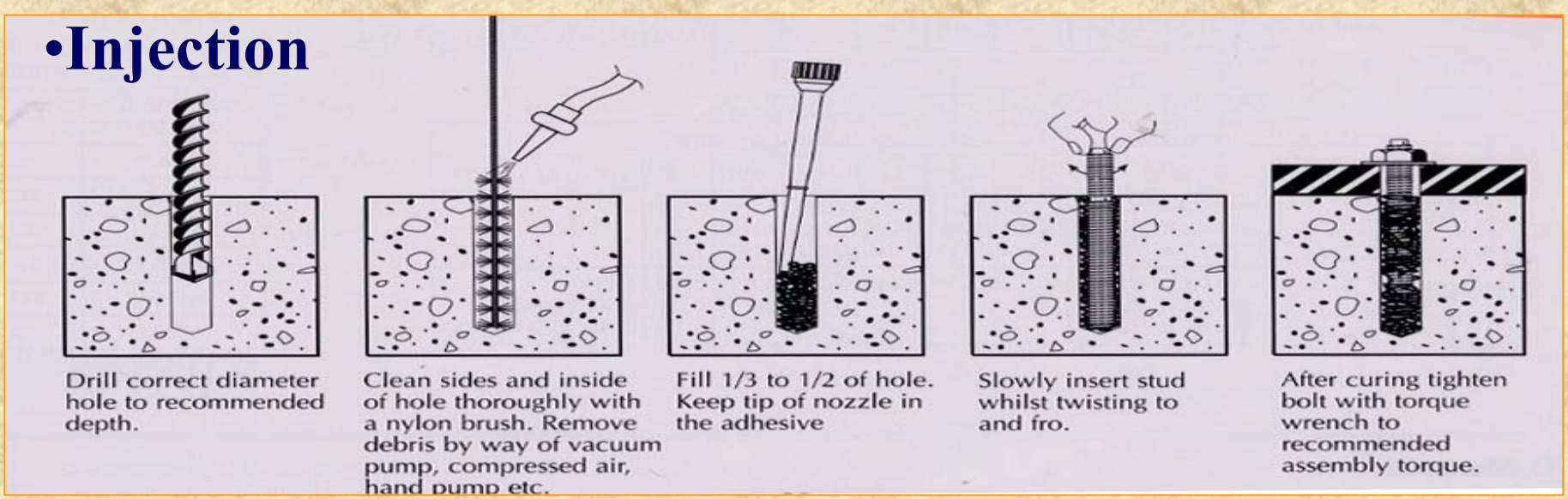
Installation

-Chemical Anchor-

- **Capsules**



- **Injection**



General Applications

Types of Anchor / Application	Heavy-Duty Mechanical	Chemical (Capsules)	Chemical (Injection)
Heavy Loading	✓		
Light Loading		✓	✓
Cyclic Loading	✓	✓	✓
Tension zone	✓	✓	✓
Cracked zone		✓	✓
Uncracked zone	✓	✓	✓
Vertical downwards installation	✓	✓	✓
Overhead installation *	✓	✓	
Lateral installation	✓	✓	✓
Angle installation		✓	✓
Space constraint (spacing & edge)		✓	✓
Narrow base member		✓	✓
Lapping of bars		✓	✓
Dowel bars		✓	✓

*For Chemical System, foil Capsule is recommended. Due to the design geometry of the capsule, the barbs at the tip of the foil capsule prevent it from dropping out of the holes for overhead installation.

HDB Applications

Elements \ Types of Anchor	Mechanical	Chemical (Capsules - Epoxy)
Vertical fins on beam (dowel bars)		✓
Stiffener (dowel bars)		✓
Lintol (dowel bars)		✓
Hanger (dowel bars)		✓
LMR Plinth (dowel bars)		✓
Beam (dowel bars)		✓
Slab (dowel bars)		✓
Canopy (dowel bars)		✓
Kerb		✓
Cladding Connection		✓
Steel structures on beam/column	✓	✓
Wall/Column plate	✓	✓
Base plate	✓	✓
Hold Down Bolts for Roof Truss	✓	
Aluminium Sunbreaker	✓	
Steel railing	✓	
Construction props	✓	
Temporary steel brackets	✓	
Communal Shelters	✓	

Note : The use of Chemical (Injection) is not recommended.

Recommendation

- **In-house design (steel to concrete) :**

  >>Cast-in dowel bars

  (*higher in capacity, easy installation)*

- **Cases for missing/misaligned dowel bars in construction:**

  *Dowel Bar **>>Chemical Anchor- Capsule is preferred**

  (*constrainst area, for starter bar)*

  *Steel-Conc.**>>Mechanical Anchor is preferred only for heavy loading**

- **Anchor to replace dowel bars :**

  ✗ T16 ==>M16 (Not based on equivalent size)

  >>Design should be computed based on the anchor catalogue

  >>Types of anchor should be selected based on the recommended guidelines

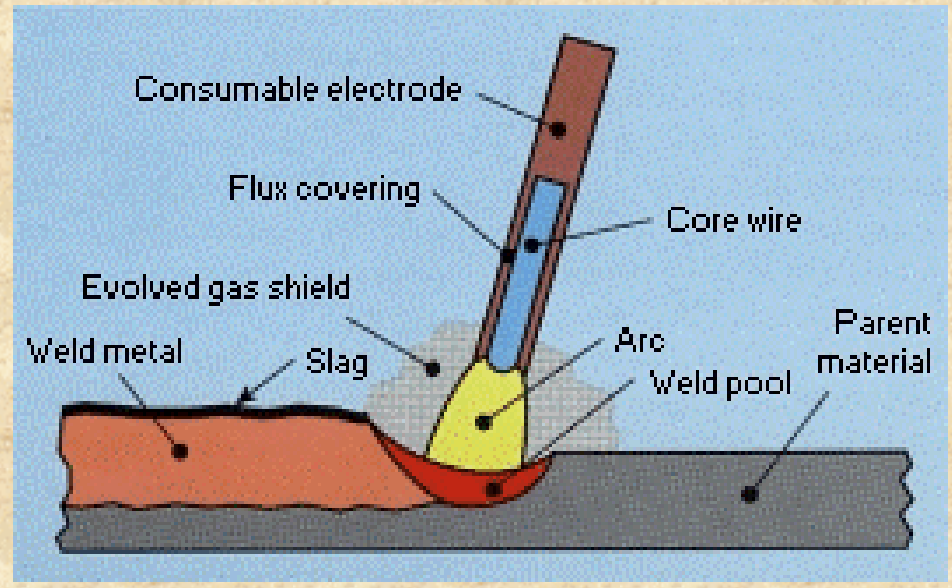
WELDS

Welding

Manual Metal Arc Welding

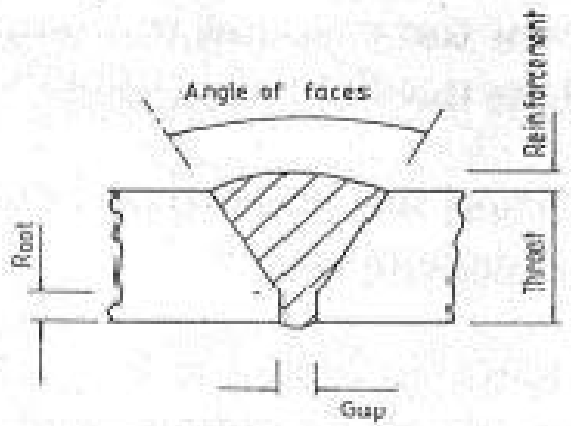
•Handheld electrode coated with flux that melts and protects molten metal

•A process of joining metal parts by fusing them and filling in with molten metal from the electrode

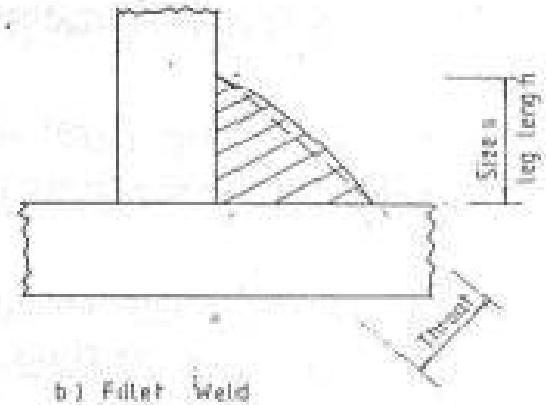


MMA welding

- Most flexible and common as can be used in all welding positions
- Quality of welding depends highly on welder skill
- Contractor must submit the certificate of welder for approval

