

CASE STUDIES IN FAILURES IN BOILERS

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Failures occur in boilers due to several reasons. The degree of damages due to failure varies. Some damages are catastrophe in nature. It gets reported due to the magnitude of the damage. Some damages are ignored. Failures can be due to poor design, inadequate instrumentation and poor keeping of boiler in water side and fire side of the boilers, improper operation & inadequate annual inspection. Every failure needs proper diagnosis for taking steps to avoid future incidents. In this paper few case studies are presented.

CASE STUDY 1- FAILURE ANALYSIS OF FURNACE SHELL PLATE

The boiler is an 8 TPH oil fired boiler. It is a three pass wet back boiler. The furnace shell plate had failed in a repetitive manner. The furnace shell plate had bulged inside two times in a six month period. The location was seen to be about 1.5 meter from the front tube sheet. The orientation of failed portion was at 6° clock position. The plate had caved towards the furnace due to internal steam pressure. The plate was locally replaced during the first failure. The second failure was also in the same location. After the bulging had taken place, the water started seeping from the repair weldment itself. After observing black smoke in chimney, the boiler was stopped by the boiler operators.

Observations during the visit

1. The failed portions of the plates were seen to be bulging towards the axis of the furnace. Scale was seen underneath the plates on water side. The extent of scales for the first failure was not known. However this time the scaling was found to be about 0.5 mm.
2. Apart from this, the boiler showed a small layer of hardness scale over the tubes. The scale is seen to be very high where the water is fed in to the boiler. There is definitely slipping of hardness to boiler.
3. The boiler water TDS reports confirmed that the TDS had been as high as 10000 ppm before first failure. After the chemical cleaning, instructions were given to operators to increase the blow down and maintain 5000 ppm of TDS in boiler water. Even then, the water TDS was seen to increase along with pH as reported by operators. In fact the pH booster dosage was stopped seeing the pH going to 11. This could have been happened due to high dosage rate of anti scalant.
4. The chemical was being added through a small plastic tank with a cock for regulation. This could result in non-uniform dosage rates. The system would be dependent on skill of the persons.
5. The burner was seen with a baffle plate inside the wind box. It was suspected that there may not be uniform air flow in the burner. Hence a ribbon test was arranged to check the uniform distribution of air. It was found that there was minimum air flow at the bottom portion. Ideally such a test must be conducted by an anemometer. The baffle plate was oriented vertically and the air distribution was checked for. An operator physically checked for distribution. This was much better this time. Yet quantification was required. A test with anemometer was recommended.

Cause for shell plate failures

1. The plate had failed at the same place twice. This clearly pointed out chances of flame impingement. Incidentally on flame impingement, the scale formation would be more. On increase in metal temperature, the plate would swell and would lead to failure.
2. There was scale present all over the boiler. It meant that there was deviation in water quality. Yet the scale thickness was not alarmingly high. The boiler was cleaned off dislodged hardness scales inside the boiler shell. Yet the quantity of dislodged scales which were lying outside the boiler house was seen to be meager.
3. The feed water hardness was not monitored properly. Even when the hardness was reported to be 24 & 44, Nalco representative had certified that all the water parameters were OK. His signed report was available.



Photo 1: The part of the furnace shell that bulged second time.



Photo 2: The back side (water side) of the bulged plate, showing scales (second time).



Photo 3: Part of the furnace shell that bulged first.



Photo 4: The back side (water side) of the bulged plate showing the scales (first time).



Photo 5: water side showing small amount of scales.



Photo 6: Burner air flow test. It showed less air flow at bottom when tested with flags.