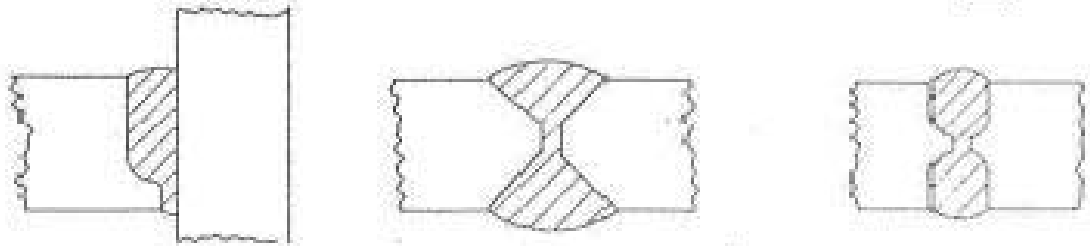


a) Single V Butt Weld



b) Fillet Weld

Types of welds

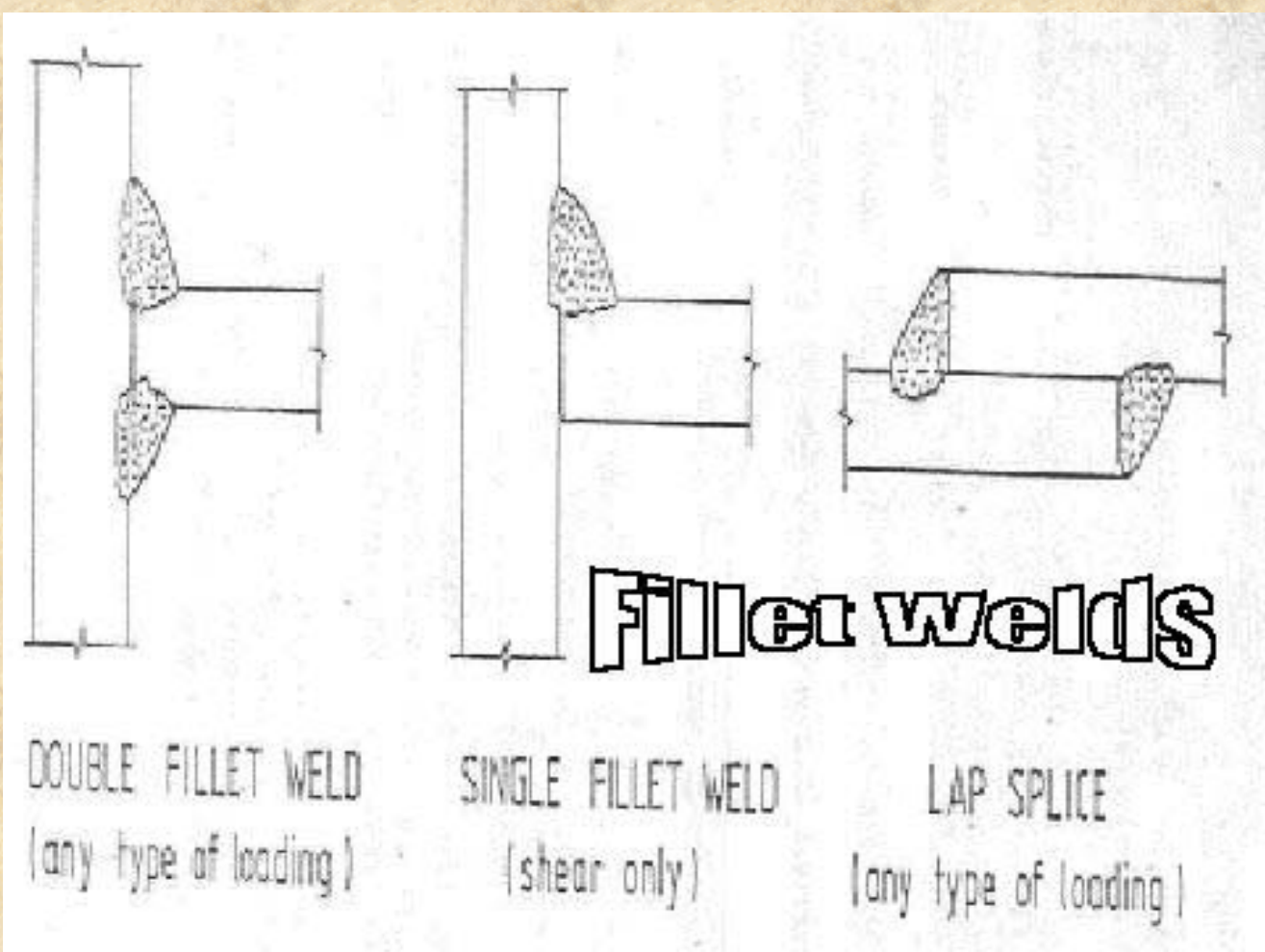


c) Types of Butt Welds

Fillet and Butt Welds

- **Fillet Weld**
- **Advantages**
- Cheap
- No preparation required
- **Disadvantages**
- Not good for fatigue(fluctuating load such as bridge)
- Less attractive appearance

- **Butt Weld**
- **Advantages**
- Better fatigue performance
- Good appearance
- **Disadvantages**
- Expensive
- Requires edge preparation


Fillet welds
DOUBLE FILLET WELD
(any type of loading)
SINGLE FILLET WELD
(shear only)
LAP SPLICE
(any type of loading)

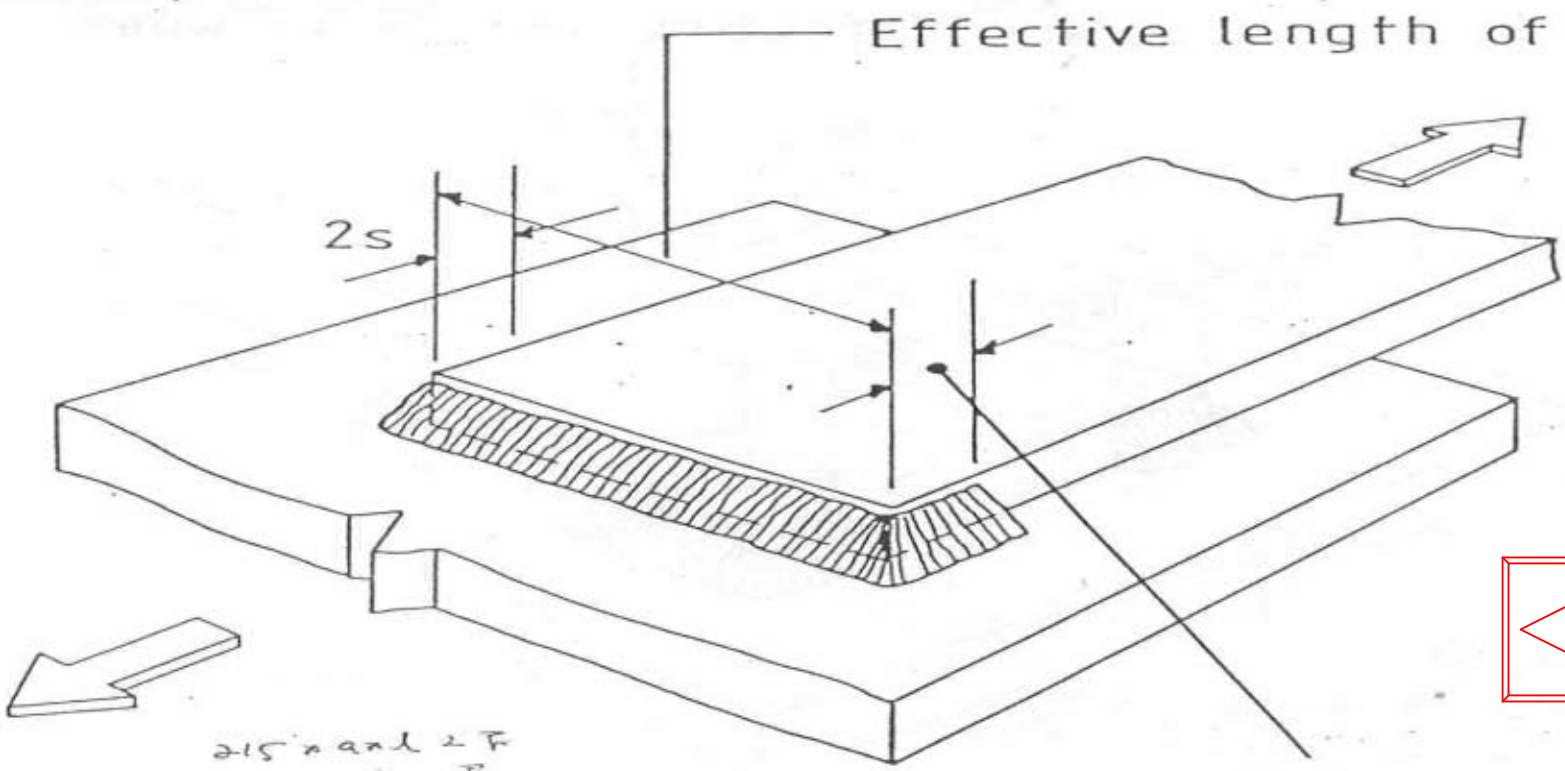
Design of Fillet Weld

- Strength of fillet weld is calculated using the throat thickness

- For 90 degrees fillet weld, throat thickness is taken as 0.7 X size of leg length
- Strength of weld = 0.7 X leg length X pw/1000 X length of weld (kN)
- where pw = capacity of fillet weld based on type of electrode used (kN/mm)

Fillet Welds Requirements

- Fillet welds terminating at ends or sides of parts should be returned continuously around corners for a distance of not less than twice the leg length
- In lap joints, minimum lap should not be less than (4 x thickness of thinner part jointed)
- Longitudinal spacing between effective lengths of weld not to exceed 300mm or 16t for compression elements
- Longitudinal spacing between effective lengths of weld not to exceed 24t for tension elements



End return ≠ 2s required by BS 5400 BS 5950 and BS 449

If an end return is impractical, the effective length is reduced by s for each corner affected

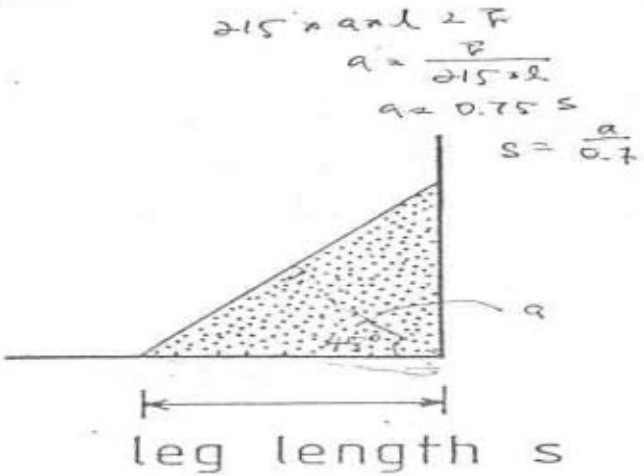
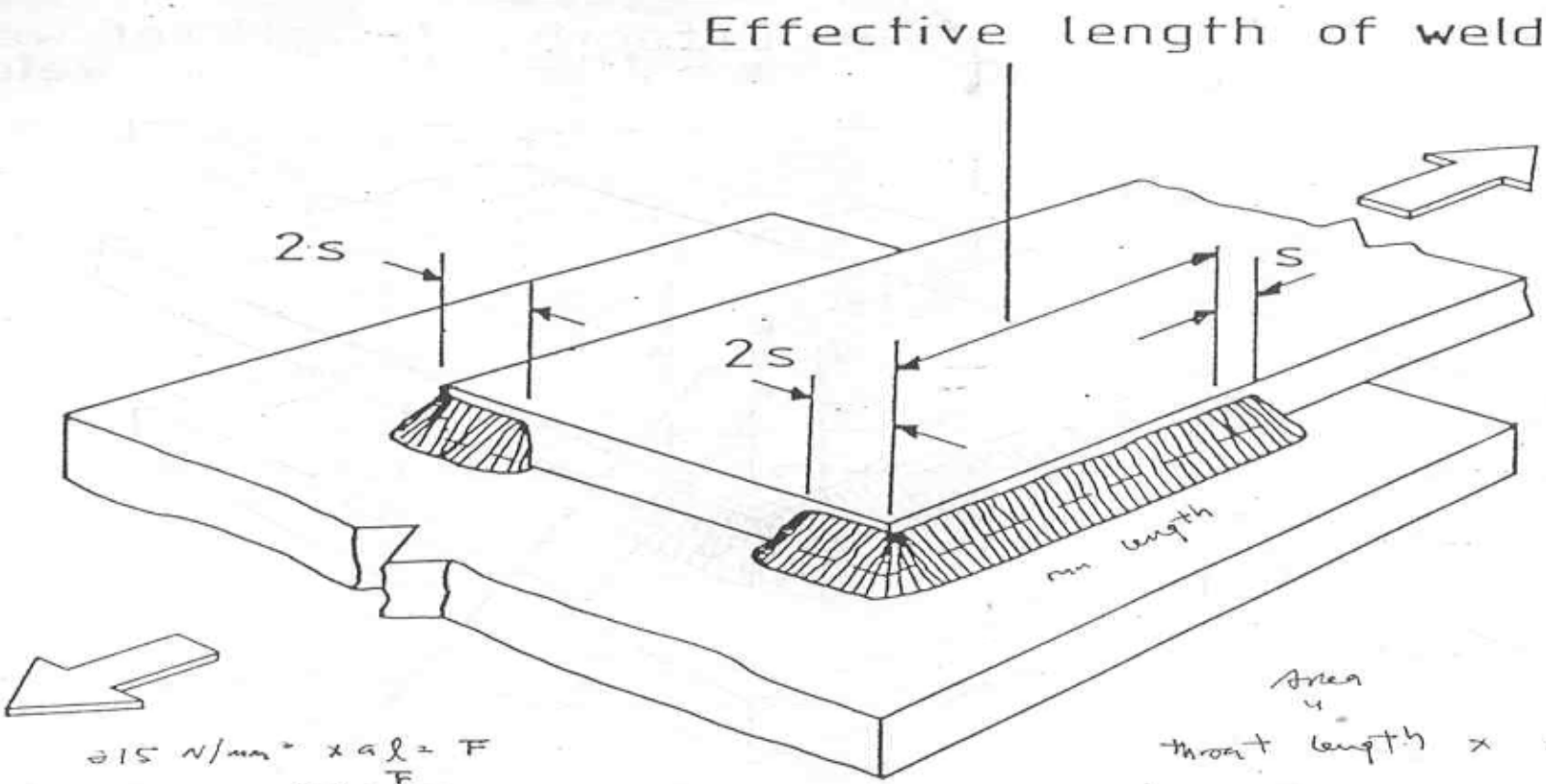