C. STEAM PRESSURE : 15881.1 cm °C F. DEAERATOR STEAM PRESURE : A ROOM

E. FEED WATER TEMP. : 60°C

G. WATER ANALYSIS :

	Condensate <i>Raw Water</i>	Feed Water	Boiler Water			Recommended Level
			No.	No.	No.	
pH	7.9	8.2	10.5			10-11.5
TDS ppm	200	350	4930			<5000
Total Hardness ppm	120	22	04			N.P.P
P Alkalinity ppm	Nil	Nil	1550			-
'M' Alkalinity ppm	250	150 <i>SILL</i>	3450			-
Caustic Alkalinity ppm	-	50 <i>SILL</i>	-			-
Sulphite (as SO ₂) ppm	-	-	-			-
Phosphate (as SO ₃) ppm	-	-	-			-

H. PRODUCT DUSAGE :

Product	Function	Present Dosage	To be Changed to
N-22341	Antiscalant	as recom	-
Alfloc 31	Oxygen Scavengers	do	-
Alfloc-113	pH Booster	do	-

I. REVIEW :

- Boiler water analysis log book : Yes / No
- Boiler Operations log book : Yes / No
- Boiler Blowdown Practic

SUMMARY : All parameters are O.K.

Safety plan

The following were advised to the plant engineers:

1. The furnace shell repair was not done to satisfactory level. Hence it was advised to carry out radiography test. But this could delay the boiler starting as there were procedures in bringing the radioactive source. Hence it was arranged to have an ultrasonic test. The local company did that at site and certified that the weldment did not have cracks.
2. The furnace shell was covered with 65 mm thick refractory brick layer to protect the weakened plate. Also this would prevent the flame impingement, if it was there earlier.
3. Furnace shell is considered to be most vulnerable part of the boiler. For safety reasons, procedures should be followed. Manufacturer only should attend to such failure. Tube replacement is a different matter and it can be attended by a boiler repairer.
4. Burner flame shape should be checked by the suppliers' service technician at the earliest. There should not be any impingement.
5. Water softener must be checked by the supplier. Hardness test kit should be replaced.
6. Hardness levels should be checked before regeneration. This is an important aspect of the water chemistry.
7. The water treatment chemical supplier is required to ensure that there is no deviation in water chemistry due to the wrong dosage of chemical itself.

Boiler shell failure can result in catastrophe. Care is required to follow the proper procedure in repair.

CASE STUDY 2: FAILURE INVESTIGATION OF A HIGH PRESSURE SHELL BOILER

This is about an investigation of a Boiler accident in the 12 TPH, 35 kg/cm², 350 deg C FBC boiler at this plant.

About this boiler

The boiler was installed about 4 years back. Almost two years the boiler had been in operation on a continuous basis after it was converted from grate firing to FBC. Previously the boiler was designed for wood chips. Later it was modified for rice husk cum GN shell firing. The boiler is provided with reciprocating pump. The feed line is connected to both shell & steam drum. The downcomers are taken from steam drum to waterwall, shell, bed coils by separate downcomers. The feed water is produced from a DM plant. The raw water TDS is < 300 ppm. The treated water TDS is about 0.1 ppm only. The blow down TDS had been 50 ppm only. The shell tubes were also seen to be clear of any deposits.

Incident

The shell that comes after the convection SH is meant for steam generation as a boiler bank. This shell is made of two segments with a cirseam. The tube sheet and main shell are of 25 mm thick. The rear part of shell got ripped off from its place. Three persons lost their life in this incident.

Observations

At the time of visit, the boiler parts were practically left in same condition after the incident. The shell plate part that came off from the main shell was available for closer inspection. Also the main shell could be examined to some extent among the debris.

Ruling out water level loss

It was learnt that the 2 nos Mobrey level controllers were operational. The feed pumps were always running on / off based on switch action from Mobrey. In the event of low water level, the main furnace tubes such waterwall & bed coils fail in this boiler since they are in high temperature area. In the event that shell goes dry, the front tube sheet opens first and not the rear. Hence it was clear that the shell burst was not due to low water level.

Possible failure modes- lamellar tear in raw material

Generally such failures can happen due to raw material defect or manufacturing defect. As the shell plate showed sign of lamellar tearing, it could have been parent material defect. Usually the shell plates are 100% ultrasonically tested for overlapping and lamellar tears at sub surface level. It was advised to conduct an ultrasonic test along the entire circumference of the failed plate. Yet the lamellar tear would not spread to entire circumference. It should have blown the shell by local opening, as the tube sheet to shell weld was quite stronger. The boiler manufacturer who visited along with Inspecting authority had blamed the incident as raw material defect with lamellar crack in the parent material itself.

Possible failure modes- by cyclic stresses

The feed water stub is terminated at shell at 450 mm from the rear tube sheet. There was no distributor pipe to direct the water away from shell plate & the weldment. The feed water temperature being 80 -90 deg C, there can be cyclic stresses at the shell to tube sheet joint. Fluctuating temperatures introduce stresses which ultimately can lead to crack propagation.

Possible failure modes- Improper weld

On closer inspection at the rear tube sheet, it was seen that the inside seam weld is not properly fused. See photo below. Also the thick tube sheet at weld zone suggests that the tube sheet is not edge prepared properly before the weldment. If this is true, plate can shear along the thickness as it is a not properly fused joint. This would like a lamellar tearing only. We can see one side of the weld holding the shell plate.

Absence of sleeve design for feed pipe

In high pressure boilers, the feed pipe has to be welded to the main shell through a sleeve pipe. There has to be feed distributor pipe and water has to be admitted in water space and not near shell plate.

The boiler had failed due to various design defects and poor workmanship only

- The edge preparation and weldment of shell & tubesheet was not as per code recommendations.
- The feedwater should not be pumped to shell where steam generation was there. The feed water should have been connected to steam drum only. This would have helped in better water chemistry at all circuits.



Photo 1: It is seen that the tube sheet to shell weld is not torn off even a bit. This can happen if the fusion was not proper.