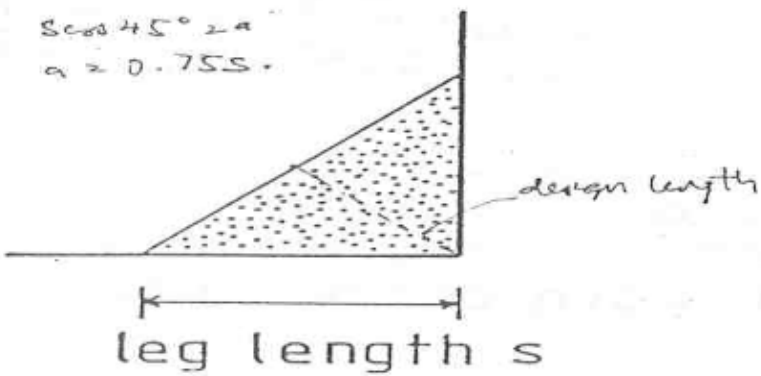
FIG. END (OR TRANSVERSE) FILLET WELD



$215\ N/mm^2 \times a\,l = F$

$a = \frac{F}{215 \times l}$

Area = throat length × run length

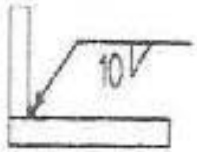
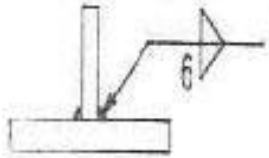
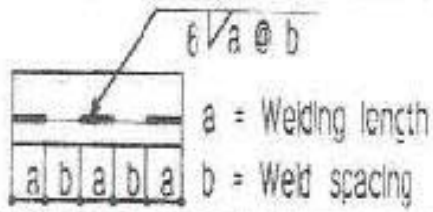


End return ≮ 2s required by BS 5400 BS 5950 and BS 449

If an end return is impractical the effective length is reduced by s for each corner affected

FIG. SIDE (OR LONGITUDINAL) FILLET WELD

WELD SYMBOLS AND ILLUSTRATIONS

Type of weld	Sketch	Weld Symbol	Illustration only (The number indicates weld size in mm)
Fillet			
			
			

Butt welds

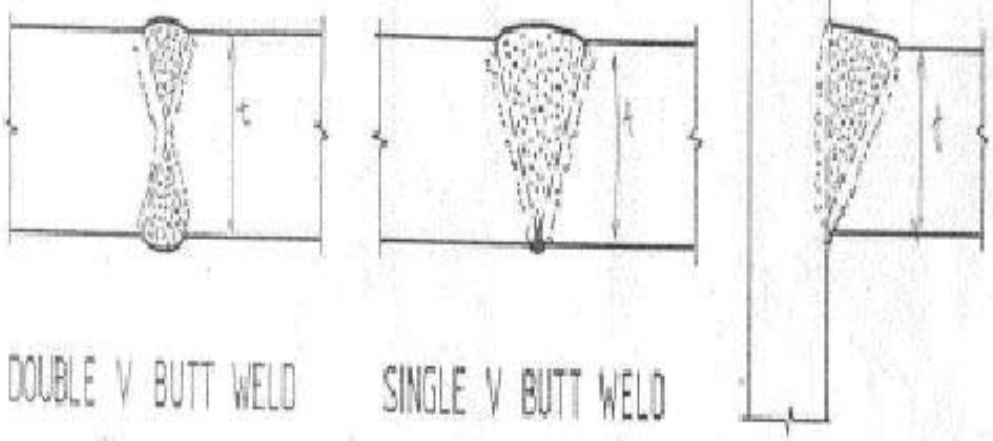
Types of butt welds for HDB's projects

Types of Butt Welds	**Thickness of plate welded**
Square	Up to 6mm
Single V	More than 6mm
Double V	More than 16mm
Single bevel	More than 6mm
Double bevel	More than 16mm

Butt weld

- Edge preparation is made by machine or flame cutting
- For steel hollow section, double V and double bevel butt weld cannot be used due to difficulty in edge preparation
- Full penetration butt weld shall be used for steel butt joints
- Strength of butt weld can be taken as the strength of the parent metal

Butt welds

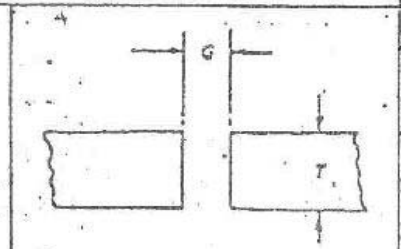


DOUBLE V BUTT WELD

SINGLE V BUTT WELD

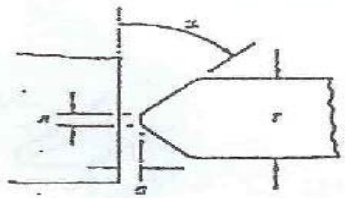
SINGLE BEVEL
BUTT WELD

TABLE 5.12.A OPEN SQUARE BUTT WELD

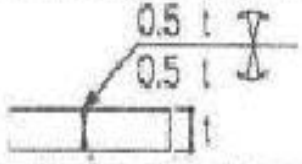
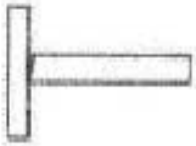
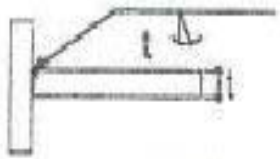
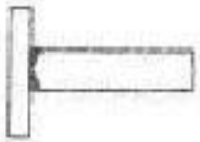
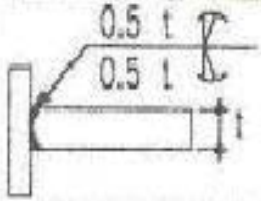
Weld detail	Welding position	Thickness T	Gap G
		mm	mm
Welded from both sides 	Flat	3–6	3
	Horizontal-vertical or vertical	3–5	3

SINGLE BEVEL
BUTT WELD

DOUBLE BEVEL BUTT WELD

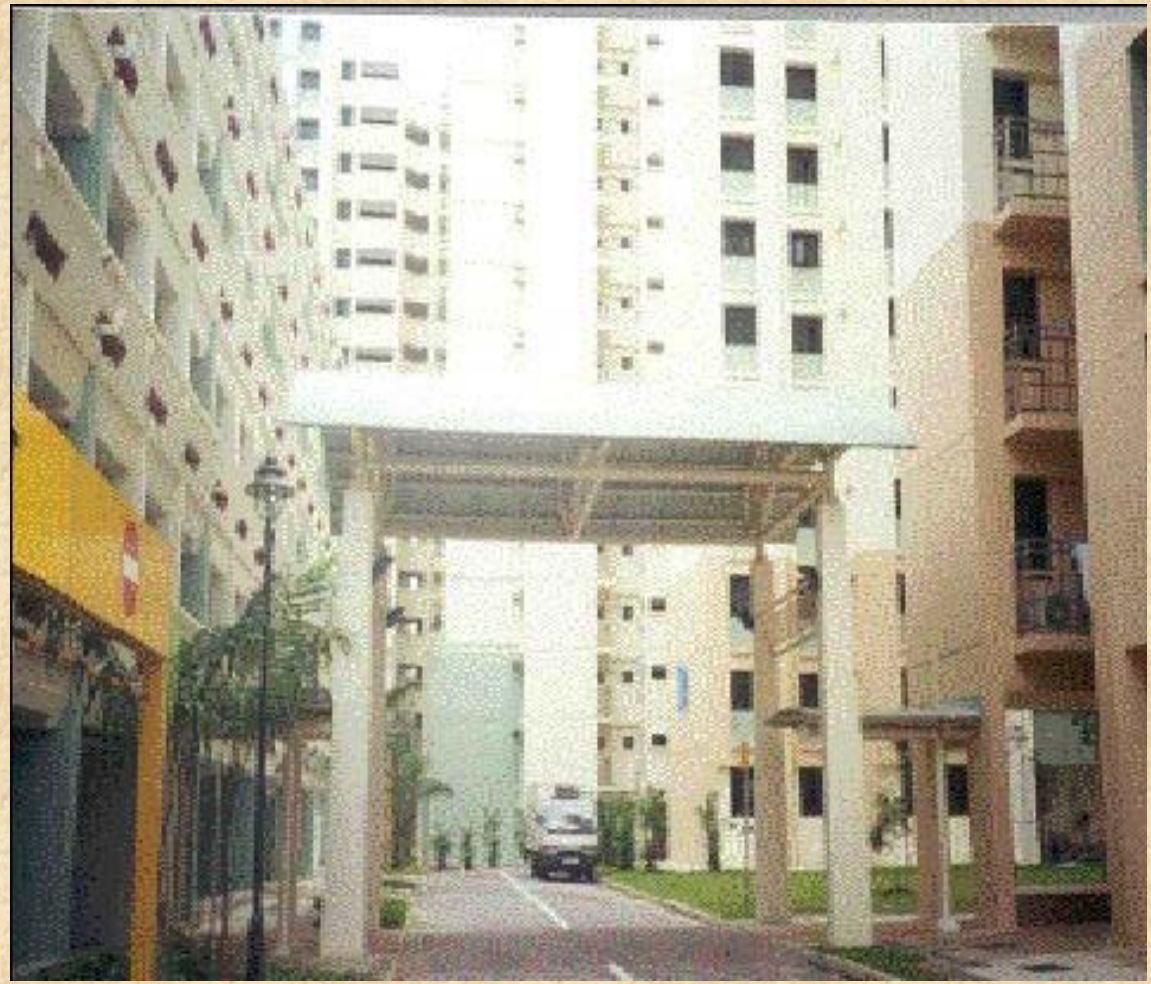
Weld detail	Welding position	Thickness T	Flat position only		
			Gap G	Angle α	Root face R
		mm	mm		mm
	All positions	Over 12	3	45°	2

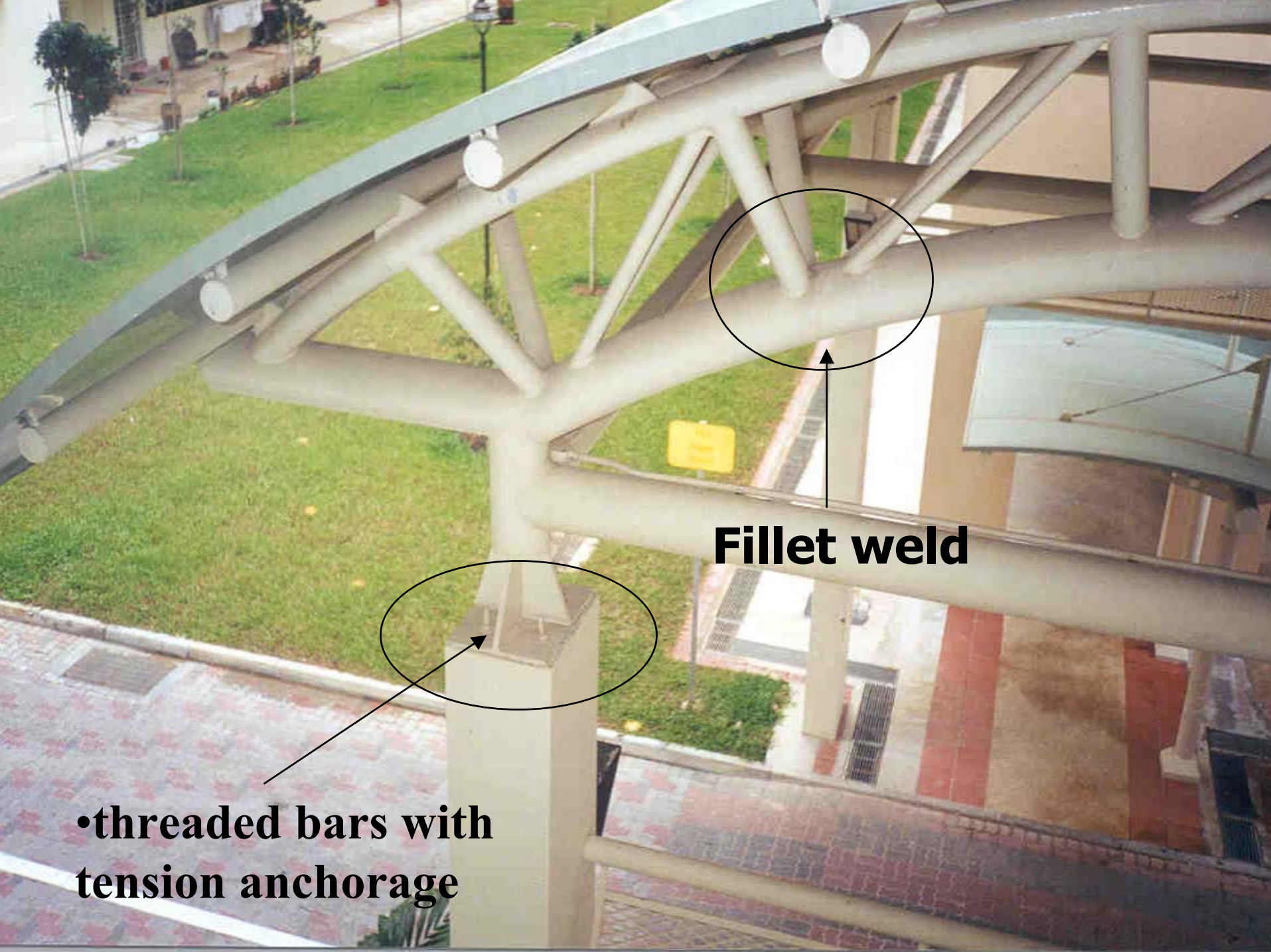
SINGLE BEVEL
BUTT WELD

Square Butt			
Single V Butt			
Double V Butt			
Single Bevel Butt			
Double Bevel Butt			

HDB Requirement for Welding

- Welding according with weld symbols and conform to BS 499
- For unspecified weld,
- butt weld to be full penetration weld of size = thickness of member
- fillet weld to be 6mm weld all round member
- Minimum of 10 % of welded joints shall be tested



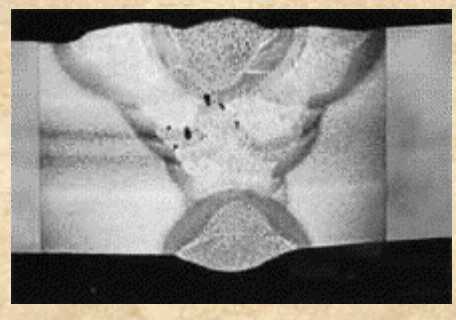

Fillet weld
•threaded bars with tension anchorage

Welding Defects

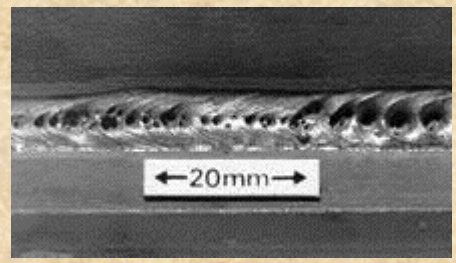
- Porosity
- Inclusions
- Lack of fusion and penetration
- Cracks - Lamellar Tearing

Porosity

- Formation of small cavities in weld metal
- Cavities are solidified gases in the molten weld pool



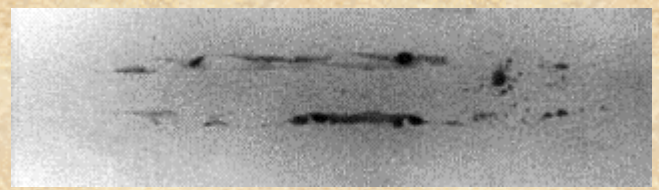
- Uniform distributed Porosity
- Caused by absorption of nitrogen,oxygen and hydrogen in molten weld



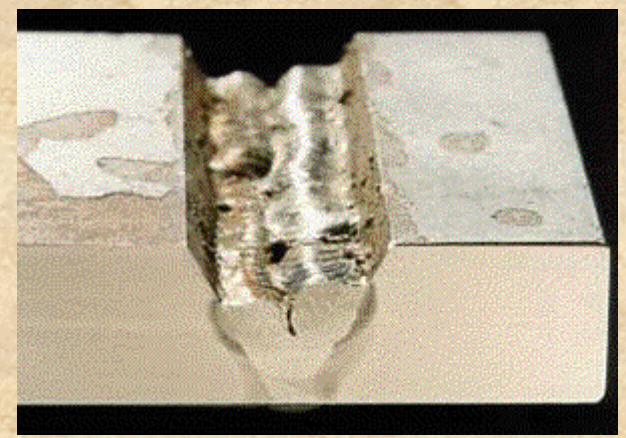
- Surface porosity
- Caused by excessive contamination (grease,dampness,atmosphere) or large amount of distributed porosity

Slag Inclusions

- Slag are non-metallic particles derived from flux
- Due to incomplete removal of slag in Manual Metal Arc welding
- Due to rust or mill scale on parent metal surfaces



- Radiograph of a butt weld showing 2 slag lines in the weld root



- Weld with pockets of slag trapped between the weld run

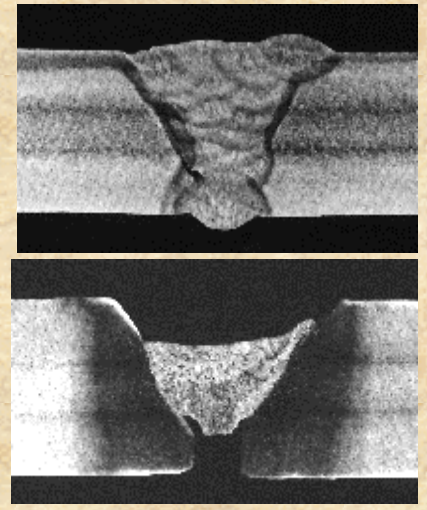
Lack of Root Fusion or Penetration

Lack of root fusion

- When the weld fails on one side of the joint in the root
- The next run of weld has not fused to the previously laid weld

Lack of root penetration

- When the weld fails on 2 sides of the joint in the root
- Mainly caused by incorrect welding conditions
- Poor welding performance