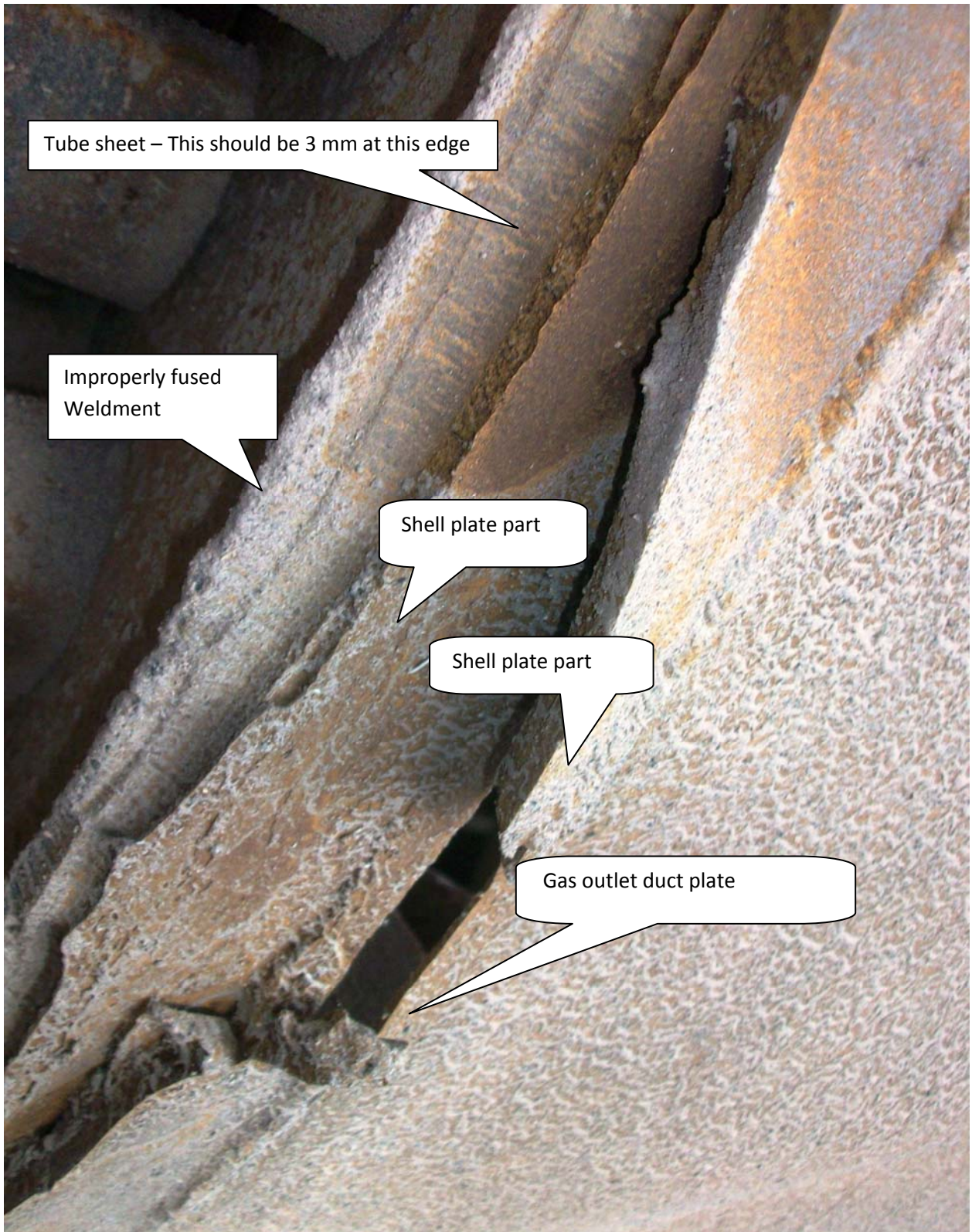


Photo 2: This is the part of shell sticking to the rear tube sheet. It is suggested to check the weld preparation once the boiler is brought down from the debris. Looking at the thickness anyone would doubt whether edge preparation was done or not for the shell. The lip is supposed to be 3 mm only. See the drawing attached in the next figure. Anybody can observe there is improper fusion of shell plate with tube sheet.



Photo 4 & 5: The feed water inlet stub to shell is seen without a sleeve pipe. This had led to cracks development due to cyclic thermal stresses. However the shell plate did not fail due to this crack as it is seen to be intact with main shell nearby.

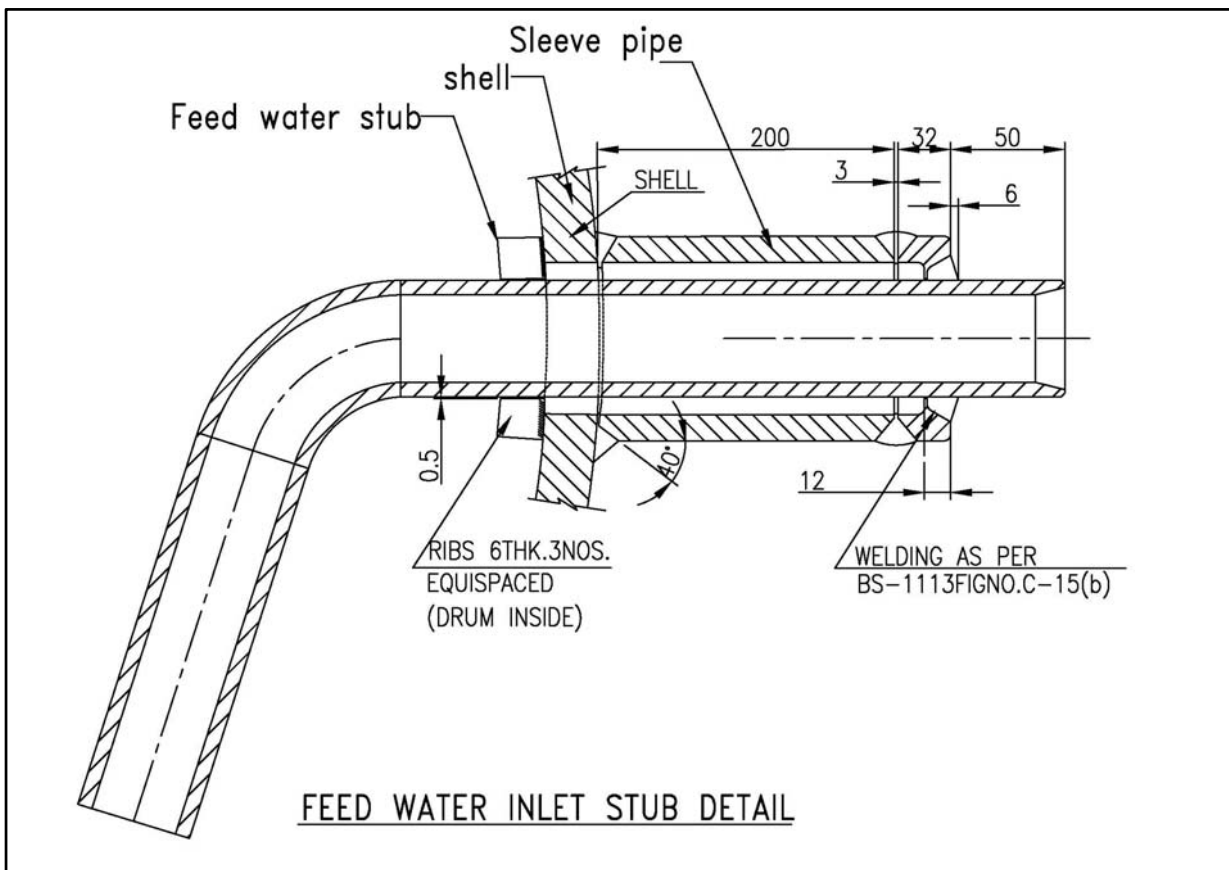


Figure 2: The above should have been the stub detail for feed water stub at both shell and steam drum.

CASE STUDY 3: DIAGNOSTIC REPORT ON MAIN STEAM LINE FAILURE

This case is about the main steam pipe failures which were experienced in the ten days. The insulation was removed and inspected by plant personnel. The steam pipe OD has grown from 168 mm to a maximum 210 mm. This can be seen from the photographs below.

The boiler is designed for 66 kg/cm² g & 495 deg C maximum. The steam pipe is of P11 material. The radiant SH outlet pipe is of 150 nb and is of 80 schedule thickness. The main steam line is also of 150 nb & of 80 Schedule. As per the standard IBR calculation this is suitable for the service conditions.

Analysis

1. The failed pipes were inspected. The pipes were seen bulged. It indicates that the pipe had not been able to withstand the service pressure under the present steam conditions. There can be material composition problem.
2. The steam temperature had gone up to 520 deg C as seen from log book. In the last one year, the steam temperature had gone up beyond design temperature on many occasions. This is due to the high amount of fines in coal.
3. It was informed that the secondary air was increased to 100% to control steam temperature.
4. The stress values of pipe come down by 30% on higher temperature and this can lead to bulging of pipes. The thickness calculation of the pipe is done based on the creep stress for 1 % elongation at design temperature / rupture stress in 100000 hrs at design temperature. At 525 deg C, the pipe can withstand a pressure of 50.32 kg/cm² only on rupture stress basis.

Actions taken to bring down the steam temperature

The bed height and furnace refractory height were adjusted to increase the heat absorption and thus the steam temperature excursion was resolved. In fact at many plants, the design temperature limits are not known to operating team.



The swelling of the pipe is seen as the pipe was unable to withstand the temperature.

CASE STUDY 4: DIAGNOSIS OF STEAM DRUM FAILURE

This case is about a catastrophic failure of the steam drum of the 14 TPH, 36 kg/ cm² FBC boiler. It was informed that the boiler had been in service for the past three years.