Lack of Root Fusion or Penetration

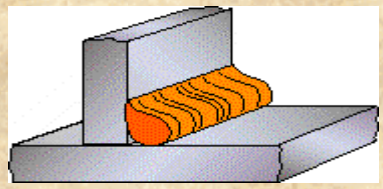
Cause of incomplete root fusion

•Excessive thick root face

•Too small a root gap

•Misplaced welds

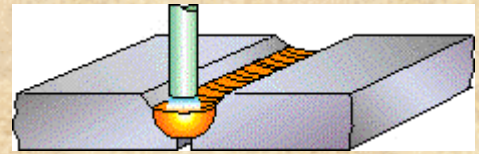
•Too low a power input



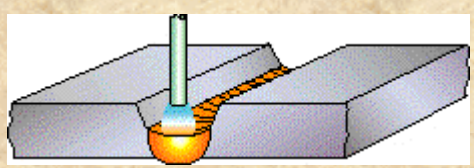
•Too low an arc (heat) input

Lack of Root Fusion or Penetration

Effect of electrode size on root fusion



•Large diameter electrode

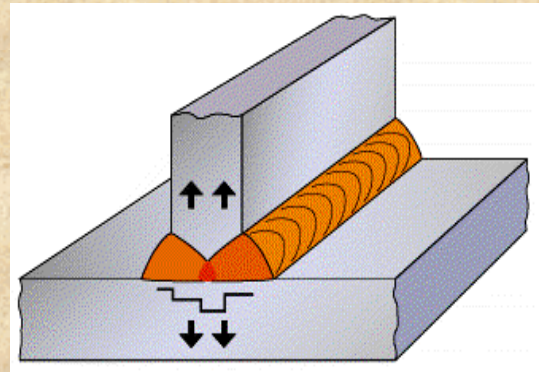


•Small diameter electrode

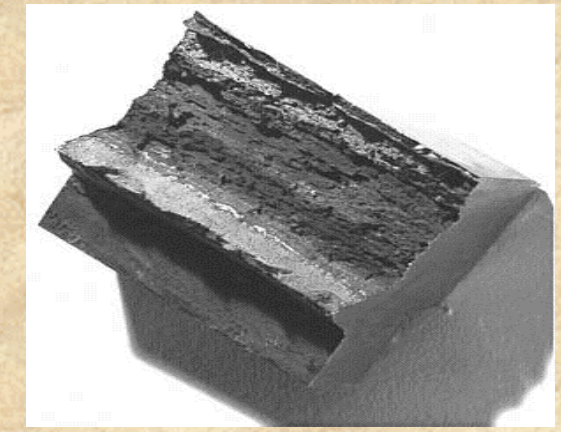
Lamellar Tearing

•As steel is rolled during manufacture,small impurities are deposited

•Construction of weld metal causes a tear



•Lamellar tearing in T welds



•‘Woody’ surface due to lamellar tear

Quality Control of Welding

1) Method of Detecting Defects in Welds

2) Checklist for Quality Control of Welding

Visual check

- Most Common and economical. Particular good for single pass welds
- Generally acceptable for fillet welds
- A procedure of standard checks to be followed by accredited inspector
- Mainly based on experience of inspector
- Detects surface imperfections only

Dye Pentration Test

- Inspection is carried out using a penetrant, cleaner and developer
- Strong dye penetrant is absorbed into surface discontinuities by capillary action
- Cleaner is used for pre-cleaning and for removing excess penetrant
- Developer(e.g. chalk powder suspension) is sprayed on to reveal any surface cracks
- Detects tight cracks, open to surface
- Detects surface imperfections only
- Use for non-ferromagnetic steel where magnetic particle test is not applicable

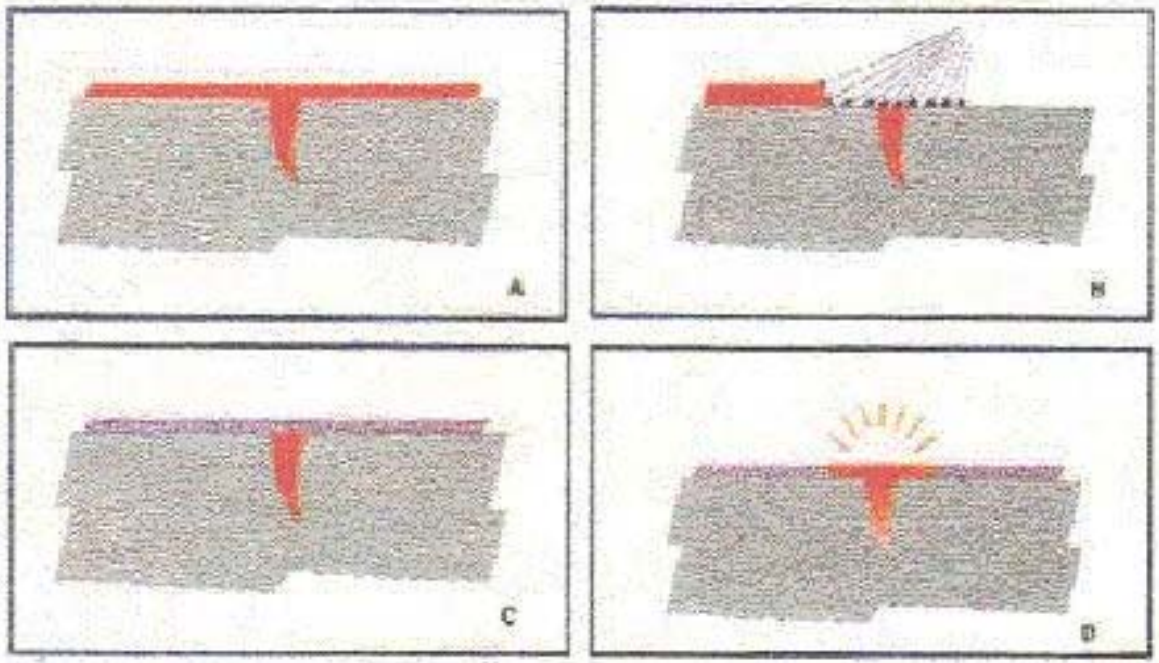
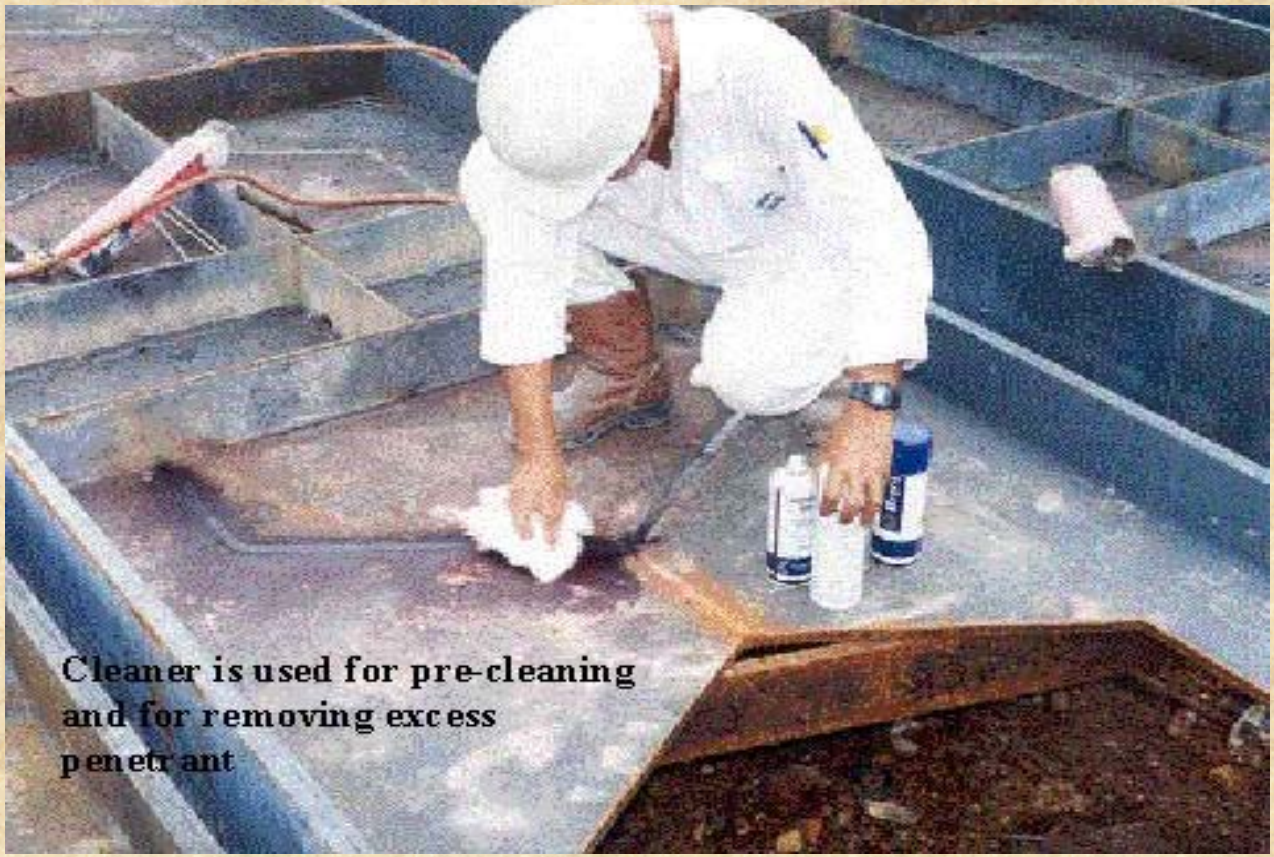
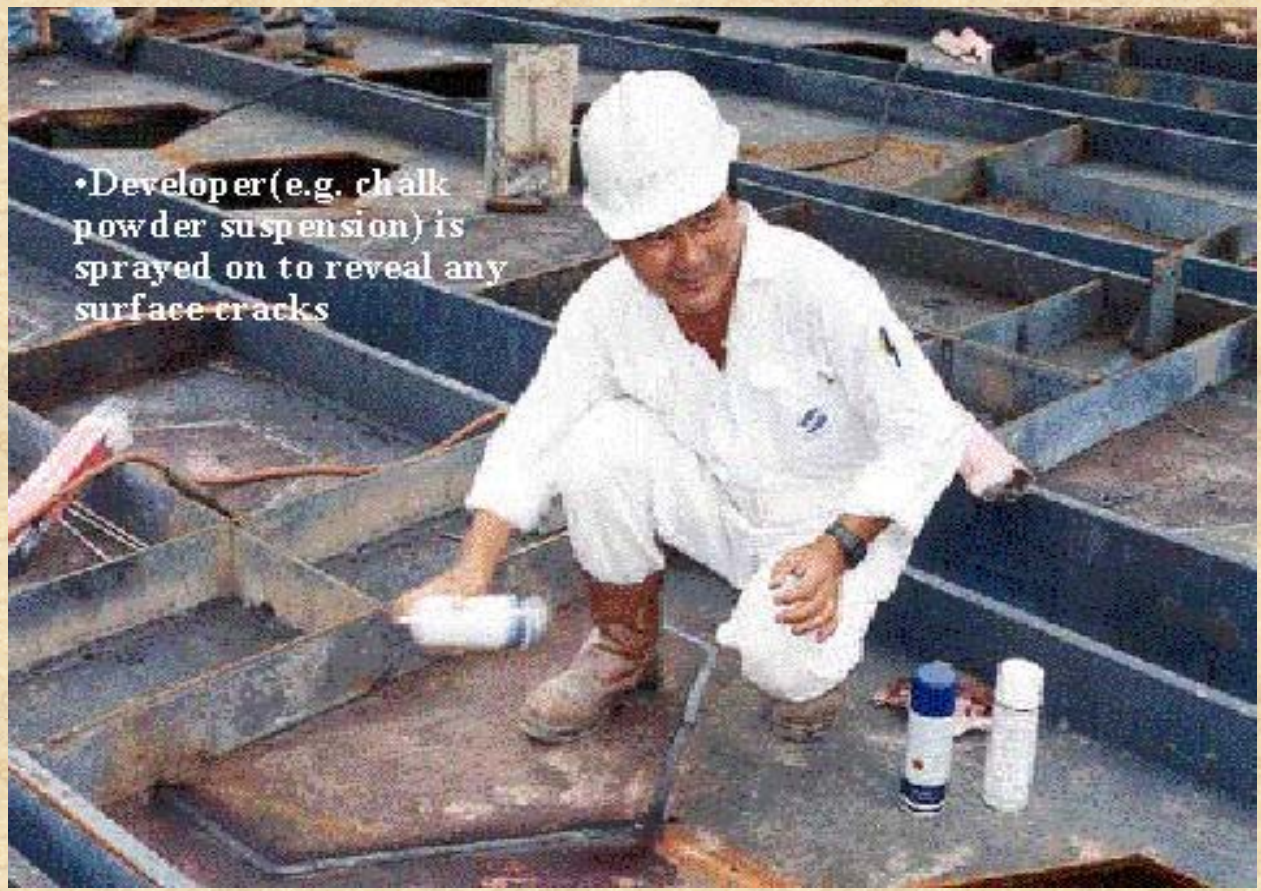