The incident had taken place almost about month ago. The steam drum had bulleted to the nearby factory upon the failure. The steam drum end plate got opened and due the reaction forces the steam drum had flown from its position. At the time of the visit, the debris was removed from the position. The steam drum was moved to manufacturer's storage yard.

Observations on inspection

Flat ends for steam drum!

The steam drum was seen with the flat end design. It was not right to have manufactured the steam drum at the time where dished ends could be procured. Flat dished ends tend to bulge under pressure. To prevent this boiler code suggests the use of gusset plates to hold the flat end plate in place. Before the welding technology was developed riveted gussets were in vogue. In the case of gussets, boiler design codes provide method of calculation for sizing the thickness and geometry of the gussets.

Welded gussets and the type of weld

The gussets are to be welded to the shell and end plates by full penetration welds. It was seen that the welds were not full penetration welds. It was also seen that the welds were not properly fused. It was also seen that the welds are undersized and not as per code requirements. The photographs taken on all the gussets can be seen below. It was seen from manufacturer's drawing that preheating was not adopted for such thick welds. It was also seen that welds were made without edge preparation to facilitate fusion and full penetration welds. IBR code had given the revised weld detail in the annexure A of chapter XII. The BS code from which IBR was formed also asks for full penetration weld.

Inspection record for fillet welds

Fillet welds are being only visually inspected at Manufacturers' works. The fillets welds cannot be easily inspected for the reason that the welds are in confined area. Records are not possible for fillet welds unlike dished end welds that are X-rayed. By virtue of choice of flat end drum for high pressure service, the steam drum had become a vulnerable element for failure.

Breaking away of weldment

If the weld is not done with proper fusion and preheating, the welds would give way in service. Boilers undergo cyclic heating and cooling depending on the plant disturbances. The fillet welds with imperfections open up gradually and result in a catastrophe. This is what happened exactly here. The gussets were found with inadequate fusion. In fact all thick fillet welds are susceptible for failure from crack creation and propagation. Absence of preheating can also cause crack development during the cooling process.

Overpressure operation

Over pressure operation of the boiler can cause failure of the flat ends. Unless all three safety valves are gagged, over pressure operations are not possible. It is also true that the factor of safety for stress value is much higher. Hence minor over pressure can not cause catastrophe.

Anchor bolts

Steam drum & shell require anchor bolts with steel / RCC structure, with proper expansion provisions. In the event of mishaps, the steam energy will be partly absorbed by the supports. In this case, the steam drum & shell were simply rested on RCC base. Due to this, the steam drum had travelled like a bullet to adjacent factory.

Conclusion

It was concluded that the failure was caused by improper weldment. The type of weldment made is not a completely fusion joint. For a properly fused joint the gusset should have been edge prepared as per annexure A of IBR chapter XII or as per BS code BS-EN-12953. Preheating should have been carried out. Weld size records should have been created.



Photo 1: The steam drum was inspected at manufacturer's storage yard. It is seen that the flat ends are provided for the steam drum, instead of dished ends. The flat end had come off from the steam drum, which had led to this incident.



Photo 2, 3 & 4: most of the welds shown are without fusion of the gussets. The weldment is not seen to the gussets. When the weld is properly fused, metal will be seen pulled out in a haphazard manner. The edge preparation is supposed to be with hardly any land as per IBR regulation / BS code.