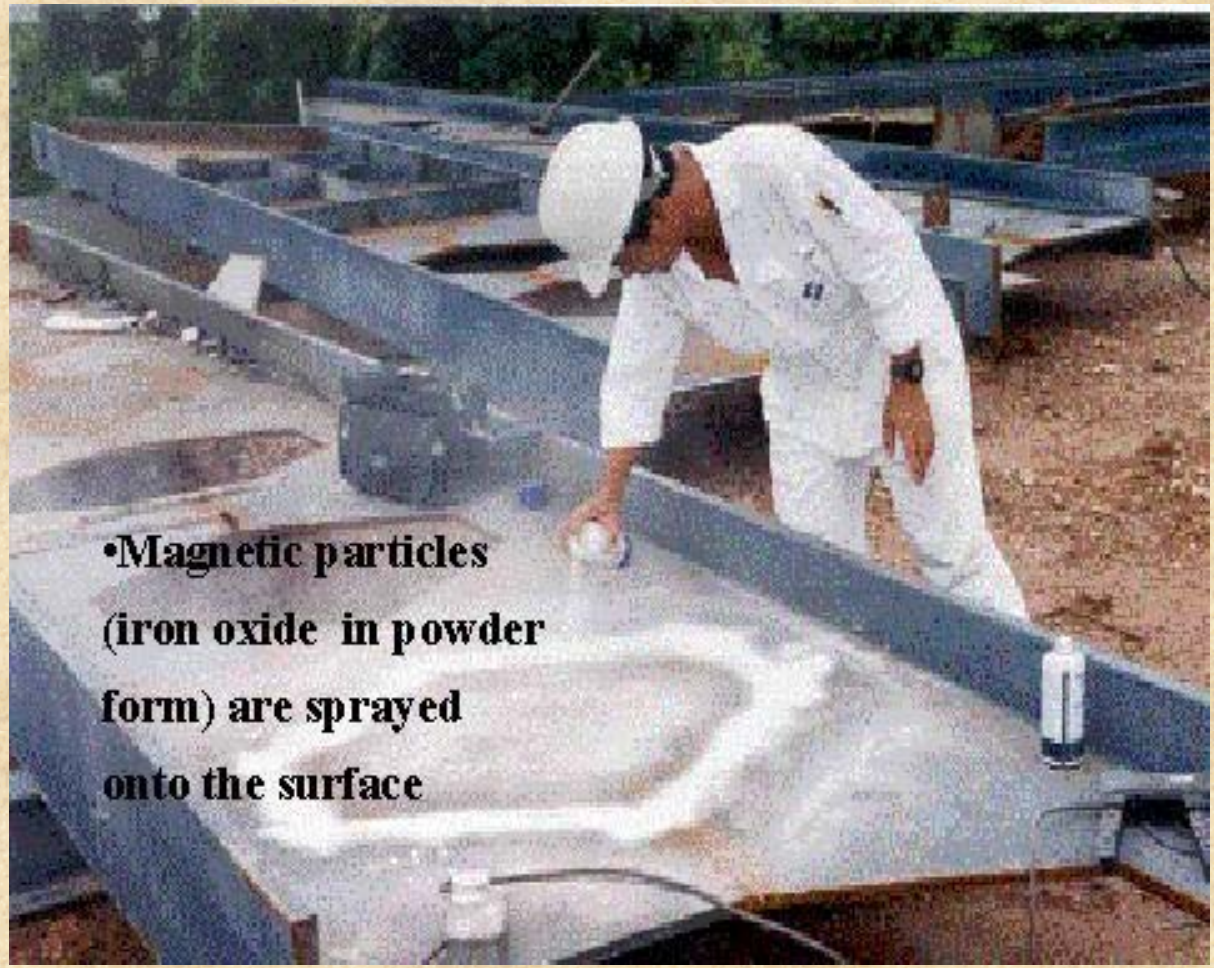
Fig. 4 — A — Penetrant applied to the surface and enters discontinuity; B — excess penetrant removed from surface; C — developer powder applied to draw penetrant out of crack. D — accentuated indication of crack as penetrant reads around the opening.

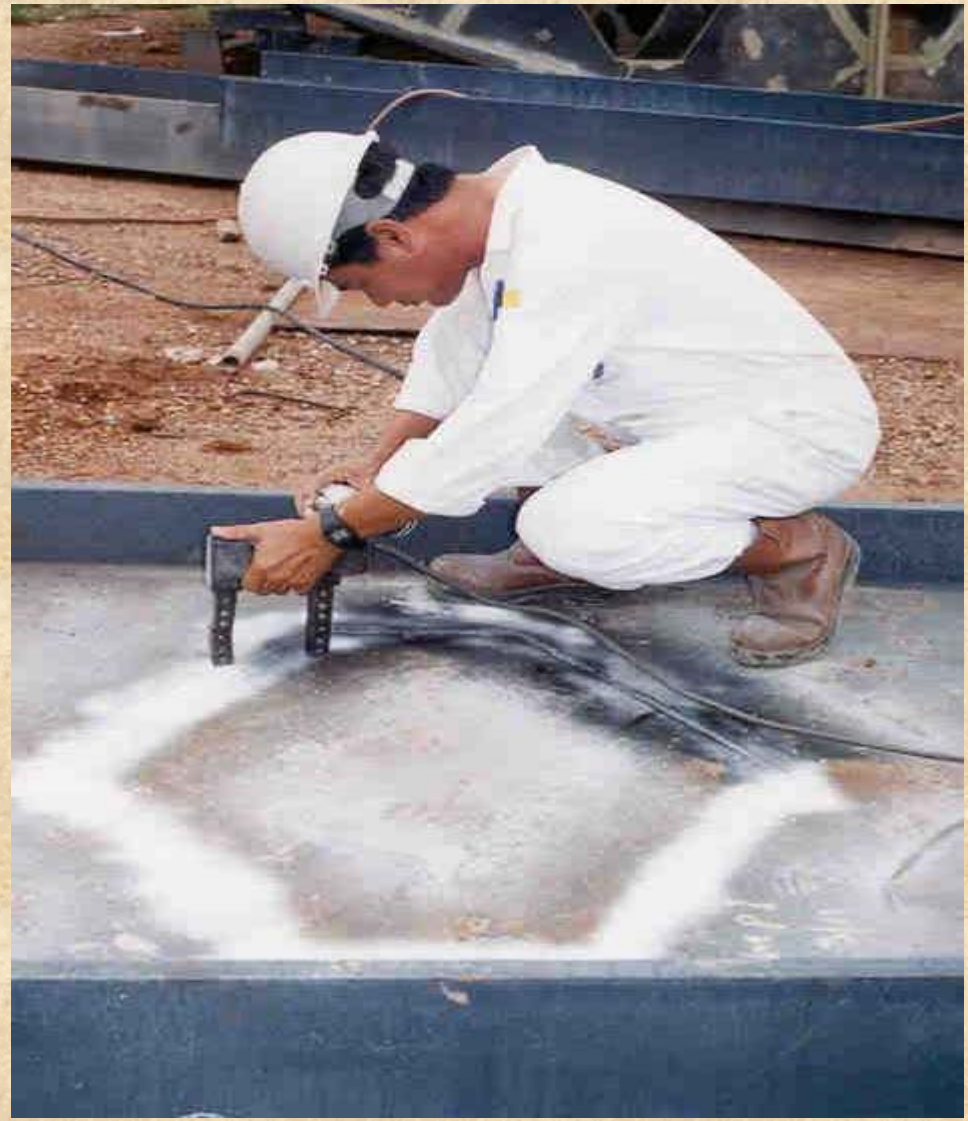

Cleaner is used for pre-cleaning
and for removing excess
penetrant


•Developer(e.g. chalk powder suspension) is sprayed on to reveal any surface cracks

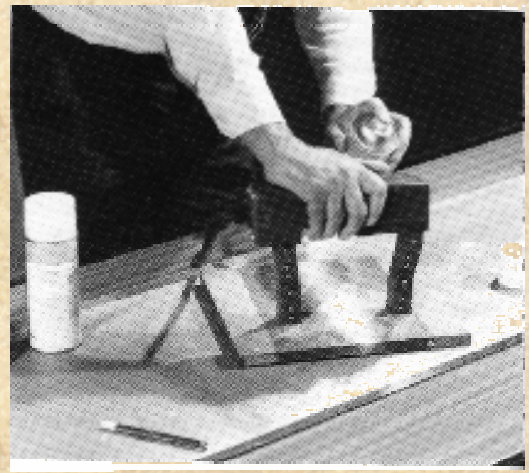
Magnetic Particle Test

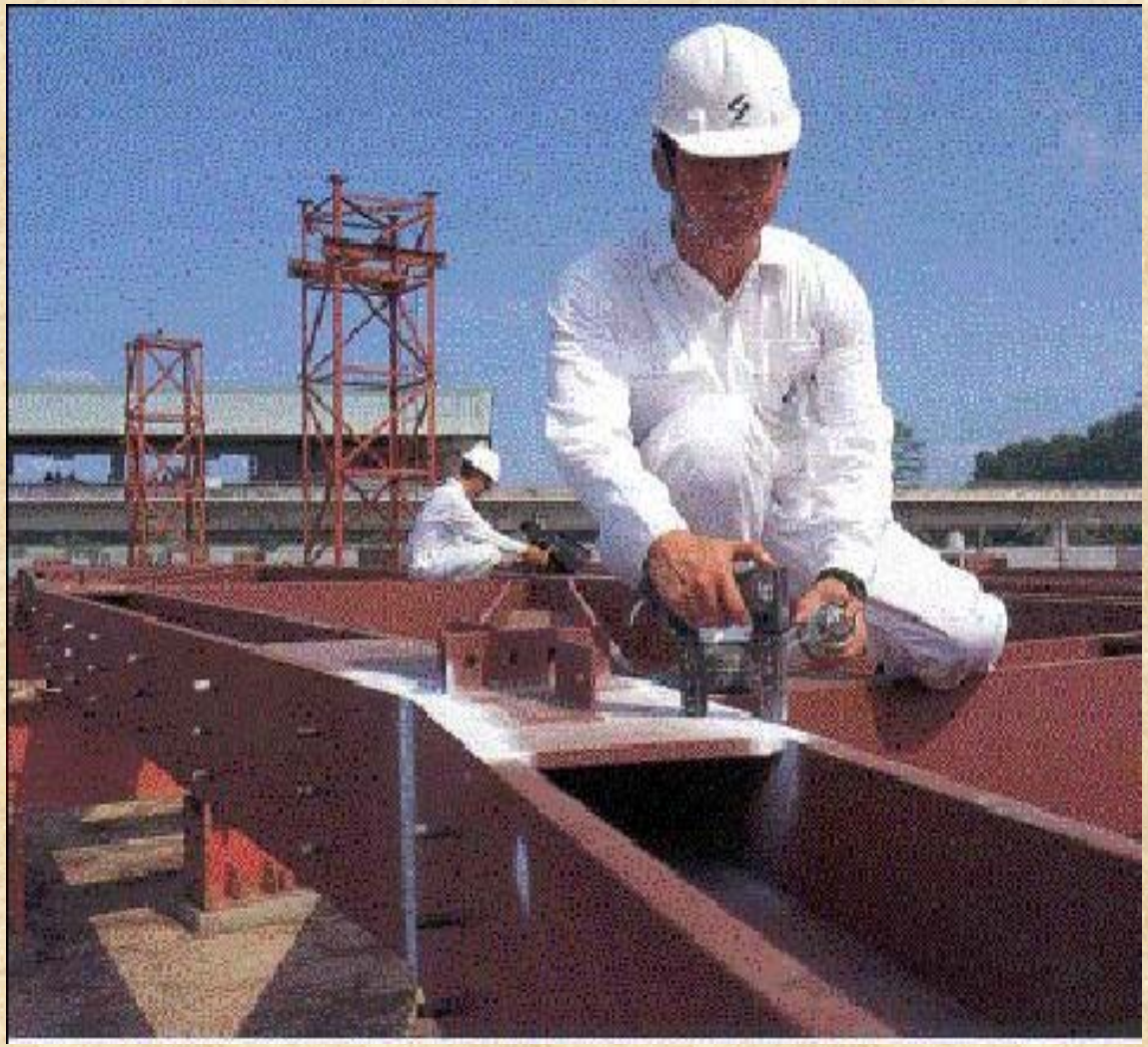
- Inspection is carried out using magnetizing equipment and magnetic particles
- Magnetic particles (iron oxide either in liquid or powder form) are placed onto the surface
- Once the magnetic particles are being magnetized, they will be collected in cavities or cracks owing to leakage flux to form a visible indication such as dark lines or points
- Use for ferromagnetic steel only. Not for stainless steel


•Magnetic particles
(iron oxide in powder
form) are sprayed
onto the surface



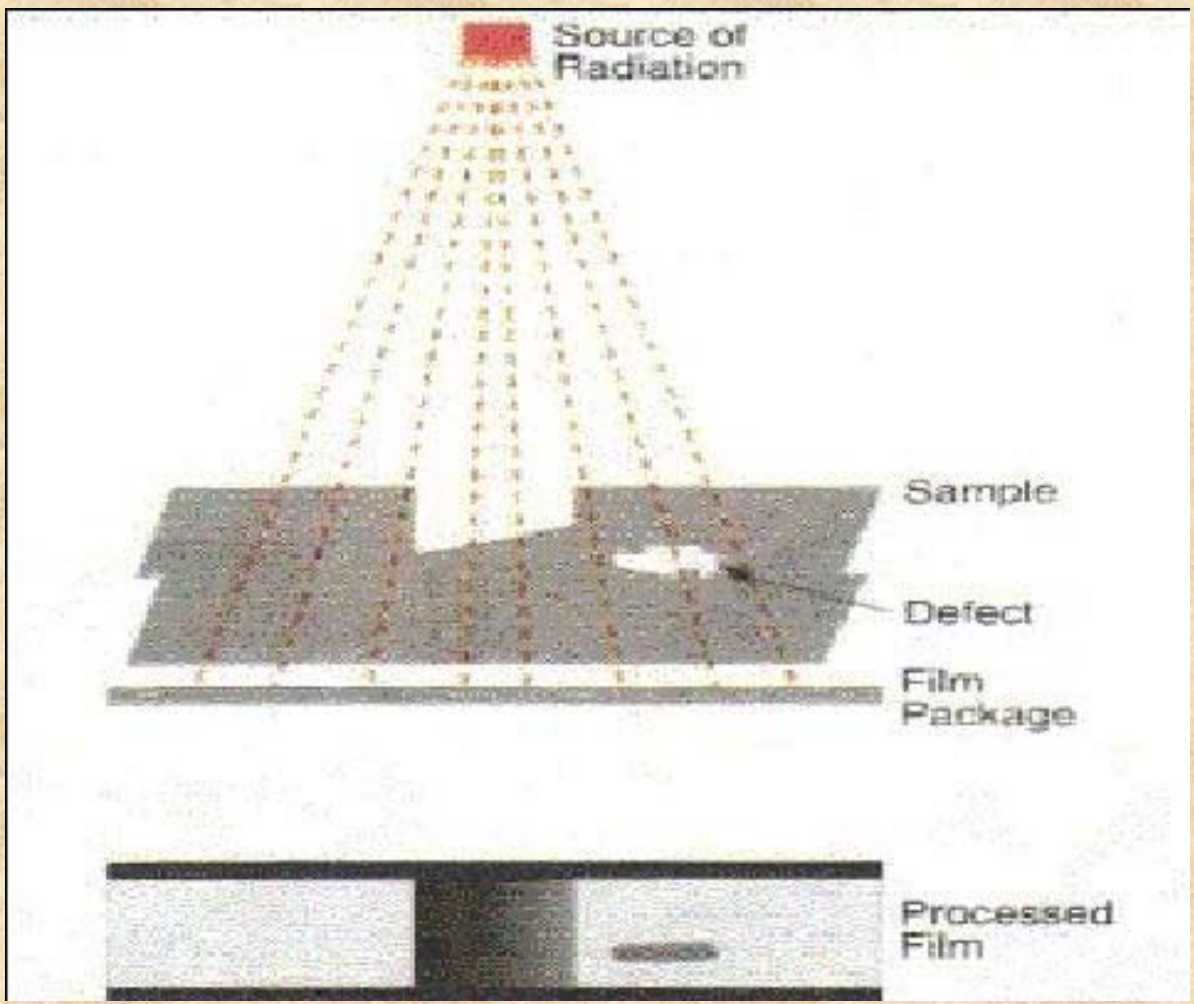
- **Magnetic equipment is used to magnetized the particles**





Radiography Test

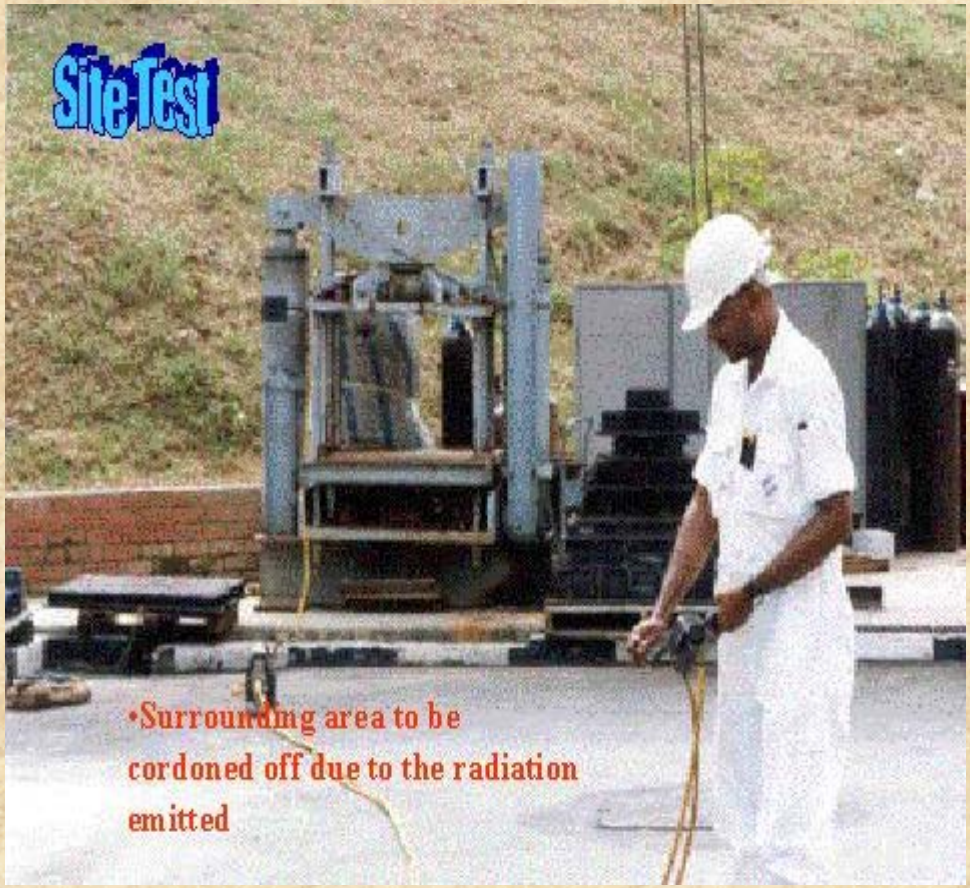
- Inspection is carried out using a radiation source and radiographic film
- Area of interest is located between the radiation source and radioactive film
- Radioactive film is exposed by radiation passing through the area of interest and image can be viewed on developed film
- Where the weld metal is thinner or has a cavity in it more radiation gets to the film and a darker image is produced
- Highly recommended for butt weld
- Can detect internal and surface discontinuities


Source of Radiation
Sample
Defect
Film Package
Processed Film

- Radioactive film is exposed by X-ray passing through the area of interest and image can be viewed on developed film