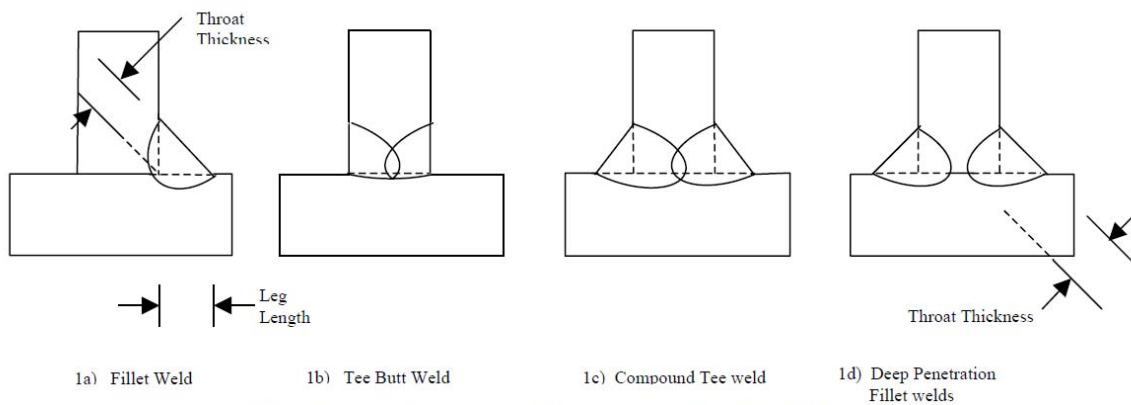
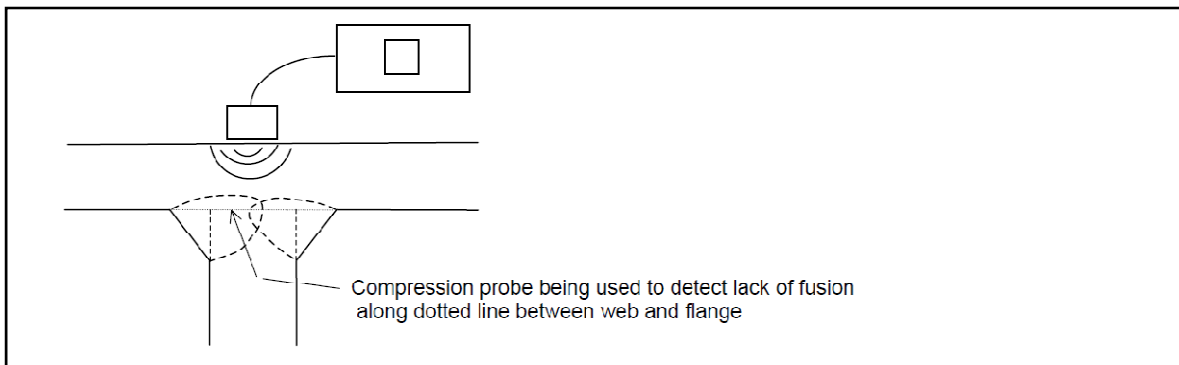


Figure 1 – Fillet, Tee Butt, Compound and Deep Penetration Fillet Welds

- a) Fillet Weld – Incomplete Penetration, generally not a full strength weld
- b) Tee Butt Weld – Complete Penetration full strength weld
- c) Compound Tee Weld – more than strong enough
- d) Deep Penetration Fillet – Incomplete Penetration (generally) full strength weld

Differences between fillet weld types: The gusset weld should have been type D as per IBR code. What was done as per 1a. This is used only structural design.



No matter what the welding process is, Tee Butt welds need to be carefully designed to ensure full fusion is consistently obtained. When producing Tee Butt welds by welding from both sides (recommended for arc welding processes) the land and bevel angle need to be designed so that the welding process can consistently achieve 70 – 80% penetration of the land from one side, Note that thicker parts will require more arc energy heat input in order to provide full fusion. When producing full penetration Tee Butt welds it is imperative to:

- Control the size of the land to close tolerances;
- Control the size and angle of the bevel when required;
- Achieve consistent fit-up every time (preferably zero root gaps);
- Use mechanized welding processes that can replicate amperage, voltage and travel speed;
- Maintain constant contact tip to work distances;
- Use a consistent pre-heat temperature;
- Ensure the power source can operate at 100% duty cycle at the nominated current and voltage.