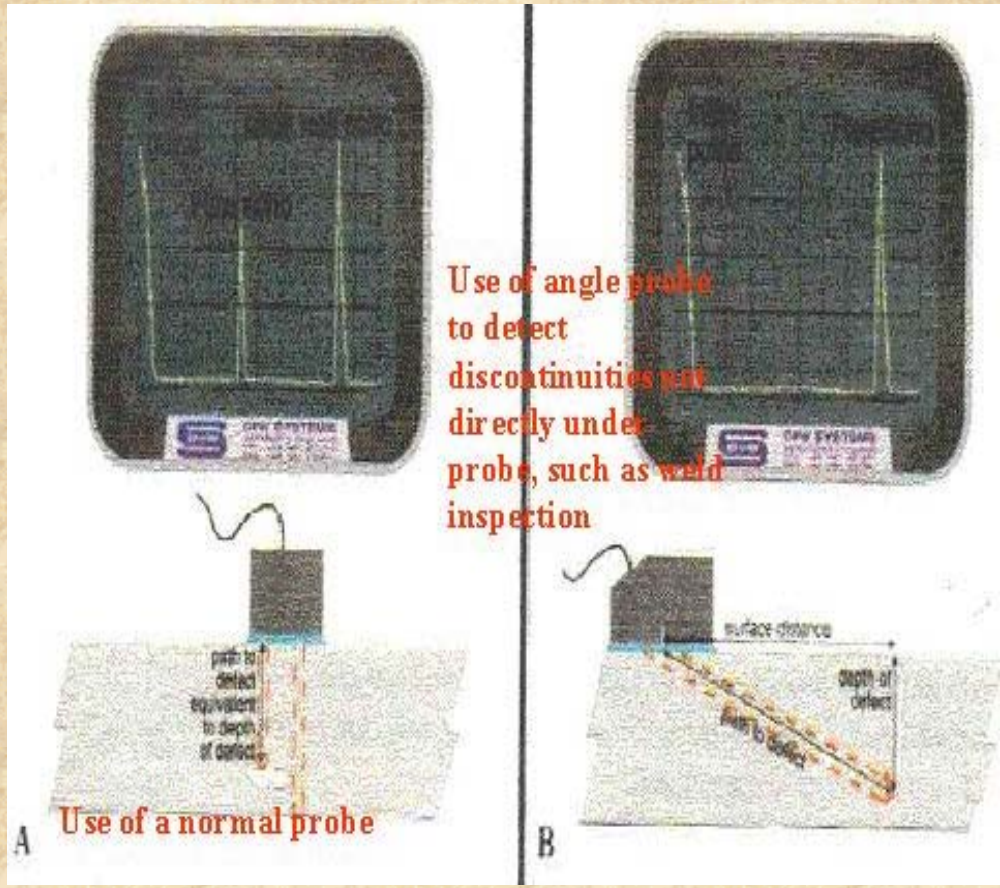

LabTest

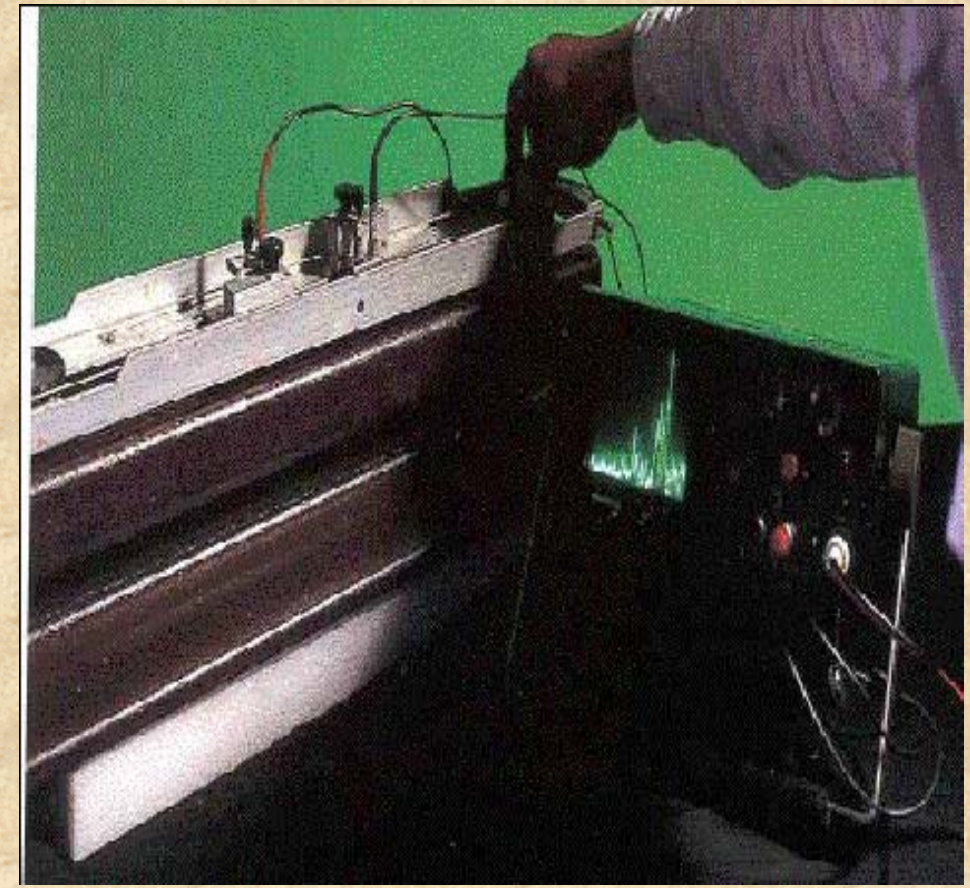

SiteTest
•Radioactive film is
exposed by Gamma
ray passing through
the area of interest and
image can be viewed
on developed film


Site Test
•Surrounding area to be cordoned off due to the radiation emitted

Ultrasonic Inspection

- Inspection is carried out using an ultrasonic flaw detector and ultrasonic probe
- Ultrasound is sent into area of interest and be reflected from a discontinuity and received by probe
- Reflected ultrasound is displayed on cathode ray tube screen in the flaw detector
- The signal in the screen is analyzed to determine the types of defect
- Good for butt weld and thick material
- Good for detecting internal discontinuities


Use of angle probe to detect discontinuities not directly under probe, such as weld inspection
path to defect equivalent to depth of defect
surface distance
depth of defect
path to defect
A
Use of a normal probe
B



Checklist for QC of welding

Qualified Welder

- Contractor to engage qualified welder for welding

Welding Procedure

- Adequate welding sequence
- Proper edge preparation
- Right electrodes are being used

Checklist for QC of welding

Visual Inspection

- craters
- slag inclusion
- weld size, contour
- cracking

Non-destructive Tests

- dye penetration
- magnetic particles inspection
- X-ray radiography
- ultrasonic testing

HDB STEEL STRUCTURE


WDN7C25


TPRC15
Column spacing = 2.5m
Column size = 139.7mm dia


Column spacing = 3m
Column size = 200mm RHS
JWN6C30

JWN1C28

Col. Size = 200-300mm dia.

Col. Spacing = 3m

BPN6C6&7

Col. Size = 168.3dia.

Col. Spacing = 2.5m


SBWN5C4-6
Col. Size = 168.3dia.
Col. Spacing = 2.5m


SBWN5C4-6


WDN7C25


JWN6C30


SBWN4C5


JWN6C11

SKN1C12&13

Col. Size = 168.3dia.

Col. Spacing = 3.5m

TP RC15

Col. Size = 219 dia.

Col. Spacing = 5m

TP Lor1 MUP

Col. Size = 168.3 dia

Col. Spacing = 4 to 5 m

SKN2C25&26

Col. Size = 219.1 dia.

Col. Spacing = 3.5m


SBWN5C4-6


SBWN5C4-6


SBWN5C4-6


JWN6C12


JWN6C12


SKYTECH

STEEL LINKBRIDGE

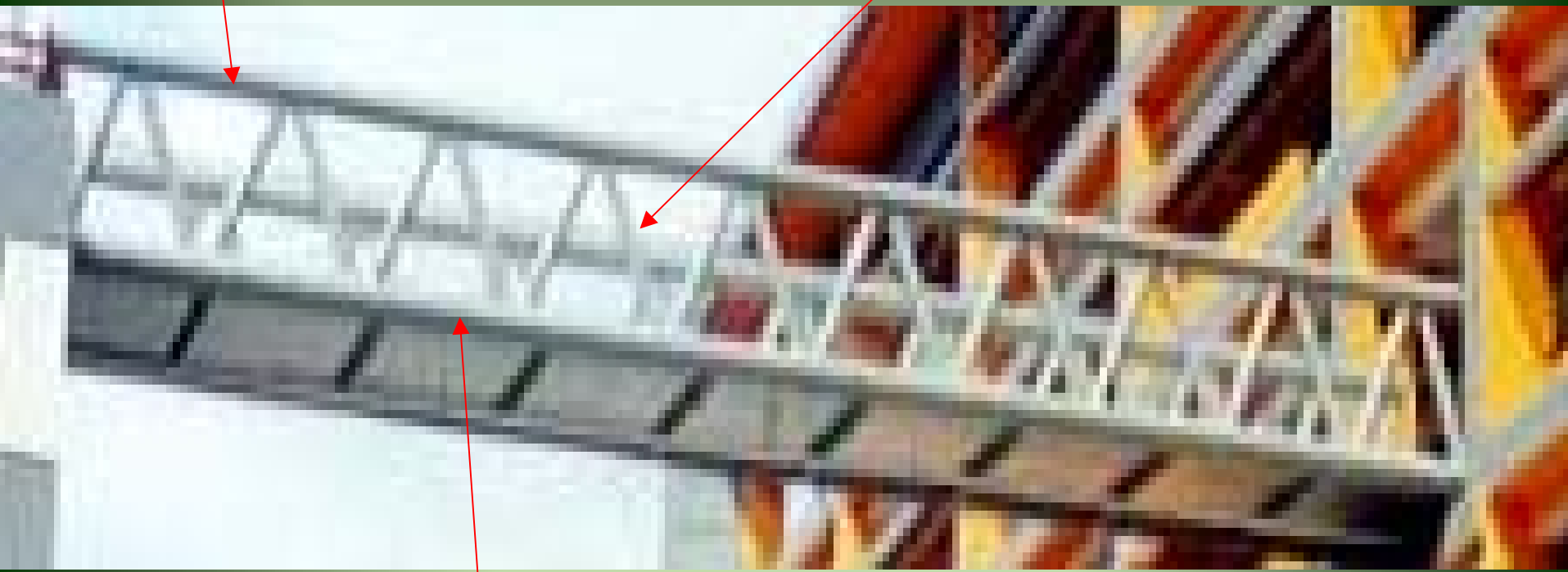
-18m in span

-link between Industrial Block and MSCP

STEEL LINKBRIDGE

CHS 355.6x10x85.2kg/m

CHS 193.7x6.3x29.1kg/m



CHS 406.4x12.5x121kg/m

-Material from UK

-Fabrication in Greensteel Pte Ltd (S)

STEEL LINKBRIDGE

Cutting

Welding

STEEL LINKBRIDGE

Welding Test - MPI

STEEL LINKBRIDGE

Galvanizing

STEEL LINKBRIDGE

Splice Connection

Welding Test - MPI & X-ray

STEEL LINKBRIDGE

Installation and Connection

STEEL LINKBRIDGE

Installation and Connection